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REPORT ON MISSION TO THE NATIONAL WATER RESOURCES AUTHORITY REPUBLIC OF YEMEN

I. ASSESSMENT OF THE GROUNDWATER EXPLORATION PROGRAMME IN TAIZ REGION

II. PROTECTION OF THE GROUNDWATER SUPPLY WELL FIELDS IN TAIZ AREA

15-29 June 2001

by

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TABLE OF CONTENTS

موجز تنفيذي

المهمة:

تقدمت الهيئة العامة للموارد المائية في الجمهورية اليمنية بطلب للخدمات الاستشارية للمستشار الإقليمي للمياه لدى الاسكوا. وبعد موافقة الأمين التنفيذي للاسكوا قمت بإنجاز المهمة المطلوبة والتي اشتملت على منهاج العمل التالي:

١- الإعداد لمشروع تحديد مناطق حماية لآبار وحقول آبار مياه الشرب لمدينة تعز وتقديم توصيات بذلك.
٢- تقييم البرنامج الاستكشافي لحفر آبار مياه جوفية عميقة لتزويد المياه لمدينة تعز وتقديم توصيات بذلك.

هذا و قد تم إنجاز المهمة حسب منهاج العمل المقترح.

أولا: مشروع حماية مصادر المياه الجوفية من التلوث:

تعتمد مدينة تعز في التزويد المائي للأغراض المنزلية والصناعية على المياه الجوفية من خلال ٣٥ بئرا موزعة على خمسة حقول للآبار في المنطقة، إضافة إلى عدد من الآبار الخاصة. وقد بلغ إنتاج حقول الآبار العامة في عام ٢٠٠٠ حوالي ٣ر٧ مليون متر مكعب.

ونظرا لارتفاع ملوحة مياه هذه الآبار، والتلوث الحاصل لمصادر المياه الجوفية، لما يزيد عن مواصفات منظمة الصحة العالمية، ومحدودية هذه المصادر المائية المتاحة للتزويد فان هناك عجز مائي في الوقت الحاضر، والذي سوف يتزايد ليصل الى ما لا يقل عن (٨) ملايين متر مكعب في عام ٢٠١٠ . ولا تستعمل مياه الشبكة حاليا لأغراض الشرب، بل للإستعمالات المنزلية الأخرى فقط. ويعتمد المواطنون على شراء مياه الشرب من الصهاريج (الوايتات) أو المياه المعبأة. وتتزود الصهاريج بالمياه من حوالي (١١) بئرا خاصة وعامة موزعة في المنطقة.

ونظرا لعدم توفر مصادر مائية بديلة واقتصادية على المدى القريب والمتوسط، والتدهور المستمر في نوعية المصادر المائية، فان حماية هذه المصادر المائية المتاحة حاليا من استمرار هذه التلوث والتدهور النوعي، يصبح أمرا هاما وضروريا، وذلك بتحديد حرم أو مناطق حماية لكل بئر أو حقل آبار، وفرض إجراءات حماية تصحيحية ووقائية داخل مناطق الحماية هذه، ووضع التشريعات والأنظمة الضرورية لتطبيق مناطق الحماية المقترحة. وقد تم في هذا التقرير تحديد المشكلة والأهداف ومبررات العمل وكذلك أسلوب العمل المناسب. كما تم إعداد خطة عمل لتنفيذ المشروع.

ومن أهم التوصيات المقترحة ما يلي:
١- إعطاء حماية مصادر مياه الشرب خاصة، والمياه الجوفية عامة الأهمية والأولوية المناسبة. وتبني الجهات الحكومية المعنية لسياسة حماية مصادر المياه الجوفية والالتزام بها والعمل على تطبيقها من خلال استراتيجيات وخطط عمل وتشريعات وأنظمة مناسبة.

٢- توفير البيانات اللازمة، وكذلك المصادر اللازمة، وأهمها الكوادر المدربة، والأجهزة والمواد المخبرية، وكذلك توفير البيانات وإعداد برنامج مراقبة مناسب لكافة مصادر مياه الشرب و لكافة مصادر التلوث المحتملة.
٣- تحقيق الفهم الواضح لنظام المياه الجوفية السائد في المنطقة، وكذلك لمصادر التلوث وطبيعة المواد الملوثة، والعلاقة أو الأهمية الهيدرولوجية والبيئية لهذه المصادر والمواد الملوثة.
٤- وضع وتنفيذ خطة العمل المقترحة من قبل فريق وطني مع تقديم تدريب مناسب لهذا الفريق، والذي يمكن أن يقوم به المستشار الإقليمي للمياه في الاسكوا حسب الحاجة، وبالتعاون مع مدير المشروع في الهيئة.

ثانيا: مشروع استكشاف المياه الجوفية في الصخور الرملية العميقة في منطقة تعز:

ابتداء هذا المشروع في بداية عام ١٩٩٨. ويشمل المشروع على حفر (١٢ بئرا) بعمق إجمالي مقداره (٥٥٠٠) مترا. وقد تم إنجاز (١١) بئرا بعمق إجمالي (٥١٤٣) مترا، والعمل جاري في حفر البئر الأخيرة في حوض وادي رسيان.

وكان الهدف من حفر هذه الآبار الوصول إلى طبقة الصخر الرملي العميقة ولسد العجز المائي في مدينة تعز. إلا أنه لم يمكن الوصول إلى هذه الطبقة الا في ستة آبار فقط في وادي الغيل وغرب وادي رسيان. أما الخمسة آبار الباقية، فقد أمكن حفر بئرين منها إلى العمق المطلوب وهو (٧٥٠) مترا، إلا أن الحفر كان في الصخور البركانية بشكل رئيسي. أما الثلاثة آبار الأخرى فلم يكن بالإمكان استمرار الحفر فيها للأعماق المطلوبة و ذلك لأسباب مختلفة موضحة في التقرير.

وكان من أهم نتائج برنامج الحفر الاستكشافي ما يلي:

١. تحتوي الطبقة الصخرية الرملية غالبا على مياه عذبة ولها انتاجية عالية نسبيا.
٢. أفضل المناطق لاستثمار المياه الجوفية من طبقة الصخر الرملي هي في الجزء الأسفل من وادي الغيل ووادي بني خولان (بحاجة إلى تأكيد) والأجزاء الوسطى والغربية من وادي رسيان، حيث يمكن البدء في حفر آبار إنتاجية في تلك المناطق.
٣. حالت بعض المسائل الاجتماعية من تنفيذ البرنامج الاستكشافي في المناطق الوسطى من حوض وادي رسبان وكذلك في الجزء الأسفل من وادي بني خولان.
٤. كان لضعف خبرة متعهد الحفر وعدم توفر المعدات ذات القدرة المناسبة أثرا سلبيا على تنفيذ المشروع.

ومن أهم التوصيات ما يلي:

١- إيجاد حل لمعارضة سكان بعض المناطق من أجل استكمال الحفر الاستكشافي والإنتاجي في مناطق وادي بني خولان وأواسط حوض وادي رسيان.
٢- البدء بحفر آبار إنتاجية لأغراض الشرب في ثلاثة حقول: الأول في الجزء السفلي من وادي الغيل، والحقلين الآخرين في المناطق الغربية من وادي رسيان.
٣- إعادة تطوير وتنظيف بئر مقبابة وبئري وادي ورزان بمعدات وطرق مناسبة ومتعهد جديد وتحويل هذه الآبار إلى آبار إنتاجية.
٤- دراسة جدوى تحلية المياه السطحية في وادي رسيان مباشرة من مجرى الوادي، أو عن طريق جمعها من شبكة آبار مناسبة، وذلك لقربها من مدينة تعز وغزارتها مع ارتفاع ملوحتها نسبيا.

EXECUTIVE SUMMARY

The Mission:

The mission was implemented upon the request of the National Water Resources Authority (NWRA) of the Republic of Yemen, and the approval of the Executive Secretary, during the period 15-29, June, 2001. The terms of reference of the mission was given as follows:

A. Evaluation of the results of the nearly completed exploratory well drilling program in Taiz area, and provision of final conclusions and recommendations.
B. Initiate a groundwater quality protection program for the current water supply well fields, which supply the city of Taiz with municipal water.

A: Protection Of The Water Supply Well Fields In Taiz Region:

Taiz city relies completely relies on groundwater resources to supply all of its uses through (35) wells distributed in five well fields in the area, in addition to about (11) private wells supplying water by private tankers. The current production rate for the well fields in the year 2000 was (7.3) million cubic meters (MCM).

Because of the pollution problem of the groundwater, the limited yielding potential of these resources, and the increasing water demand, two problems will arise: The decreasing availability of the water supply, as well as the suitability of the water for the intended uses. The water shortage for municipal water supplies will exceed (7.5) MCM by the year 2010.

The lack of alternative water supply sources for Taiz in the near and medium-term future, therefore dictates that a groundwater protection policy and strategy be adopted, and an implementation plan be formulated. A pre-requisite for such actions is to assess the current future resource and pollution status.

Recommendations:

- Give top priority for groundwater protection from depletion and deterioration. Groundwater quality degradation is as serious as groundwater depletion. This can be best achieved through developing a groundwater protection strategy and p lan.
- Ensure proper assessment and understanding of the available groundwater systems including: their potential, vulnerability, and their behavior and response to human activities and interference.
- Ensure the provision of the required support for developing and implementing such strategy and action, including in particular the institutional, capacity building, and the legislative aspects.
- Apply the methodology developed in this study to other water supply wells and well fields by the national team, e.g. Ebb and Aden well fields.
- Develop a medium term plan to augment the existing municipal water supply well fields by additional wells in areas such as wadi Al gayl, Wadi Bani Khawlan, Wadi al Dhabab (a tributary for Wadi .Rassyan west of Taiz, and lower Wadi Rassyan.

