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Arab Centre for the Studies of Arid Zones and Dry Lands
ACSAD
Damascus

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Management, Protection and Sustainable Use of Groundwater and Soil Resources in the Arab Region

Volume 7

Guideline for Groundwater Monitoring

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Guideline for Groundwater Monitoring

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Foreword

The increasing awareness of water issues in the Arab Region and the prospect of an emerging water crisis during the first decade of the 21st century has led to growing concern about the sustainable use of water resources.

Since the Arab Region extends over arid and semi-arid zones, groundwater constitutes the main source of water supply. Protection of this resource is indispensably necessary to ensure sustainable development.

ACSAD and BGR focus exactly on this issue by implementing their joint project **"Management, Protection and Sustainable Use of Groundwater and Soil Resources in the Arab Region".**

This report constitutes one of the important outputs of the project. The report aims at the prevention of groundwater pollution and presents suitable methods for the protection of groundwater resources in the Arab Region.

ACSAD is indebted to BGR and its staff for their fruitful cooperation in our joint project.

By making this publication available to a wider audience, we hope to provide not only technical solutions but also promote awareness for these aspects in the Arab Region.

Dr. Adel Safar
Director General
ACSAD

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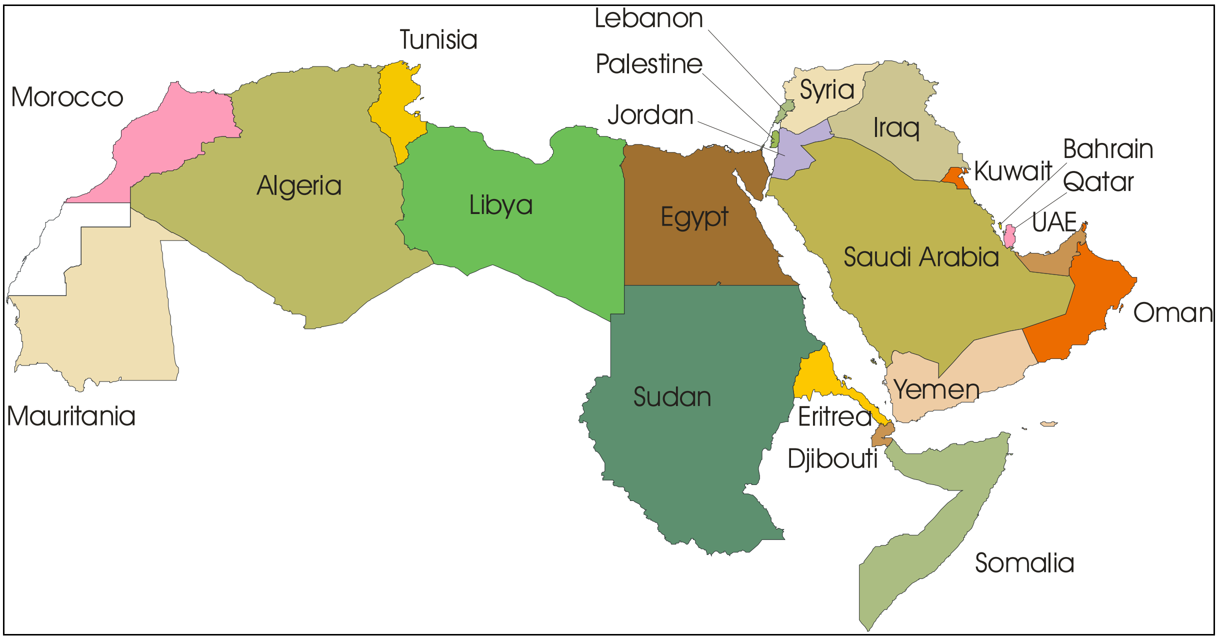
Lebanon	Libya	Mauritania	Morocco
Oman	Palestine	Qatar	Saudi Arabia
Somalia	Sudan	Syria	Tunisia
United Arab Emirates	Yemen		



Foreword

This report is part of a series of Technical Reports published by the Technical Cooperation Project “Management, Protection and Sustainable Use of Groundwater and Soil Resources in the Arab Region”, which is being implemented by the Federal Institute for Geosciences and Natural Resources (BGR), Germany, and the Arab Centre for the Studies of Arid Zones and Dry Lands (ACSAD). This project started in August 1997 and its second phase ended in December 2003.

