



**REPUBLIC OF YEMEN
MINISTRY OF WATER AND ENVIRONMENT
SANA'A BASIN WATER MANAGEMENT PROJECT**

(IDA CREDIT 3774-YEM)

Sub-Component 3(d)

**Hydro-geological and Water Resources
Monitoring and Investigations**

**ACTIVITY 1: AQUIFER STORAGE INVESTIGATIONS AND ASSESSMENT
DRAFT FINAL REPORT**

Financed by: The World Bank

April, 2009

HYDROSULT Inc.
Consultants, Experts-conseils

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Chapter 1. INTRODUCTION

GENERAL OUTLINES

Sub-component 3(d), subject of this report, is composed of five activities/tasks. One of these activities, namely; "Satellite Imagery Studies" is implemented under a separate contract by GAF in collaboration with NWRA. The other four activities executed under our contract and work plan are:

- Aquifer storage investigations and assessment,
- Hydrological monitoring and analyses,
- Aquifer modeling studies, and
- Sub-basin water quantity, quality and monitoring.

The above activities were executed by a team of experts from Hydrosult-Canada, WEC-Yemen and TNO-the Netherlands, in collaboration with staff from the NWRA Sana'a branch and from the Central Water Monitoring Unit of the Ministry of Agriculture and Irrigation.

Activity 1, Aquifer storage investigations and assessment, aims at obtaining a clear picture of the main groundwater reservoirs of the Sana'a Basin, including the geometry of these units (upper, lower, and lateral boundaries), their spatial lithological variation, hydraulic properties of the aquifer and the volumes of groundwater stored under present conditions. Under the present contract, two distinct groundwater reservoirs were considered: (a) Quaternary sediments; (b) Cretaceous Tawilah sandstone group.

1.1 Teamwork Approach

The consultant's specialists and NWRA staff involved in Activity 1 worked as one team. NWRA Sana'a branch assigned four counterparts to manage the work of the consultant and, at the same time, to develop their own capacity through participation in the work and on-the-job training. The consultant acted as a mentor and coach to the NWRA specialists. Table 1.1 illustrates the team composition of activity 1 and NWRA Sana'a branch counterparts.

Table 1-1 Team work of Activity 1

Name	Status	Firm
Dr. Ismail Najjar	Project Director	HYDROSULT
Dr. Samir Hijazeen	Project coordinator	HYDROSULT
Dr. Wim v.d. Linden	Senior hydrogeological consultant	HYDROSULT
Dr. Mohamed Gad	Regional hydrogeological consultant	HYDROSULT
Dr. Naif Abu-Lohom	Local hydrogeological consultant	WEC
Dr. Mohamed El-Hosary*	Hydrogeological consultant	HYDROSULT
Dr. Ahmed Marjoa	Hydrogeological consultant	HYDROSULT

Name	Status	Firm
Eng. Amin El-sabry	Geologist	NWRA (Sana'a Branch)
Eng. Ahmed Sharaf	Geologist	NWRA (Sana'a Branch)
Eng. Mohamed Soltan	Geologist	NWRA (Sana'a Branch)
Eng. Serwah Abdel-Baki	Geologist	HYDROSULT
Eng. Khaled El-Bar	Geologist	NWRA (Sana'a Branch)
Eng. Mohamed Emad	GIS expert	HYDROSULT
Miss Mona El-Sofi	On-the-job training (GIS specialist)	NWRA (Sana'a Branch)
Elham El-Qorashy	Secretariat	HYDROSULT
Abdel-Aziz El-Raboe'i	Technician	NWRA (Sana'a Branch)
Fuad Amin	Technician	NWRA (Sana'a Branch)
Hamid El-Kawkabani	Driver	HYDROSULT

1.2 Sub-activities of activity 1

The sub-activities of activity 1 included preparatory work, additional field data acquisition (geological field surveys, laboratory analysis on cores of Tawilah sandstone, collection and interpretation of information from exploratory boreholes, field work pumping tests and interpretation of pumping tests) and production of outputs.

The preparatory work was carried out under the supervision of both local and regional hydrogeologists accompanied by other team members and counterparts. Activities included inventory and review of existing reports and maps, inventory and review of supplemental data and information, first trial for processing and interpreting all data and information reviewed, as well as the identification of main information gaps. Intensive office work was carried out during 6 months to cover these activities.

Additional field data acquisition sub-activity included geological field surveys, laboratory tests on cores of Tawilah sandstone, collection and interpretation of information from exploratory boreholes, field mapping work and pumping tests.