- On the long run, conduct a feasibility study for desalinating the brackish base flow of Wadi Warazan. The water can be taken directly from the stream or preferably from a well distributed network of shallow to medium depth wells.
- Study the feasibility of constructing storage and recharge dams on the main wadies, but with extreme caution not to seriously damage the existing natural distribution system for the groundwater recharge, the drainage system, which supplies most of the private shallow irrigation wells, and the down stream water rights.

B: The Exploratory Drilling Program:

Conclusions:

- Only six of the drilled wells penetrated the targeted sandstone aquifer.
- Confirmed groundwater potential in the sandstone aquifer in Wadi Al-Ghayl, at relatively moderate depth, within 300 m. the water quality is good
- It is believed that there is additional potential for groundwater potential in lower Wadi Al-Ghayl, lower Wadi Bani Khawlan, and lower Wadi Rassyan.
- The results of the exploratory well drilling program indicate that the highest well productivity is for the sandstone aquifer (10-20 l/s), while most of the wells tapping the alluvial or the volcanic aquifers had low yields (< 4 l/s).
- The water salinity, as electrical conductivity, in all wells ranged from 1015 to 3800 u-mhos. The highest salinity was found in Wadi Warazan wells, and in the volcanic aquifer, and the lowest salinity in Wadi Al-Ghayl wells, and in the sandstone aquifer.
- The depth to the sandstone in Wadi Warazan and upper Wadi Rassyan is highly variable, greater than 750 meters. There is doubt about the lateral extent and hydraulic continuity of the sandstone formations, particularly in these areas.
- Drilling in upper Wadi Rassyan and in Wadi Warazan failed to reach to the deep sandstone aquifer.

Recommendations On The Possible Future Action:

1. Resolving the social constraint on drilling in Wadi Bani Khawlan and Wadi Rassyan and complete the exploration program in those areas.
2. Re-do well cleaning and development in Miqbaba well, and in the two Warazan wells using adequate equipment and procedures, and preferably different drilling contractor.
3. Drilling of production wells in middle and lower Wadi al-Ghayl, and in lower Wadi Rassyan.
4. Consider Wadi Warazan surface base flow as a potential source for Taiz water supply, directly or after desalination. The base flow water may be pumped directly from the stream or from a well-designed network of shallow and medium depth wells.

THE MAIN REPORT

MISSION IMPLEMENTATION:

The mission was implemented upon the request of the National Water Resources Authority (NWRA) of the Republic of Yemen, and the approval of the Executive Secretary, during the period 15-29, June, 2001.

The terms of reference of the mission was given as follows:

- ❖ Evaluation of the results of the nearly completed exploratory well drilling program in Taiz area, and provide final conclusions and recommendations.

- ❖ Initiate a protection program for the groundwater well fields, which supply the city of Taiz with municipal water.

The mission was performed in accordance with the terms of reference.

Upon return to ESCWA office in Beirut, the data obtained was analyzed and evaluated, and a mission report has also been prepared.

During the mission, consultation meetings were made with the following officials:

1. Jamal Abdu / Director, National Water Resources Authority.
2. Mohammad Danich / Head, Water Studies Sector.
3. Abdallah Saleh Saif / NWRA Project Manager in Taiz.

The work was then continued with the following NWRA staff members:

1. Abdallah Saleh Saif / NWRA Project Manager in Taiz.
2. Ahmed Abdul Rub Ali Qbadhi / Water Studies Sector.
3. Eng. Geol. Khalid Shujaa'
4. Eng. Geol. Noor Eddin M. Abdu
5. Eng./Water & Env. Natheer Basheer
6. Eng./Agri. Ahmed Albasha
7. Chemist, Bakeel Ali Mohammed

PART –I

PROTECTION OF THE GROUNDWATER SUPPLY WELL FIELDSFOR THE CITY OF TAIZ

PROTECTION OF THE GROUNDWATER SUPPLY WELL FIELDS FOR THE CITY OF TAIZ

BACKGROUND

Current Water Resources:

The city if Taiz like other cities in the republic of Yemen relies on groundwater for public supplies as well as for the industrial activities. The existing water supply well fields are either over exploited, like Haima well field, or heavily polluted like, Haugala, Howban, and Taiz city well fields.

Groundwater, in the Taiz region occurs in three geological types of rocks, the quaternary alluvial deposits, which are mostly found along stream channels and in the plains, the tertiary volcanics, and the Taweelah sandstone formation.

The groundwater in the alluvial deposits is sometimes hydraulically connected with the groundwater found in the fractured upper parts of the volcanic rocks as in Wadi Warazan. The groundwater in this case is under water table conditions (not confined).

Groundwater Potential And Balance:

A rough estimate of the average annual groundwater subsurface outflow from the four catchment areas in the Taiz region has been calculated as follows in million cubic meters per year:

Area	Annual outflow (MCM/YR.)
W. Bani Khaulan	3
W. Al-Ghayl	9
W. Rasyan	15
W. Waran	24
Total	51

Adding about 20 MCM/YR, which leave the area as surface base flow, will yield a total annual recharge of 71 MCM/YR. The annual pumping from all wells in the region is estimated at 52.6 MCM/YR.

It is obvious that the overall groundwater balance in the region is almost even. However, it varies from one catchment to another.

It was mentioned in the previous studies that the groundwater balance in Wadi Al-Ghayl and Wadi Bani Khawlan is almost even, with the total extraction equaling the total recharge. This means that any further well drilling and long-term extraction will adversely affect the existing agricultural developments on the long run, particularly those based on shallow dug wells.

The shallow groundwater in Wadi Warazan also seems in balance, with the annual recharge equaling the two discharge components, the base flow discharge, and the pumping from wells. Increased pumping from wells will cause a decrease in the base flow discharge.

On the other hand, the situation in lower and middle Wadi Rassyan seems better, with a possible chance for additional groundwater abstraction.

The above given groundwater balances do not include the deep sandstone aquifer in any of the catchment areas.

Current Water Demand And Supply For Taiz:

The city of Taiz witnessed significant urban development over the last ten years. This development was seen as accelerated increase in population due to migration from rural areas, and large housing development. According to the census of 1994, the population of the city of Taiz was 400,000 people.

The municipal water supply for the city depends mainly on groundwater resources and a limited water supply network. In addition, at least eleven private water wells supply relatively fresh groundwater to the public, for drinking purposes, through private water tankers.

Groundwater resources are the main water supply for municipal, industrial, and irrigation uses in Taiz region. The 2000 water use pattern was as follows:

Table (1) : Water supply for various uses in Taiz region

Type of use		Quantity, (MCM)
Domestic:		
	Urban :	8
	Rural :	2.8
Industrial		0.8
Irrigation		41
Total		52.6

The water supply rates and sources for the city of Taiz, through the network only, was as follows in 1996 and 2000:

Table (2): Comparison Of The Well Field Production For Taiz Water Supply In 1996 & 2000

Well field	No. of wells 1996	No. of wells 2000	Supply rate 1996		Supply Rate 2000	
			L/S	MCM/YR/	L/S	MCM/YR/
Taiz City	11	12	45	1.419	27.3	0.86
Haujelah & Howban	7	9	56	1.77	76.12	2.4
Haima	7	11	35	1.104	116.6	3.68
Hbair	3	3	40	1.261	15.93	0.5
TOTAL	**28**	**35**	**176**	**5.55**	**235.6**	**7.42**

It is obvious that there was an increase in the water supply of 33% over about four years. Most of the wells in the above given well fields tap the alluvial aquifer, and range in depth from 20-60m., except Taiz and Hbair wells which reach down to 400 m.

Future Municipal Water Demand:

The future municipal water demand has been estimated in the previous mission report based on annual population growth rate of 4% till the year 2005, then a decreasing rate to 3.5% till the year 2010. A summary of the estimated future water demand is given in is given and shown in annexes(1,2).

It is obvious that the deficit in 2010 may range from a minimum of 7.6 to 15.5 MCM/YR above the 2000 supply rate (8MCM).

In the absence of new alternative water supply sources, protection of the existing water supply sources from depletion and pollution becomes very important and essential to meet the future water demand.

Possible Future Water Resources:

Groundwater has been and will remain the most important and viable option for Taiz water supply in the present and the future.

However, the shallow aquifers in the region are highly developed for irrigation by the private sector, in addition to their being highly vulnerable to pollution from different pollution sources.

Most of the water supply wells in the Taiz region suffers from relatively high salinity, and are polluted by municipal solid and liquid wastes, as well as from industrial wasters, and to some extent from irrigation return flows. Moreover, these wells are being pumped at their maximum capacity. Therefore, the supply rate of the current sources is not guaranteed and may not be sustainable for the future.

The latest exploratory drilling program for the deep groundwater has not given encouraging results for significant additional potential for the deep sandstone aquifer, except in few areas.

Desalination of the base flow in Wadi Warazan may prove an economical option, because of its proximity to Taiz, compared to the sea, and because of its low salinity as compared to the sea water salinity. However, the downstream water uses and water rights need to be considered and evaluated.

The last long-term option for water supply for Taiz region would be seawater desalination from Aden coast. The pumping and conveyance coasts would be high however, in addition to the cost of desalination.

Therefore, protection of the available limited and vulnerable groundwater resources from depletion and pollution is the first necessary step that the government should undertake before seeking new, but costly water sources.

In addition to resource protection, we should keep in mind the potential for water saving which can be attained, by rehabilitating the water supply network, in order to reduce the un-accounted-for-water, which currently amounts to about 50% of the total water supply.