ACSAD was established within the framework of the Arab League in 1971 as an autonomous, intergovernmental organization.

Many Arab countries are facing major environmental challenges. Water scarcity and pollution in conjunction with the loss, degradation and contamination of land resources have become core problems affecting public health and the socio-economic development. Water and soil resources represent exhaustible and vulnerable resources. Thus, a sustainable development of the Arab region requires the implementation of guidelines concerning the protection and sustainable use of groundwater resources and soils. The formulation and dissemination of such guidelines are one of the main goals of the project.

The present report deals with the issue of Groundwater Monitoring in ACSAD member countries. Since the renewable water resources in many ACSAD member countries are very scarce, the monitoring of these resources with regard to quantity and quality is a task of prime importance.

The agricultural development in most of these countries started in the early 1970s and nowadays an increasingly large share of the renewable water resources is being used for irrigation. Water demand has risen sharply, not only for agricultural but also for industrial and domestic uses. In many countries where surface water resources are scarce by nature, increasing amounts of groundwater are mobilized to suffice these needs, often accepting an overdraft of the renewable groundwater resources. This has resulted in strong declines of the water levels over vast areas. Often it takes years of careful monitoring before these effects become obvious. The strong declines may be the result of previous overestimations of the long-term available renewable groundwater resources. The possible negative effects of such overexploitation encompass: the depletion of the resource and the deterioration of water quality, for instance as a result of saltwater or brackish water intrusion, of the influx of chemical substances or of hydrochemical processes in the aquifer due to the altered environmental conditions (redox, pH, etc.). Once affected by such drastic changes in the hydrochemical composition, the rehabilitation of these aquifers may require enormous efforts. Declining water levels may result in increased abstraction costs because wells have to be continuously deepened or relocated.

The increased agricultural land use brought about a deterioration of groundwater qualities in many areas through the application of fertilizers and pesticides. This is noticed chiefly by the increasing salinities caused by irrigation return flows, but also by continuous increases in the nitrate and total dissolved solids (TDS) contents in groundwaters downstream of extensively cultivated areas.

Groundwater quality is also largely affected by other land uses which may be hazardous to groundwater, such as industrial sites, oil storage/filling facilities, sewage effluents (treated and untreated sewage), waste disposal sites (legal/illegal), etc., and which are accumulated especially in urban and heavily industrialized areas, and which may only become evident if groundwater monitoring is being carried out for this purpose.

Groundwater monitoring provides information of prime importance to water resources management decision makers. Therefore, collection, processing, interpretation and presentation of such data need to be conducted by appropriate means in order to obtain the correct output and to draw the right conclusions. Many mistakes can already be made when collecting data in the field. Appropriately trained staff and sufficient technical and financial resources are prerequisites for good monitoring results.

Often no written procedures exist for conducting groundwater level or quality monitoring. The aim of this report is to assist the responsible authorities in establishing a groundwater resources monitoring plan and conducting measurements and assessments in the appropriate manner.

Groundwater monitoring may be conducted for many different purposes, such as:

- general characterization of the groundwater flow system; identification of groundwater exploitation potential and groundwater quality; recording of reference values for undisturbed groundwater (natural background values);
- identification of threats to the groundwater and of the vulnerability of the groundwater system to pollution;
- response of the aquifer system to groundwater abstraction (changes in water level and chemical composition; e.g. for groundwater resources management/modeling);
- response of the aquifer system to individual land uses (changes in chemical composition in time and space);
- response of the aquifer system to groundwater pollution (changes in chemical composition in time and space); identification of pathway and velocity of propagation of hazardous substances;
- interaction of the groundwater system with the surface water system.

UNECE (1999) distinguishes three main categories of monitoring:

- <u>statutory (or strategic) monitoring</u> (to meet legal obligations, such as standards for maximum allowed limits of contents in water and soil);
- <u>surveillance monitoring</u> (to assess the state of groundwater quality and quantity over space and time);

- operational monitoring (e.g. to evaluate long-term changes in the quality of water used for domestic water supply; to evaluate the success of land reclamation programs; or to evaluate the existence or extent of a known or possible pollution).