Geological field surveys focused mainly on the geologic and hydrogeologic characteristics of both the cretaceous Tawilah sandstone and alluvium aquifer and were carried out during a period of three months (December 2006 to February 2007). The aim of these surveys was to delineate the aquifer geometry and geologic structures in Nihm and Bani Hushaish localities. The geological field surveys were extended to the upper catchments of Wadi Surdud, Wadi Al Khared, Wadi Al Ahgur and Hamadan, in addition to the above activities. Furthermore, the consultant's hydrogeological team delineated the geologic and hydrogeologic setting of NWSA NW and NE well fields and verified the contact between the present two aquifers, measured the water levels in the data logger stations representing the two well fields and validated and updated the old monitoring network with NWRA Sana'a branch counterparts.

In order to test certain hydraulic parameters of the Tawila sandstone aquifer, it was decided to select a number of cores representing this formation, which were drilled, prepared and shipped to Egypt, where tests on effective porosity were conducted.

Pumping tests of variable durations were conducted in 33 private wells. These included step drawdown tests, continuous pumping and drawdown recovery observations. In addition, the consultant re-analysed the results of 45 previous pumping tests and conducted new tests in 6 wells. It should also be mentioned that the consultant conducted pumping tests in a number of the large-diameter dug wells, whereby the Papadopolus method was applied for the first time in Sana'a Basin.

Outputs of the sub-activity included maps and cross-sections, technical notes (10 notes, Table 1.3), quarterly reports (3 quarterly reports) and a draft final technical report.

Table 1-2 All technical notes and quarterly reports produced during the work of Activity 1

Output	Date	Author(s)	Description
Technical note 1 Review of existing reports and maps	October 2 006	Dr. Naif Abu-Lohom	Review of geological and stratigraphical sequence of Sana'a Basin Review of hydrogeological studies of the Sana'a Basin Review of previous well inventory surveys, annual drawdown and aquifer geometry Review of previous hydrogeological cross-sections Review of supplementary data
Technical note 2 Processing and interpretation of data	October 2 006	Dr. Naif Abu-Lohom	Processing and Interpretation of all data previously collected Reviewing with Dr. S. K. Sharma the work done so far in activity 1
Technical note 3 Identification of main information gaps and field work plan	November 2006	Dr. Naif Abu-Lohom	Gaps related to delineation of the aquifers Gaps related to capacity of the aquifers
Technical note 4 Geologic field activity in Nihm area	January 2 007	Dr. Mohamed Gad Dr. Naif Abu-Lohom	Delineation of Tawilah sandstone aquifer geometry and geologic structures in Nihm area
Technical note 5 Geologic field activity in Bani Husheish area	January 2 007	Dr. Mohamed Gad Dr. Naif Abu-Lohom	Delineation of aquifer geometry of both Tawilah sandstone and Alluvium aquifers, as well as geologic structures in Bani Husheish area

Output	Date	Author(s)	Description
Technical note 6	January 2007	Dr. Mohamed Gad	Raw data of 10 pumping tests
First quarterly report	January 2007	Dr. Mohamed Gad Dr. Naif Abu-Lohom	Inventory and review of the previous reports, maps and supplementary data Finalization of identification of the principle information gaps. Writing and submission of technical note about the principle information gaps Proposed a field work plan to be followed to fill the information gaps identified Geological field work carried out in Nihm and Bani Husheish areas December 9-27, 2006
Technical note 6 Re-evaluation of previous pumping test data	February 2007	Dr. Ahmed Marjoui	Re-evaluation of previous pumping tests data Execution and interpretation of new pumping tests
Technical note 7 New pumping tests in Sana'a Basin	February 2007	Dr. Mohamed Gad Dr. Naif Abu-Lohom	Raw data from the 23 pumping tests carried out in Alluvium (15 tests), Tawilah sandstone (6 tests) and volcanic (2 tests) aquifers
Second quarterly report	March 2007	Dr. Mohamed Gad Dr. Naif Abu-Lohom	Introduction Geological field survey Hydrogeologic aspects Aquifer tests Conclusions and recommendations
Technical note 9 Geological field work carried out in upper Wadi surdud catchment	June 2007	Dr. Naif Abu-Lohom	Delineation of Tawilah sandstone aquifer geometry and geologic structure in Upper Wadi Surdud catchment
Technical note 10 Capacity building	June 2007	Dr. Mohamed Gad	Training course in using RS and GIS in hydrogeology for Capacity Building

Output	Date	Author(s)	Description
Third quarterly report	July 2007	Dr. Mohamed Gad Dr. Naif Abu-Lohom	Delineation of aquifer boundaries in the basin Delineation of western and eastern NWSA well fields Collection of sandstone core samples New pumping test activity Groundwater depletion data Capacity building Summary and conclusions

The draft final technical note on Activity 1 integrated all information contained in the technical notes. The outputs of the sub-activities which were used in the preparation of the technical report are listed in Table 1.4.