OBJECTIVES, NEEDS AND JUSTIFICATIONS FOR ACTION

The Project Objectives:

The main objectives of the needed project may be defined as follows:

- Delineation of groundwater protection zones for the Taiz water supply wells and well fields.
- Recommending a set of protective, preventive, and corrective measures to be applied for the various protection zones for the various water supply sources.
- Recommending a set of legislations, regulations and a plan work .
- Developing a systematic monitoring program for the water supply system, as well as for the waste disposal sites.
- Develop guidelines for implementation and control.

Groundwater Pollution In Taiz Region:

The groundwater quality in Taiz region has deteriorated for different reasons, and from different sources. Evidences of water quality deterioration and pollution are demonstrated in terms of chemical and biological changes, such as increased water salinity, occurrence of abnormally high concentrations of nitrates and some heavy metals, and detection of fecal coliform bacteria. Such water quality deterioration has affected the suitability of the groundwater particularly for drinking purposes where the concentration of certain parameters have exceeded the WHO standards.

Previous studies indicated that agricultural pollution is the least hazardous, as the use of pesticides is very limited in the area (mostly for qat). However, it is not possible so far to test for pesticides. The most significant pollution effect from agriculture is the increased groundwater salinity and of nitrates concentration. However, municipal and some industrial wastes are more responsible for high nitrate concentrations in groundwater.

Urban and Industrial pollution in Taiz have resulted in increased heavy metal concentrations such as Al, Cd, Ni, Fe and Mn above the WHO standards. It has also caused an increased water salinity and nitrate concentration. The nitrate level in 27 public water supply wells had an average of 61 mg/l, a maximum of 160 mg/l, and a minimum of 2 mg/l.

The increase of salinity and nitrate concentration in the water supply wells, have been partly managed by dilution, through blending the inferior quality water of Haujala, Howban, and the city well fields, with the relatively better quality water of Haima and Hbair well fields.

The main sources for groundwater pollution include: Urban run-off, uncontrolled solid waste disposal, uncontrolled sewage disposal in stream channels and land surface, industrial waste effluents, leaky sewerage networks and septic tanks, uncontrolled disposal of local sewerage systems, landfills, waste water lagoons and various other types of urban pollution sources from

other various activities. So far no treatment activities have been reported for solid or liquid wastes in Taiz prior to their disposal.

Groundwater Vulnerability in Taiz Region:

The groundwater resources tapped by the water supply well fields occur under water table, unconfined conditions. The aquifers consist of either alluvial deposits or fractured volcanics or both. They are replenished from the rainwater runoff along the stream channels. The depth to the water table is relatively shallow, within few meters below ground surface. Such aquifers usually have sufficiently high infiltration rate and permeability to allow downward movement and horizontal migration of pollutants for considerable distances.

The topsoil conditions overlying the groundwater are also favorable for infiltration and percolation of liquid wastes and leachates from rainwater, irrigation water or stream flow water, downward to reach the water table.

Under the prevailing shallow water table conditions in these areas, infiltration of polluted surface runoff, or any solid or liquid wastes disposed on the ground surface, within or near the stream channels, will ultimately reach the groundwater.

Therefore such aquifers are considered vulnerable to pollution from any liquid or solid waste disposed on the land surface overlying the groundwater table. The groundwater pollution problem is accelerated by the sensitive hydrogeological conditions of the groundwater systems in Taiz area However more work will be done during this study for detailed classification of the area according to the vulnerability levels.

Because of the relatively slow movement of water in the subsurface, evidences of pollution might not appear within short time. However, the appearance of pollution in groundwater is only a matter of time, and once contaminants reach the groundwater, their removal or attenuation may take tens of years.

The water level in the well fields varies greatly throughout the year in response to recharge and pumping. The annual variations in these well fields range from 2.7 to 168m. Such high seasonal and annual fluctuations indicate that the aquifer has limited storage, and it is highly vulnerable to groundwater pumping and to drought events.

The Need And Justifications For Government Interference And Action:

When groundwater pollution is discovered, an action is required, and an interference of the management institution(s) of water resources is called upon. The level of interference, and nature of action required depend on a number of factors:

1- The types of water uses which rely on the affected water source, and the quality requirement of these water uses with reference to the country adopted water use standards.

2- The type and concentration of the contaminants, as well as the potential threat to the intended water use, particularly human health.

3- The sensitivity of the groundwater source to be affected by the contaminants, and its natural capacity to attenuate and dilute the contaminant(s).

4- The state and level of development of the water supply source, and the availability of alternative water resource(s) to substitute or to augment the polluted water source and the current water supplies.

5- The capability of the government and private institution to deal with the problem in terms of defining the problem and risk, conducting the necessary surveys, including investigations and studies, and developing and implementing a strategic groundwater protection plan.

6- The current status of water legislations and regulations in terms of their current capacity to deal with such problems, the capability to adjust the current legislations to deal with the current needs, and the capability of the government to **effectively** enforce the legislations and regulations.

7- Other social, economic and political issues which are important at the local level.

Need For Planning And Management:

When pollution threat for water resources exist, and the aquifer is vulnerable to pollution, planning for groundwater protection should be started as early as possible, because remediation and rehabilitation of aquifers are costly and are not easy processes. Taking early steps to protect groundwater resources, particularly those used for domestic supply, by preventing contamination is usually, more effective and less costly than waiting until the resource is polluted.

This is particularly true when alternative surface or other groundwater supplies are not technically, socially and economically available in the near future. Such situation dictates that we have to wisely manage what we have today, and be aware of this fact at all levels of management and decision-making. But, how can we sustain these scarce, limited and vulnerable water resources without adopting a groundwater protection strategy and action plan, and without committing ourselves to the protection goal!

The situation in Taiz has already past that stage. Groundwater pollution is already existing to an advanced state. If no action is taken, the groundwater resource might become completely unsuitable for municipal uses without advanced and costly treatment and rehabilitation. We are late, but hopefully not too late.

Groundwater protection needs good planning, sincere commitment and support from the government, and need skilled technical and management capabilities and manpower. It also needs adequate and supported institutions as well as appropriate legislations, regulations and enforcement.

The most important requirements for planning and managing a groundwater protection strategy include the following:

- Clear policy and objectives.
- Commitment and resources availability.
- The availability of data and a systematic monitoring program.
- The availability of a reasonable, practical response system.
- Understanding the resource potentials and the demands.
- A good feel of the potential impacts of the selected course of action.
- Appropriate institutional and legislative framework.
- An appropriate flexible action plan, and means and tools for implementation

APPROACHES FOR GROUNDWATER PROTECTION

In view of the factors and the conditions explained in the previous chapter, the concerned government institution(s) should decide on the approach to deal with the problem, and the level and ways of interference. The available approaches range from complete protection of the groundwater aquifers from pollution, to unrestricted maximum development of the water resources. The first approach imposes strict control and restrictions on other socio-economic development. On the other hand, the second approach leaves the resources without any protection, and may ultimately lead to the abandonment of the groundwater resource on the long run. A middle approach would live up with some pollution effects of the human activities, but would allow some controlled groundwater quality degradation. This approach will necessitate some treatment of the water prior to its use.

The first approach relies mostly on preventive and precautionary measures, while the third middle approach relies on mostly corrective, and to a certain extent preventive measures. The selection of the most appropriate and balanced approach will depend on the local conditions concerning the above-mentioned controlling factors.

The government might also choose from a long list of alternatives such as:

- Closure of the water supply wells, in case of the availability of other water supply sources.
- Treatment of the contaminated water by appropriate means.
- Closure of the wastewater source.
- Treatment of the wastes prior to disposal.
- Delineating and imposing protection zones around the water supply wells an well fields, and possibly around the wastes sites.

New concepts for water pollution control have emerged and have been applied in the developed countries, and in many countries of the third world. Treatment of wastes, particularly liquid wastes, is a very effective approach to prevent pollution. This conforms with the concept that polluters should pay.

However, even after treatment of the wastes at the source, there will remain some smaller size, but highly concentrated residues. These residues have to be safely disposed somewhere, whether on the ground surface or in the sub-surface. Proper selection of disposal sites should consider the hydrologic and hydrogeologic factors and setup at the selected site. The best and least expensive way is to find a site, which is naturally safe, particularly hydrologically and hydrogeologically. If such locations cannot be found, then engineering should interfere to provide the protection required at the site. The management practices of waste disposal sites (land fills) are well known, and the appropriate practices can be adapted to the local conditions and then adopted.

In situations of heavily polluted aquifers such as in urban areas like the city of Taiz, where the municipal wastes would be difficult to control, and the quality deterioration of the local groundwater is difficult to stop, substitution of this groundwater source with another fresh and clean groundwater source, if available, may provide part of the solution.

Based on the geographic coverage, and the type and base of the adopted action, one of the following two approaches may be applied:

1. A comprehensive protection plan around the public water supply wells and well fields, which would rely on corrective as well as preventive measures depending on the pollution status.

2. A general protection plan for the groundwater resource at the regional scale. This plan would include the entire hydrologic catchment or groundwater basin, and would largely rely on the preventive approach.

The rightful approach is to conduct the needed surveys, investigations and studies before selecting an approach, and applying new restrictive measures and regulations.

1. The Regulatory Approach:

This approach centers on regulations and enforcement. It may provide a reasonable degree of protection in terms of control. Its success depends on the capacity of the current legislations and regulations to deal with the problem as well as on the degree of enforcement of these legislations and regulations.