In principle, every natural or man-made facility where groundwater is accessible may be used to monitor the groundwater level or quality of groundwater. However, in reality many of the existing sites are not suitable because they do not reflect the natural conditions in the aquifer itself. In most cases monitoring wells have to be constructed for the specific monitoring purpose.

The following guideline describes in detail for the individual monitoring purposes how monitoring locations should be selected, what has to be considered when drilling and constructing the site, which equipment could be used, how often and for which time periods monitoring should be undertaken, and how monitoring data should be collected, stored and processed. It also gives some indication about the costs involved.

Since the principles of collection of groundwater level monitoring data are different in their requirements from those of the collection of groundwater quality data, and because there often exist two independent monitoring networks, these two monitoring objectives are described in separate parts of this guideline. To avoid duplications in either of these parts certain issues are described in more detail in those parts where they are more relevant. It is, however, recommended to consider both respective chapters when planning or implementing groundwater monitoring networks. It must be stated clearly, however, that the operation of two independent groundwater monitoring networks, one for groundwater level monitoring, the other for groundwater quality monitoring, does often not make sense.

The author is grateful for the support by some companies working in the field of groundwater monitoring or producing the required equipment.

Part A – Groundwater Level Monitoring

1 Objectives and Strategies

Groundwater level monitoring is conducted to obtain readings of the elevation of the water table or the piezometric head. This elevation changes with time depending on the recharge and discharge characteristics and the hydraulic parameters of the aquifer system but also on short-term and long-term changes in the climate, groundwater withdrawals and land use changes.

Due to human interventions groundwater flow has been altered in many regions, both in horizontal and in vertical directions. Large-scale developments and land use changes may result in regional or local increases or decreases of groundwater recharge or discharge.

In general, groundwater monitoring encompasses the following components (UNECE 1999):

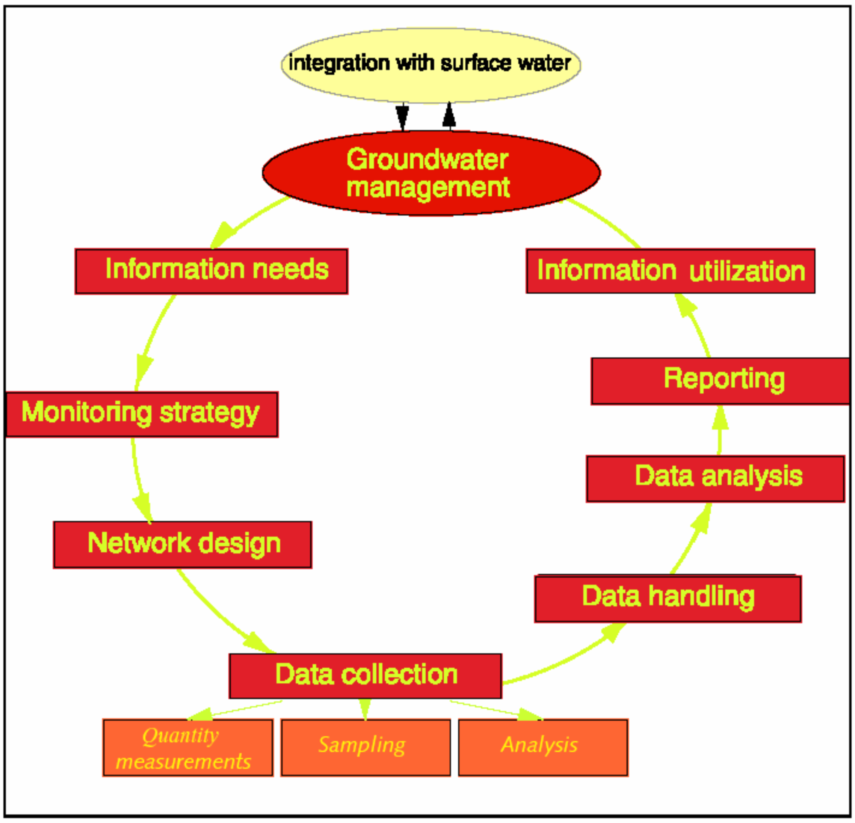


Figure 1: Components of Groundwater Monitoring

In order to design a monitoring network appropriately, the objectives and information needs as well as the aim of information utilization have to be defined. Furthermore, policies concerning groundwater management have to be developed to decide what happens if certain threshold values (for water levels or water quality) are trespassed.