This draft technical report consists of eight chapters. All maps and cross-sections were prepared and reviewed by all the hydrogeologists of the consultant's team in full cooperation with the NWRA counterpart team.

Table 1-3 Tangible outputs under Activity 1

No	Items	Additional Specifications	Number of Maps Developed
1	Geological/lithological maps (+ cross-sections)	Spatial variation of lithology, structural geological features	3 specified maps, 1 fence diagram and 17 cross-sections
2	Maps of aquifer geometry	Showing upper, lower and thickness boundaries of the units	10 specific maps
3	Maps of hydraulic aquifer parameters	Transmissivity, storage coefficient, (porosity as well, if possible)	9 specific maps and 3 location maps
4	Potentiometric maps	Showing regionalized present-day groundwater piezometric levels (SWL) in each aquifer unit	7 maps for Alluvium aquifer and 4 maps for Tawilah sandstone aquifer
5	Groundwater depletion maps	Showing approximate groundwater level declines (in m) since 'pre-development time' (say around 1970)	10 depletion maps for both Alluvium and Tawilah sandstone aquifers
6	Groundwater storage maps	Lateral variation of assessed storage expressed as the height of an equivalent water column (m), for different depth intervals below land surface	7 specified maps for Alluvium aquifer and 4 for Tawilah sandstone aquifer

No	Items	Additional Specifications	Number of Maps Developed
1.2	Technical notes and report (specified under 1.2.1 through 1.2.7)	Including technical notes on single activities carried out and a comprehensive technical report	----
1.2.1	Technical note on review of existing reports and data	Information on geology, lithology, geometry, hydraulic parameters, water levels, stored groundwater volumes and water quality of main aquifers in Sana'a Basin	3 technical notes
1.2.2	Technical note on geological field work carried out	Field observations on properties and lateral extent of the main aquifer units	3 technical notes
1.2.3	Technical note on aquifer tests	Interpretation of pumping tests carried out to determine hydraulic aquifer parameters	2 technical notes
1.2.4	Technical note on tests and other measurements on the exploration wells	Description and litho-stratigraphic / hydraulic interpretation of information derived from the three exploration wells (logs, samples)	In preparation
1.2.5	Technical report on Activity 1	Final report on all the results of Activity 1, including an integrated assessment and analysis of groundwater storage and how it has changed over time; furthermore, identifying zones of special potential or concern related to groundwater storage	1 draft final technical report

1.3 Proposed timing of the sub-activities and outputs

Implementation of Activity 1 was scheduled to follow the time schedule shown in Table 1.5. The total duration from start to finalization of sub-component 3d was planned over 24 months. However, the actual duration of implementing these activities was shorter than planned.

Table 1-4 Timetable of the different sub-activities carried out in Activity 1

No	Sub-activity	2006												2007												2008	
		2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	
1.1	Preparatory activities																										
1.1.1	Inventory and review of existing reports and maps	■																									
1.1.2	Inventory and review of supplementary data and information			■																							
1.1.3	Processing and interpretation of all data and information reviewed				■																						
1.1.4	Identification of main information gaps							■																			
1.2	Additional field data acquisition																										
1.2.1	Geological field surveys									■																	
1.2.2	Laboratory analysis on cores of Tawilah Sandstone											■															
1.2.3	Collection and interpretation of information from exploratory boreholes	■																									
1.2.4	Field work pumping tests											■															
1.2.5	Interpretation of pumping tests											■															
1.3	Production of outputs																										
1.3.1	Database									■																	
1.3.2	Maps and cross-sections											■															
1.3.3	Technical notes							■		■																	
1.3.4	Final technical report																			■							
1.4	General advisory services								■																		

1.4 Capacity building

Capacity building and training was provided through direct participation of the assigned counterparts in office and field work activities, and through a series of structured training courses that were imparted by the consultant to those specialists of the Sana'a Basin Sana'a Office who did not receive on-the-job training during the course of implementation of the project.