Usually, only the major cases of pollution require legislative action. However, this approach would not be helpful if developing the required legislations and regulations is going to take too long time. In addition, it is important in such cases that the pollution sources are well known and proved, and do not require lengthy investigations to be identified and proved. Otherwise such regulatory approach cannot be applied.

Its advantage is that it requires little planning and management efforts in the future. This is useful when planning and management capabilities are lacking, and when extensive and lengthy investigations, which are not available at the time, are required for accurate definition of the problem and the venue for action.

Therefore, this approach may be selected in the following cases and conditions:

1. If the pollution problem is serious, and quick government interference and action is required to protect human lives and health, and in the meanwhile, there is not enough time to carry out extensive surveys and investigations.

2. If the pollution source is very well known and identified without any suspicion, particularly if the pollution source is concentrated at a point or a small area (point-pollution) that makes it easy to control and deal with.

3. If the government institution concerned does not have the planning and management capacity to deal with and follow-up of the problem in a long-term management plan.

The required regulatory mechanism would range from:

- Prohibiting certain development activities,
- Prohibiting certain water uses within the protection zones.

- Closure of wells for non-domestic water uses, and prohibiting drilling of new wells within the protection area.
- Restricting groundwater pumping for domestic uses only.
- Concentrating polluting activities and waste disposal sites to certain selected safe areas.

2. The Planning and Management Approach:

This approach can be subdivided into a management approach for aquifers already suffering from various levels of pollution, and a planning approach for aquifers which are vulnerable and sensitive to pollution, and potential pollution sources are either existing or planned in the future, but pollution has not been observed. The methodology for developing a protection plan for the two types is the same, and is based on the delineation of groundwater protection areas/zones around the wells and well fields. Such zoning can be applied at any level: local, regional, or basin-wide.

The management approach recognizes the need for controlling degradation by mostly corrective measures, such as water treatment, and sometimes supported by preventive measures; while the planning approach is based on controlled protection mainly by preventive measures such as integrated water and land management, and comprehensive monitoring system.

The planning and management approach assumes that there will be a minimum level of impacts of human activities on groundwater quality regardless of the technological and regulatory precautions. Therefore we should manage, by zoning, to protect the groundwater supplies from further deterioration to the limit that put them out of use, and to protect other clean aquifers or water sources. However, the use of controlled degradation approach, the management approach, has much wider applications to cases where groundwater contamination has already occurred as in the case of Haugala and Al-Howban well fields.

In heavily polluted wells and well fields, remediation and rehabilitation of the aquifer may prove technically and economically feasible. This technique has already been partly applied for one or two city wells in Taiz. Those wells, which have high nitrate concentration, were pumped out for several hours before the water was introduced into the network.

It is worth-mentioning that there is another similar zoning approach for groundwater protection, which utilizes a slightly different way of zoning, by creating protection/preventive zones around the waste sources themselves instead of having them around the water sources.

Again, as in the regulatory approach, the delineation of protection or controlled degradation /assimilation zones in the planning/management approach, requires the application of special regulatory alternatives, which vary in the level of restrictions from one zone to another, and from one situation to the other, based on the site specific conditions and pollution specifics.

The success of this approach depends on proper consideration of certain factors:

1. Understanding the basic site and area hydrogeology which is a critical factor for evaluating the hydrogeological significance of a pollution source. A clear understanding of the hydraulic properties of the aquifer and the overlying unsaturated zone, as well as a

clear understanding of the type and size of the prevailing groundwater flow system(s). Special investigations and studies may be needed to attain such understanding.

2. The nature and characteristics of wastes, their toxicity, mobility, and attenuation rate.

3. Waste segregation, and waste treatment processes, at the pollution source, prior to disposal, will be very helpful. Truly toxic wastes must be transferred and disposed in a hydrogeologically safe site or incinerated. Other non-toxic decomposable contaminants can be managed through the zoning approach.

4. Adequate legislations and regulations

The weakest links in the whole waste management and groundwater protection are:

- The lack of enforcement of regulations,
- The lack of monitoring,
- The lack of control and responsive plans, and
- The lack of awareness at the land users and waste producers' level.
- The lack of trained staff and equipment.

REQUIREMENTS FOR IMPLEMENTATION

The requirements for implementing the groundwater protection program are given as follows:

A) Administrative And Institutional Requirements:

The main responsibility for implementing the protection strategy lies with the government and its concerned institutions. However, the various water users, particularly the industrial sector, who really makes profit, should share the responsibility in all aspects including the financial aspects. Where do our industries stand from the globally accepted concept of clean technologies, and clean environment. The participation of this sector, is very important for a successful implementation of the protection strategy, as well as for sustainable water resources development

The project will be implemented by The National Water Resources Authority, (NWRA), with a major role given to their local office in Taiz. Close cooperation is needed with the National water Supply Authority (NWSA) at Taiz, and with other concerned local institutions. UN ESCWA regional adviser on water issues will provide technical and managerial support to the national team.

The requirements for implementation for the current project includes:

1. Assigning a work team who is interested, capable and committed to fulfill the tasks assigned to them. This team would be from Taiz office of NWRA, and may include members from NWSA, as they are close to the area, and they are acquainted with the locations and local conditions. Engineer, Abdallah Saleh Saif, the head of Taiz office of NWRA may act as the team leader. He suggested the following staff from his office to be the field team members:

    1) Eng. Geol. Khalid Shujaa'
    2) Eng. Geol. Noor Eddin M. Abdu
    3) Eng./Water & Env. Natheer Basheer
    4) Eng./Agri. Ahmed Albasha
    5) Chemist, Bakeel Ali Mohammed

Eng. Geol. Ahmed Abdul Rub, from Sana' main office of NWRA is proposed to act as a coordinator.

The work team will receive on-the-job training, as well as a formal one-week training on groundwater protection by ESCWA Regional Adviser during the project period.

2. Planning of the daily and weekly activities is necessary. Using a detailed plan of work, and a checklist of the needed weekly activities would be helpful.

3. Cooperation with the concerned government and private authorities particularly the National Water Supply Authority (NWSA) and the Chamber of Commerce is needed.

4. Official letters should be forwarded, with a copy to be hand carried during the visits to the industrial sites, from the Head of NWRA as well as from the local Governor, to all the industrial entities in Taiz area, with similar announcements on the local radio and television.

These means should instruct the factory owners and managers to cooperate and facilitate the work of the team.

5. Benefiting from the computer facilities at NWRA office in Taiz will be useful and required for the following tasks:

   a) Creating a database for the project components: wells, well fields, pollution sources, groundwater abstraction, and water quality. Each might be in a separate directory.

   b) To create the necessary base maps, and other thematic maps needed for the project.

6. The services of ESCWA regional adviser will be planned and provided according to the phases and progress of work by the national team.

7. During this mission a meeting was held with the concerned staff of NWSA, and I took the chance to visit their laboratory. The following important observations and requirements have to be made for special attention:

   a) Generally, the whole set-up and space of the laboratory is not adequate.

   b) The chemical reagents used for analysis have passed the expiry date by more than two years.

   c) Equipment and chemicals needed for analyzing sodium, potassium and heavy metals are not available.

   d) The parameters PH, EC, DO need to be measured directly in the field. Field equipment for such measurements are not available.

   e) The available microscope needed for bacteriological count is broken and need to be replaced.

   f) Appropriate equipment and material needed for accurate bacteriological testing, BOD and COD determination are not available.

   g) The chemical material supply for the laboratory should be provided on yearly basis to have the laboratory properly operational.

   h) A systematic monitoring program for the water well fields and waste effluents quality need to be designed and implemented.

The fulfillment of the above laboratory needs, from the regular budget or through some UN or international assistance program, such as the German BGR project, is important ant necessary, and is a pre-requisites to any water quality and pollution control management, and protection program.

B) Policy Requirements:

- The key factor for success of a groundwater protection program is the adoption by the government of a policy with clear objectives for protection. Such policy should be conformable with the land use policy and the socio-economic development objectives and should be given a high priority.

- The second key factor is the development of a protection strategy and action plan which are supported by adequate legal and institutional setup, and enforcement mechanism.

- The policy and strategy should be based on good understanding of the hydrogeological system conditions, the demand and supply requirements, as well as that of the nature of the activities and behavior of the pollutants.

- Protection zones should consider the future needs for water demand and other socio-economic development.

- The policy and strategy development should benefit from the regional and international experience.

C) Technical Requirements:

There are also technical requirements for the success of the groundwater resources protection strategy, which require the identification, definition and evaluation of the following:

- A study of the hydrological properties of the watershed, and the hydrogeological properties of the groundwater basin.

- A good understanding of the groundwater flow system and the hydraulic properties of the groundwater system.

- Determination of the infiltration characteristics of the vadose zone.

- Strengthening the capacity of the existing laboratory of NWSA at Taiz, particularly with equipment and materials/reagents required for analysis.

- Designing and implementing an appropriate water supply, and water resources monitoring system.

- A knowledge of the groundwater withdrawal and discharge areas as wells as the types of water uses.

- The existing and potential water pollution sources.

- The current pollution status, level and type of pollution.

- Identification of the potential impacts.

- Land use map for the current and planned socio-economic activities.
- A knowledge of the natural purification capacity of the soils and rocks.
- Aquifer vulnerability map.
- Delineation of the protection zones by applying appropriate mathematical models.

D) Management And Manpower Requirements:

The Regional Adviser on water resources at ESCWA, an Engr. Abdullah Saleh Saif, Drector of NWRA office at Taiz, may act as co-managers for the project. In addition, ESCWA Regional Adviser will provide on-job-training, and formal training for the national team in the needed areas and topics as necessary.

E) Fulfilling the Legislative and regulations requirements for the implementation phase.

GROUNDWATER MONITORING SYSTEM

Monitoring of the effects of human activities on the hydrogeological system includes identification of the possible and potential causes and source of pollution and measurements of their impacts on the groundwater quality.

In areas where the effects of human activities on groundwater resources are not yet apparent, while the potential sources of pollution are existing, the purpose of monitoring is to achieve timely identification of pollution and designing the required preventive measures.

In areas where pollution of groundwater already exist, the purpose of the monitoring system is to design the treatment system and other rehabilitation corrective measures as well as to try minimize or stop the pollution process.

So far the monitoring system for the groundwater supply well fields in Taiz area is very poor, inconsistent, and inadequate in terms of coverage, frequency, and the parameters needed to be determined. The laboratory at NWSA in Taiz is poorly equipped in terms of equipment, material supply of reagents, manpower and available space.

Water samples from the water supply system are only collected upon request or for a specific need. Samples are rarely collected from individual wells. They are mostly collected from pooled water (composite samples). Therefore, there is no systematic monitoring system for the water supply well fields and distribution system. Only one monthly sample is being collected from:

- Haima and Haiber well field.
- Haugala well field.
- Howban well field.
- And from the city wells.

For example, there are no equipment for field measurement of pH, EC and DO. There are also no equipment for measuring sodium , potassium and heavy metals. The facilities for bacteriological analysis and microorganisms are not adequate particularly the microscope.

This monitoring system needs to be completely redesigned, supported and implemented. This is vitally important as pollution of the water supply sources is already existing, and action is necessarily to plan for their treatment and to protect human health.

Moreover, monitoring of the pollution sources does not even exist for different reasons, most seriously the denial of access of government officials to those resources.

PRELIMINARY PLAN OF WORK

In order to evaluate the current status and define the problem, and conduct the required studies and planning, we need basic data on the various elements contributing to the problem. The success of the protection program will largely depend on the availability of such data. The work plan should be flexible, and directed towards achieving the required objectives. The work plan may be implemented in three phases. The activities involved in each phase are detailed in the following pages.

Explanations and clarifications on any technical matters or means and ways of implementing the various parts of the work can be provided by ESCWA Regional Adviser during the coming missions, or communicated through the fax or e-mail.

Phase 1: Preparatory Phase, (~ 2 Months) :

A: Problem Definition:

The groundwater pollution problem and the requirements for solutions will be defined, by characterizing the following:

- The type and level of existing and potential contaminants..
- The potential contaminants and their potential threat and hazard to the water supplies of Taiz.
- The existing and potential sources of pollution and their possible linkages to and contribution to the current pollution problem.
- The local and regional groundwater flow system(s) contributing to the existing water supply well fields, and the hydraulic properties of the related aquifers.
- The hydrogeological significance of the existing pollution sources in relation to the existing water supply well fields.
- Water source assessment, at the well field level, by identifying the characteristics of the hydrogeological setup of each well field and individual well.
- Tentative and possible solutions to the pollution problem for each case.
- Appropriate approaches for developing a groundwater source / resource protection plans.
- Data gaps, and data required to be collected during the second phase.
- The required resources to achieve that in terms of trained technicians, laboratory and field equipment, and chemical materials needed for the analysis.
- A time framework to perform the above activities.

B: Defining The Program Objectives:

In view of the problem definition obtained, and the potential threat on the limited and scarce water supply sources, the lack of alternative resources at least on the medium

term, and the importance of sustaining the existing well fields, quantitatively and qualitatively for Taiz water supply, the following strategic objectives for the groundwater supply management in Taiz can be identified:

- ❖ Improve and maintain adequate municipal water supply in terms of quality, quantity, time, and space, in order to protect human health and improve the standard of living.
- ❖ Protect and sustain the available groundwater resources for the future, and protect the environment.
- ❖ Control the current pollution of the groundwater supplies and try to reduce it.
- ❖ Develop and implement a practical simple rehabilitation program for the polluted water supply sources.
- ❖ Control and regulate the current and future solid and liquid waste disposal practices, particularly the urban and industrial wastes.
- ❖ Integrate the water and land use planning efforts.
- ❖ Develop the capacity of the national staff in the field of water pollution and groundwater protection.
- ❖ Introduce an appropriate methodology for delineation of protection zones for groundwater wells and well fields.

C: Data Collection Program

During the mission, the following sources for the relevant data were identified:

- ❑ National Water Resources Authority (NWRA) at Sana'a.
- ❑ National Water Resources Authority (NWRA), Taiz office.
- ❑ National Water supply Authority at Taiz, (NWSA).
- ❑ Taiz Chamber Of commerce.

The data to be gathered and maintained in a special database file for this project includes the following:

1. Well Fields' Data:

- A general regional topographic/hydrologic map showing the catchment and basin boundaries and the locations of the well fields (scale 1: 100,00)
- A specific map for each well field (scale 1: 10,000) or (1:20,00) which shows:
  - The locations of all producing, non-producing and abandoned wells.
  - Water storage facilities.

- Layout of pipeline connections.
- Chlorination facilities.
- Pumps' houses and petrol storage tanks.
- Workshop, if existing.
- Fenced areas.
- Guard house and sanitation facility.

- Average monthly and annual production rates from the well field in total and the availability of flow meters.
- Water quality control data for the bulk water.

2: Well data:

The following hydrogeologic and hydraulic data will be required for the individual wells in order to assess their hydraulic performance and to be used for the overall well field assessment:

- Well identification, number, ownership, location, etc…
- Well construction details: depth, diameter, casing and screen, drilling method and construction date.
- Screen type, length, diameter, location/depth, slot size or open area.
- Pump details: Type, capacity (horse power), length and diameter of pump and riser pipe.
- Power source.
- Well hydraulics: Average pumping rate, maximum drawdown.
- Pumping test data and results: Average pumping rate, static water level, maximum drawdown, hydraulic conductivity, aquifer thickness, transmissivity, storage coefficient, and date and type of test.
- Historical monitoring results of changes in water level, well discharge, and water quality.
- Detailed chemical analysis results (give dates).
- Current well status: Producing and in operation, abandoned, dry, monitoring, etc…
- Operation details: average monthly pumping rate.

3: Pollution Sources:

All existing potential pollution sources need to be survey data to be collected. Some previous study and inventory reports include such data. We need to update these data.

a) Municipal wastewater sources (solid and liquid urban and rural).

- Areas in Taiz served by the main sewerage network which is connected to the Buraihi lagoon, including the number of house connection and the number of population served (if possible). The available information on the rate of daily discharge in Buraihi lagoon, water quality samples need to collected and analysed.

- Areas in Taiz served by secondary sewerage networks, also the number of households served. Information on the location and rate of discharge and water quality should be collected.

- Areas in Taiz served by septic tanks, open or closed, including the number of households, (and the population served if possible).

- Areas of Taiz and the surroundings not served by any of the above facilities need to be delineated, with data to be collected on the number of households and population.

- Solid waste disposal sites for the city of Taiz. In addition stream channels crossing the city where garbage and other wastes are haphazardly disposed should be mapped.

- The cemeteries.

- The hospitals.

- Collections or grouping of small industries and mechanic workshops.

a) Industrial pollution sources:

Previous reports have gathered some information, on different dates, on the existing industries within and around Sana'a and the water supply well fields. The Department of Industry at the Chamber of Commerce was reported as one source of such information. Some data included, the type of products, the water demand, the rate of wastewater production, and little or no information on any waste treatment prior to disposal. Such data need to be collected and organized for updating during the second phase of the project.

However, during this phase, the sites of the industries need to be exactly located on the main regional base map. Some chemical analysis results on polluted groundwater, including heavy metals, were reported by Welle, J. Vandar, 1996.

c) Agricultural Wastes:

Very little information has been reported on agricultural wastes. However, it was reported by Welle, 1996, that natural fertilizers are mostly applied while using the traditional irrigation flooding method.

With respect to pesticides, welle, 1996, reported that pesticides are applied to the qat crops one day prior to their harvesting and selling. However, no groundwater analysis have been done for pesticides.

In general the effect of irrigation may be in terms of increasing the salinity of the relatively shallow groundwater as a result of salt leaching from the soil, and high rate of evaporation.

However, delineation of the irrigated areas around and upstream of the well fields will be necessary.

4: Well Fields' Water Quality Data:

Water quality data from previous sampling programs, investigations and studies need to be compiled in one file. The data may be in photocopies of original laboratory analysis sheets or tables in the previous study reports. The available data should be organized in a special data base file. It is important that the sampling, the source, and the date to be clearly identified. All sampling sites may be compiled on a special map.

Samples taken from the water supply system should mention whether they represent one well or a composite water source or reservoir. The data should include the major cations and anions, the significant heavy metals where possible, the Nitrates, EC, TDS, pH, and the bacteriological analysis.

5: Domestic water supplies by tankers:

Data on all the wells selling water for the public for domestic water use need to be collected. The data should include:

- Well data (same as for NWSA wells as possible).
- Pumped or sold water quantity, (Number of monthly tankers sold).
- Water quality data for each well.

6: Current and future land use plans.

Phase 2 : Updating And Collection Of Additional Data,(~ 4 Months):

During this phase, it will be required to:

① Update the existing data on well fields, and all the potential sources of pollution, municipal, industrial, agricultural through actual field surveys, measurements, and sampling.

② Collect water samples from all the water supply wells and reservoirs, and analyze them for the following parameters:

a) Chemical Analysis:

- Electrical conductivity, pH, and dissolved oxygen (fields measurements).
- Major cations: Na, K, Ca, Mg
- Major anions: Cl, SO_4, CO_3, HCO_3,NO_3
- Heavy metals: Boron, hexa-chromium, lead, arsenic, cadmium, selenium, cyanide, mercury.

b) Biological and bacteriological analysis:

- Total coliform, fecal coliform.
- Total organic carbon.
- BOD, COD,

③ Collect water samples for chemical and biological analysis, from all existing potential sources of pollution, particularly the municipal and industrial sources.

- The flood flows in the streams crossing the city of Taiz are expected to be a significant source of pollution as they carry huge amounts of variable types of municipal wastes. Therefore, sampling of the initial flood of the flood season, in particular, would be important.

- The inlets and outlets of the Buraihi lagoon as well as Al-Amira dam should also be sampled at least once a month, with respect to water quality and flow rate.

- The disposal sites of local secondary sewerage networks, which are not connected to the Buraihi conveyance pipeline should also be sampled and measured.

- Effluents from all the industrial sources should be sampled, and their flow rate measured, the disposal sites should be described in detail. Any local treatment prior to disposal should be described and reported.

- The analysis for the industrial wastes should include the major cations and anions, in addition to the heavy metals, chemical oxygen demand, and biochemical oxygen demand.

- Analysis for the municipal waste sources should include in addition to the above, the bacteriological analysis as well as the total organic carbon. The significance of the organic carbon is because it indicates the possible level of forming the tri-halomethanes upon chlorination. Tri-halomethanes may cause cancer at high concentration.

- Bacteriological analysis should also be performed for samples from food processing factories.

- Analysis for heavy metals is important for industrial wastes as well as for wells near municipal solid waste disposal sites.

- It is very important that the rate of flow or discharge for each industrial or municipal waste effluent be measured and reported at the time of sampling of each effluent. The discharge rate, together with the contaminants concentration will give us the total daily pollution load of each source, which is more important than merely the contaminant concentration or type.

- Initially one sample should be taken from each pollution source. However, for highly variable effluent discharges, a morning and afternoon samples and flow measurements will be preferred.

- Industrial effluent samples should be taken from the discharge pipe and not from a pond or lagoon.

- Based on the results of analysis of this initial mass sampling, the important sampling sites will be selected and prioritized according to their significance, and possibly for double-checking on certain sites. Also a general and specific monitoring program can be designed in terms of locations, parameters to be monitored and the frequency.

- The arial distribution of certain parameters can then be shown on special maps; and compared with the hydrogeological maps in order to demonstrate their hydrogeological significance.

Phase 3: Developing a groundwater protection plan, (~ 6 months):

Phases 1&2, are expected to end up with an appropriate data base for water quality management and for developing a groundwater protection plan. This database will be analyzed, evaluated, and interpreted as follows:

1- Pollution source assessment, which would include highlighting the most significant and serious sources of pollution as well as most significant contaminants. Hazardous and toxic contaminants will be identified and separated from non-hazardous contaminants. The level of hazard and risk of each contaminant will be determined.

2- The hydrogeological significance of each waste disposal site and for each contaminant will be determined at the local and basin levels.

3- The hydrogeological and hydraulic characteristics and features of each well and well field site will be determined, and demonstrated by appropriate set of hydrological and hydrochemical maps. These maps will be fit into the regional and basin-wide maps to give the regional significance of local activities.

4- Hydrochemical maps to show the arial distribution of the significant chemical parameters will be produced.

5- A land-use map will be prepared for the study area to show at least the following:

- Urban, and rural areas.
- Industrial areas, (compounds) (small industries and workshops).
- Major industrial sites.
- Landfill areas (solid waste disposal sites for the city).
- Polluted streams, particularly in Taiz area.
- Cemeteries.
- Irrigated areas.
- The plans for urban or industrial future expansion should be identified.

6- A vulnerability map will be prepared for the study area to show the sensitive areas for groundwater pollution.

7- A computer model will be used to simulate the groundwater flow pattern as well as the hydraulic performance of each well field. The model will be used to delineate the capture zones for the wells and well fields for selected travel times, in order to delineate the boundaries of the required groundwater protection zones.

8- Finally appropriate corrective, preventive and pre cautionary measures, including legislative requirements, will be determined to provide the required level of protection for each protection zone and waste disposal site.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions:

- The following conclusions can be made with respect to the groundwater quality deterioration and pollution:

- Most of the Taiz city wells and the wells of Haujala and Howban well fields are already polluted by municipal and industrial wastes. This pollution is demonstrated as an increase in the waster salinity, and in the nitrate concentration (up to 160 mg/l). Pollution with heavy metals and biological pollution are also expected. The situation is currently managed by blending the water of these well fields with the better-quality water pumped from Haima and Hbair well fields. No treatment, except chlorination, is currently practiced.

- There is no control on the drinking water supplies by tankers by the private sector, nor on the private water supply wells. No chlorination of this water takes place, and no water sampling and testing is being practiced for this sector of drinking water supply.

- The current practice of quality control and monitoring is not sufficient Individual wells are not sampled. Only grouped or combined water samples are being taken.

- The capability of the existing laboratory of NWSA at Taiz is very insufficient, in terms of equipment, reagents, man power and space.

- Alternative water supply options other than the groundwater is unlikely in the short and medium term. There for, protection of these scarce and valuable resources is vital and urgent.

Recommendations:

- Give top priority for groundwater protection from depletion and deterioration. Groundwater quality degradation is as serious as groundwater depletion. This can be best achieved through developing a groundwater protection strategy and plan.

- Ensure providing the required support for developing and implementing such strategy and action plan in all the areas of legislation and regulations, provision of laboratory equipment and material, and strengthening the capacity building in water quality management and source and resource protection.

- Implement the proposed protection plan as a pilot case study in order to develop and introduce an adequate methodology, which can then be applied to other water supply wells and well fields by the national team.

- Enforce an appropriate groundwater management strategy and plan, which would control well drilling and water pumping.

- Develop a medium term plan to augment the existing municipal water supply well fields by additional wells in areas such as wadi Al gayl, Wadi Bani Khawlan, Wadi al Dhabab (a tributary for Wadi .Rassyan west of Taiz, and lower Wadi Rassyan.
- On the long run, conduct a feasibility study for desalination for desalinating the brackish base flow of Wadi Warazan Because of its proximity to Taiz, and its relatively high altitude. The water can be taken directly from the stream or preferably from a well distributed network of shallow to medium depth wells.
- Study the feasibility of constructing storage and recharge dams on the main wadies, but with extreme caution not to seriously damage the existing natural groundwater recharge system which supplies most of the private shallow irrigation wells, and the down stream water rights.

PART II

EVALUATION OF THE EXPLORATORY WELL DRILLING PROGRAM

EVALUATION OF THE EXPLORATORY WELL DRILLING PROGRAM

Summary Of The Exploratory Drilling Results:

The current exploratory well drilling program was started in February 1998 for the purpose of exploring the potential for additional fresh water resources for the municipal Water supply of the city of Taiz. The program included the drilling of 5500 meters at several locations. Eleven wells have been drilled and completed and one well was still under drilling by June 2001 with a total depth of 5393 meters. Annex (1), gives the location and the final depth of the drilled wells.

Only six of the drilled wells penetrated the sandstone aquifer, mainly in Wadi Al-Ghayl, lower Wadi Rasyan, and in the area west of Taiz. The other five wells were fully completed in the volcanics, mostly because of failure to continue drilling to the needed depth, or because the design depths of the wells as estimated from geophysical surveys were underestimated. Wells' depth statistics are as follows:

Well Depth Statistics

	Sandstone	Volcanic	Overall
Average	358	516	421
Maximum	362	750	750
Minimum	234	210	210

The results of exploratory well program indicate that the highest well productivity was for wells tapping the sandstone aquifer, while most of the wells tapping the alluvial or the volcanic aquifers had low yields, as shown bellow and in annexes (2-5):

Well Yield Statistics

	Sandstone	Volcanic	Overall
Average	10.3	2.5	8.0
Maximum	20.12	4.0	20.12
Minimum	2.0	1.0	1.0

Two of the most successful wells were in Wadi Al-GhaylNos. (2 &3), and one well in Wadi Rassyan, No. (7) have yields ranging fro 10-20 l/s. The other wells had low yields not exceeding (4) l/s. The overall yield from all wells was 72 l./sec., with an average of 7.2 l./sec. per well, or 1.69 l./sec. per 100 m. of drilling.

The drilled exploratory wells may be classified according to Well Yield And Aquifer Type as follows:

No. of drilled Wells	Well Yield l/sec.	Aquifer type	
		Sandstone	Volcanic
1	V. High	1	-
2	High	2	-
3	Moderate	1	2
4	Low	1	3
1	Dry	55	-

Water samples were taken for chemical analysis upon completion and testing of the wells. The electrical conductivity of the groundwater in all wells ranged from 1015 to 3800 u-mhos. The highest salinity was found in Wadi Warazan well (9). On the other hand, the lowest salinity was found in two wells in Wadi Al-Ghayl (2,3), and well number (7) in Kzeijah west of Taiz, followed by well number (10) at Qarqar in lower Wadi Rasyan,. The following table gives some statistics on the groundwater salinity in the drilled wells.

Groundwater Salinity

	Sandstone	Volcanic	Overall
Average	1117	2366	1810
Maximum	1450	4800	4800
Minimum	1002	2150	1002

The following table and annex (3) indicate the following:

- Groundwater salinity is less for the sandstone aquifer and in Wadi Al-Ghayl in particular, where the salinity ranged from 1015 to 1136 u-mhos.
- The highest salinity was found in Wadi Warazan, and was mainly from the volcanics aquifer at a depth of 535 m {well (9)}.
- The average salinity for the sandstone wells was 1117 u-mhos, and that for the wells tapping the volcanics and/or alluvium was 2366 u-mhos.
- The variation of salinity with depth can be summarized as follows:

Water Quality For The drilled wells

Well depth m.	Well No.	Temperature C°	Electrical Conductivity
210	6	31.5	2150
298	2	31	1015
347	3	32.2	1136
353	7	35.5	1316
354	10	32.0	1450
535	9	40.0	3800
750	4,1	34,35	1900, 2150 respectively.

This information indicates that there is a general increase of water salinity and temperature with depth for most wells.

Evaluation of the Exploratory Well Drilling Program In The Different Catchment areas:

Wadi Al Ghayl:

Three wells have been drilled in Wadi al-Ghayl, (Al-Hasb, al-Qist and Al-Sawa), (NEB-2, 3, 5). They all penetrated the sandstone formation. However, Al-Sawa well was dry because it was located in the up thrown side of a fault where the sandstone formation was unsaturated. The other two wells, Al-Qist and Al-Hasb, have the highest yielding capacity among all the drilled wells (15 & 20 ℓ/sec.). Their water salinity was also the lowest, being 1316 & 1015 micro-mhos respectively.

Generally, drilling in Wadi al-Ghayl was successful and economical, may be because of the relatively shallow depths being less than 350 meters.

The results of drilling in this area are encouraging in terms of both the relatively high yielding capacity of the wells, the low groundwater salinity, and the relatively shallow depth to the sandstone formation.

Potential additional drilling sites for production purposes may be located in the middle and in the down-stream area of Wadi Al-Ghayl catchment.

However, as the current production from this area is almost in balance with the annual rate of replenishment, additional pumping is expected to affect the shallow depth irrigation wells. This is because of the hydraulic interconnection between the shallow and deep aquifers in this area. This adverse effect can be minimized in the short and medium terms by proper design of the new deep wells. In this case, the shallow aquifer and about 50% of the lower volcanics should be completely sealed off, and isolated from the lower sandstone aquifer by proper cementing job using the double plug displacement method.

Wadi Bani Khawlan:

One well was drilled in this area (Al-Mindafa, NEB-6), to a depth of 210m. The well was very low yielding, and its water has moderate salinity, (EC=2150). The well was completed in the volcanics without penetrating any part of the sandstone formation.

No drilling was possible in the lower part of the catchment for social constraints. This lower part of the catchment is believed to have good yielding potential, and the sandstone aquifer is within reasonable depth, less than 300 meters.

Wadi Warazan:

Two exploratory wells, NEB-8 and MEB-11, have been drilled in this area to depths 562 and 750 meters respectively.

These two wells were completed totally in the volcanics without reaching the sandstone formation, which is either deeper than expected or not existing at the given sites.

The two wells had low yields which was less than 2 ℓ/sec., and high salinity, 3800-4800 micro-mhos (EC). Some loss of circulation zones were encountered particularly in well No. 8. these zone are believed to have relatively good water yielding capacities. However, they were badly plugged with all kinds of materials, without any testing.

The excessive depth of the volcanis at these two sites may be attributed to their proximity from a line of volcanic necks in this area.

It is expected that using heavy and thick bentonite mud in drilling these two wells have had a negative effect on the yielding capacity of the lower volcanics.

Moreover, it is believed that the inadequate experience of the contractor, the inadequate capacity of his equipment, and the inadequate drilling design, with respect to the diameter, have limited the capability to greater depth. In addition, the results of the geophysical survey, on which depth interpretation was made, were not very accurate.

On the other hand, inadequate development and cleaning of these wells would reduce the yielding capacity of the wells. The insufficient capacity of the air compressor and mud pump, and the development procedure adopted, are responsibly for this failure.

It is possible that redevelopment of these two wells by appropriate equipment and procedure would improve the yielding capacity of these two wells.

For economic reasons related to the excessive depth to the sandstone in this area, and for the high salinity expected at such depth, it is not encouraging to pursue deep drilling in this area, knowing that a 900 meter deep well in this area will be close to the sea level.

Wadi Rassyan:

Three wells have been drilled in Wadi Rassyan, Mikbaba (NEB-4) in the upper part, Kuzigah and Kurbur, (NEB-7 &8 respectively), in the western downstream parts. Only the last two penetrated through the sandstone aquifer. Mikbaba well was totally in the volcanics, and the sandstone depth was greater than 750 meters in this area. The yielding capacity of the three wells was moderate to low, and exceeding 4 ℓ/sec.

The water salinity was low for the sandstone wells (around 1400 micro-mhos), and moderate for the volcanic aquifer in NEB-4, being 2600 micro-mhos.

Three exploratory well sites were recommended for drilling in this area in my precious report to NWRA, however, it was not possible to drill at any of these sites because of social constraints. A new substitute site was selected by NWRA few kilometers to the north of the proposed site. The well was drilled to a depth of 250 meters at the time of last mission when it was visited. However, the drilling operation was stopped because of mechanical failure. The well was first drilled by air and foam, then its was continued using bentonite mud because of the low capacity of the air compressor.

It is worth mentioning that lengthy halt of drilling operations without continued mud circulation would cause permanent plugging of the rock fractures and pore spaces, no matter how much development would be done.

If the social problems can be resolved on the proposed three site, there is a good opportunity to have good production capacity at these sites.

Conclusions And Recommendations

Conclusions:

The nearly completed exploratory well drilling results have provided the following conclusions:

1- Confirmed groundwater potential in the sandstone aquifer in Wadi Al-Ghayl, at relatively moderate depth, within 300 m. the water quality is good. A well controlled drilling quality is good. A well controlled drilling and production rate should be ensured in order to minimize the short and medium term effects on the existing private irrigation wells.

2- It is believed that there is additional potential for groundwater potential in lower Wadi Al-Ghayl and lower Wadi Rassyan. However, the social problem did not allow for confirmative drilling particularly in Wadi Al-Ghayl.

The drilling depths in Wadi Al-Ghayl are adequate, within 300 meters, while it varies from 400-800 meters in Wadi Rassyan.

3- Drilling in upper Wadi Rassyan and in Wadi Warazan failed to reach to the deep sandstone aquifer for different reasons. Inadequate capacity of the equipment used, in appropriate design of drilling diameter, are some of those reasons. Geological complexity is another reason.

The depth to the sandstone, if existing is highly variable, it is greater than 750 meters, and there is doubt about the lateral extent and hydraulic continuity of the sandstone formations, particularly in Wadi Warazan, Taiz area, and in upper Wadi Rassyan.

General Recommendations:

The possible future recommendations and actions may include the following:

1. Resolve the social constraint on drilling in Wadi Bani Khawlan and Wadi Rassyan and complete the exploration program in those areas.
2. Drill production / test wells, in groups of five wells at each site, in middle and lower Wadi al-Ghayl, and in lower Wadi Rassyan.
3. Re-do well cleaning and development in Mokbaba well and in the two Warazan wells suing adequate equipment and procedures.
4. In view of the limited occurrence and potential for the deep groundwater in Taiz Region, it is recommended to adopt and undertake a groundwater protection strategy and a program for the shallow water supply well fields in order to maintain and sustain at least the current supply rates. There is a real threat of pollution and depletion of these groundwater supplies.
5. Consider Wadi Warazan surface base flow as a potential source for Taiz water supply, directly or after desalination. The base flow water may be pumped directly from the stream or from a well-designed network of shallow and medium depth wells.

Specific Recommendations:

Well Drilling:

1. In the absence of strict control on the properties of the drilling fluid, particularly when bentonite is used, drilling in hard rock, particularly within the water-bearing zones (aquifers) it is preferable and more efficient to use the air and foam method. It is fast, effective, and maintains a clean borehole free from mud.

2. If an adequate air compressor, with sufficient air volume and air pressure delivery, is used, problems in loss of circulation zones can be minimized. If the air circulation loss persists, we may temporarily switch to mud rotary. Complete and permanent plugging of these zones should not be allowed at all, as these zones are expected to be the most productive for water.

Well Development:

An efficient mud cleaning procedure should be used including but not limited to the following, and in the given sequence:

1. Hole reaming
2. Washing with polyphosphates, while using jetting or surging as feasible. The use of appropriate tools is important.
3. Surging by the airlift technique.
4. High and variable rate pumping and surging.

Wadi Warazan Wells Nos. 9 &11, should be redeveloped by the above given methods to increase their yield.

Wadi Rassyan Well No.12: Drilling should be continued as possible with air and foam. This is a must as soon as the sand stone starts to appear.

Potential Areas for Drilling production wells:

Based on well productivity, water quality, depth to the sandstone aquifer and social constraints, the potential groundwater areas for production well drilling may be ranked as follows, with the first being the best, and having the highest priority. The priority for drilling may be stated as follows:

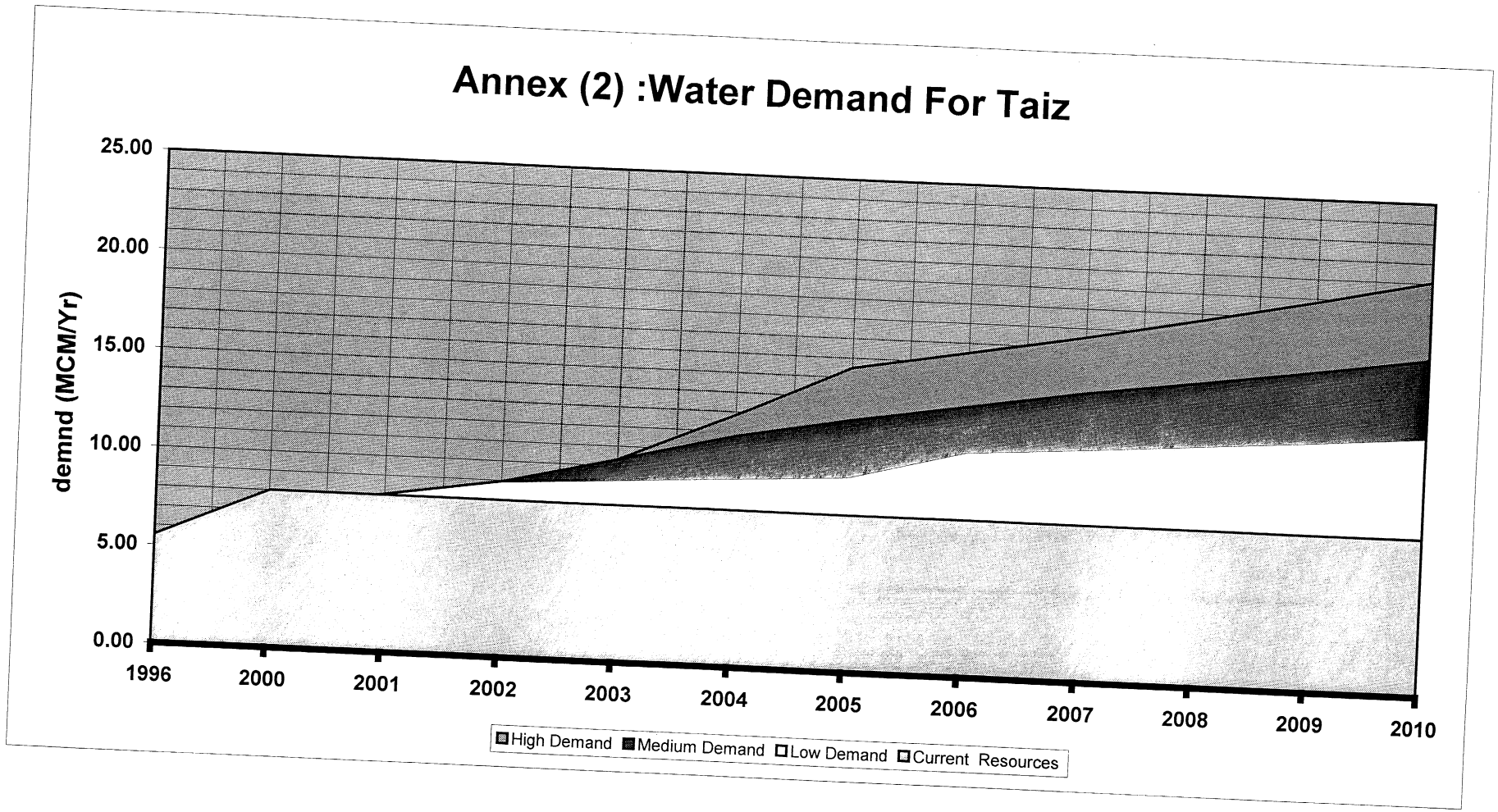
1. Middle and lower W. Al-Ghayl
2. Lower W. Bani Khawlan
3. Lower W. Rasyan
4. Middle W. Rasyan
5. Upper W. Rasyan

ANNEXES

Annex (1)

ESTIMATED WATER DEMAND FOR THE CITY OF TAI'Z

Year	*HIGH ESTIMATE*		*MODERATE ESTIMATE*		*LOW ESTIMATE*	
	Demand MCM/Yr	Deficit / Shortage (Ref. 1996) MCM/Yr	Demand MCM/Yr	Deficit / Shortage (Ref. 1996) MCM/Yr	Demand MCM/Yr	Deficit / Shortage (Ref. 1996) MCM/Yr
1994						
1996	5.55		5.55		5.55	
2000	7.39	-1.84	7.39	-1.84	7.39	-1.84
2001	8.06	-2.51	8.06	-2.51	8.06	-2.51
2002	8.97	-3.42	8.97	-3.42	8.97	-3.42
2003	10.33	-4.78	10.33	-4.78	9.30	-3.75
2004	12.84	-7.29	11.77	-6.22	9.63	-4.08
2005	15.51	-9.96	12.85	-7.30	9.97	-4.42
2006	16.51	-10.96	13.76	-8.21	11.46	-5.91
2007	17.56	-12.01	14.71	-9.16	11.87	-6.32
2008	18.67	-13.12	15.47	-9.92	12.28	-6.73
2009	19.83	-14.28	16.27	-10.72	12.71	-7.16
2010	21.05	-15.50	17.10	-11.55	13.16	-7.61


Annex (2) :Water Demand For Taiz
demnd (MCM/Yr)
25.00
20.00
15.00
10.00
5.00
0.00
1996
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
High Demand
Medium Demand
Low Demand
Current Resources

Annex (3)

Location And Depth Of The Drilled Exploratory Wells

Well Number	Location		Coordinates		Well Depth M.
	Area	Wadi	East	North	
1	Al-Dhabab	Bani Khawlan	383848	1499693	750
2	Al-Hasb	Al-Ghayl	384848	1467427	298
3	Al-Qist	Al-Ghayl	382918	1486118	347
4	Al-Miqbabah	Rassyan	398050	1514123	750
5	Al-Siwa'a	Al-Ghayl	387262	14748822	234
6	Al-Minthafah	Al-Ghayl	375143	1476074	210
8	Al-Husaineh	West of Tai'z	376989	1500574	562
9	Warazan	Warazan	416373	1480760	535
10	Qarqar	Rassyan	371353	1505350	354
11	Warazan	Warazan			750
12	Rassyan	Rassyan			250 ?

Annex (4)

Productivity Of the Drilled Exploratry wells

WELL NUMBER	Location	Well Yield liters/sec	Draw-down m.	Specific Capacity l/sec/m	Productivity	Aquifer Type (Material) ***
1	Al Dhabab-Bani-khawlwn	4.0	84.87	0.047	Moderate	All+B
2	Alhasb-W Al Gail	20.0	12.50	1.600	High	SS
3	Al-Qist W Al Gail	15.0	0.29	51.724	Very High	SS
4	Al-Miqbabah Rassyan	3.0	190.00	0.016	Moderate	All+B
5	Al-Sawa W Al Gail	0.0			Dry	SS
6	Al-Mithafa AlGail	0.5	–	–	Low	All+B
7	Al-Khzaijh Rassyan	10.0	82.11	0.122	High	SS
8	Al-Husainah Rassyan	3.0	103.43	0.029	Low	ALL+B+SS
9	Warazan	13.0	21.16	0.614	Moderate	B
10	Qarqar Rassyan	3.5	12.00	0.292	Low	ALL+B+SS
11	Warazan				Low	
12	Rassyan				?	
Total Well Yield (l / sec) :		72.0				

*** All : Alluvium , SS : Sandstone , B : Basalt

Annex (5)

Summary of Wells'Productivities

Parameater	Values
Number of wells	12
Total Drilling Depth	5393
Successful Wells Number : % Success :	 6 50%
Total Well Yield (l / sec.)	72
Ave. Yield Per Well (l /se	6.00
Yield /100 m.of drilling l/sec)	1.34

Annex (6)

Well Productivity By Area

Area	Number of Drilled Wells	Well Productiviity				
		V. High	High	Moderate	Low	Dry
Wadi Al- Ghayl / *** Aquifer :	4	1 SS	1 SS		1 B	1 SS
Wadi Bani Khawlan *** Aquifer :	1				1 B	
Wadi Warazan *** Aquifer :	2			1 B	1	
Wadi Rassyan *** Aquifer :	2				2 B	
West of Ta'izz *** Aquifer :	2			1 SS	1 SS+B	
Total	11	1	1	2	6	1

Summary :

Out of 10 drilled wells there are:

1 Well	Of very High Productivity
1 Well	Of High Productivity
2 Wells	Of Moderate Productivity
5 Wells	Of Low Productivity
1 Well	Dry

Annex (7)

Well Productivity By Aquifer Type

Well Productivity	Number Of Wells in each aquifer			Total
	Alluvium	Sandstone	Basalt	
Very High		1		1
High		2		2
Moderate	2	2	2	4
Low	1	1	2	4
Dry Well				1
Total	3	6	7	12

Note : Total Number of Wells = (12)

Well Yield (l / s)	Aquifer			Total
	Alluvium	Sandstone	Basalt	
Total Well's Yield (l / s)		51.5	20.5	72
Average Well Yield (l / s)		8	3.9	

Annex (8)

Grounwater Quality In The Drilled Exploratory Wells

Well Number	Location		Electrical	Tempreture	Well Depth
	Area	Wadi	Conductivity	deg. Cent.	M.
B					
9	Warazan	Warazan	3800	40	535
All + B					
1	Al-Dhabab	Bani Khawlan	2530	35	750
4	Al-Miqbabah	Rassyan	1900	34	750
10	Qarqar	Rassyan	1450	32	354
6	Al-Minthafah	Al-Ghayl	2150	31.5	210
Range :	1450 - 2530				
Average :	2008				
All + B + SS					
8	Al-Husaineh	est of Tai'z+C2	1002	50.45	562
SS					
2	Al-Hasb	Al-Ghayl	1015	31	298
3	Al-Qist	Al-Ghayl	1136	32.2	347
5	Al-Siwa'a	Al-Ghayl	dry		234
7	Khzeijah	West of Tai'z	1316	35.5	353
Range :	1015-1316				
Average :	1156				

*** All : Alluvium , SS : Sandstone , B : Basalt