UNECE (1999) propose the following design and implementation process for a groundwater monitoring network:

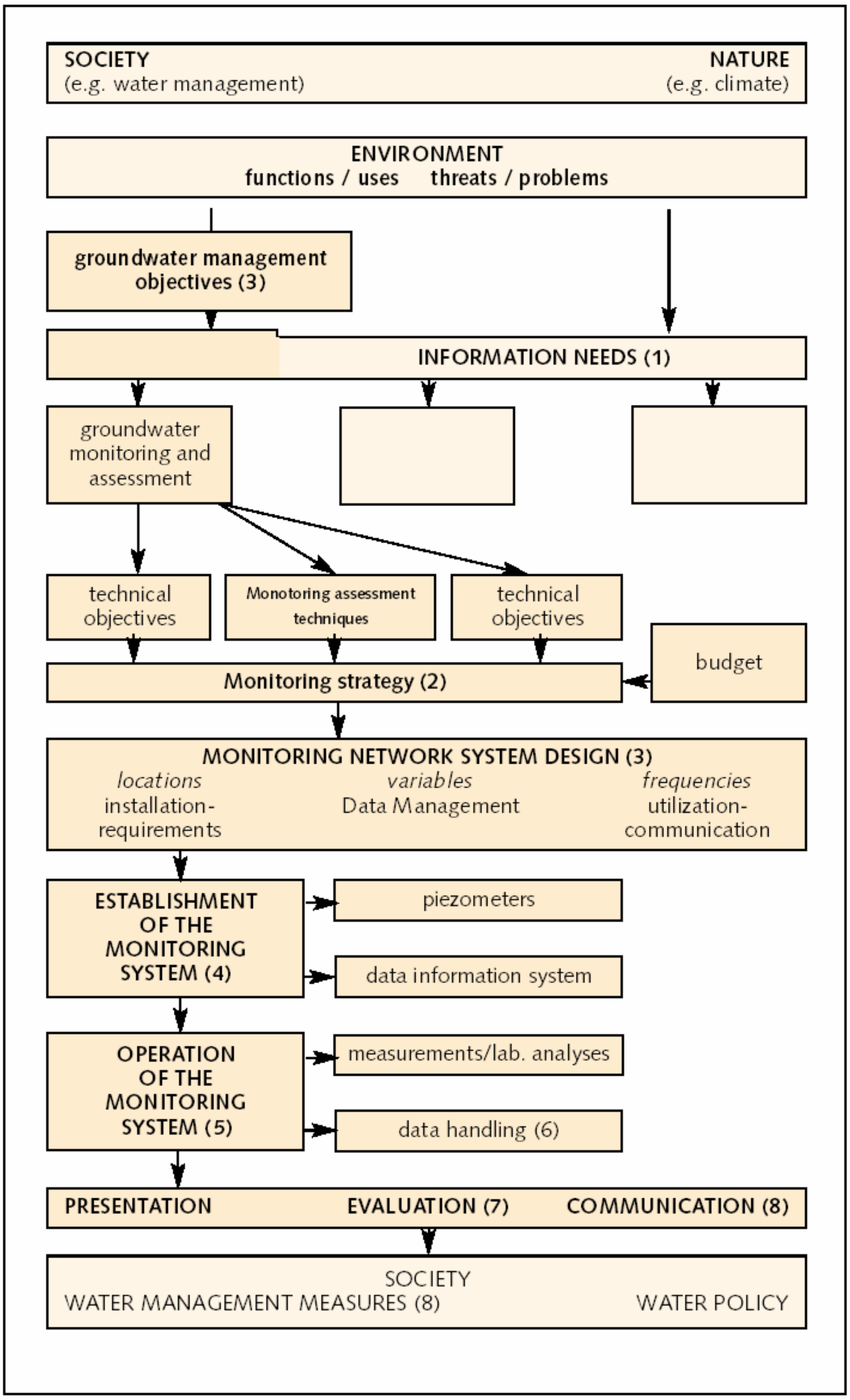


Figure 2: Design and Implementation Process of a Groundwater Monitoring Network

The main purposes of water level monitoring networks are :

- To provide data from pumping tests for the evaluation of the hydraulic properties of an aquifer at a specific location;
- To provide data for the preparation of potentiometric maps of individual aquifers/regions;
- To provide data for the evaluation of (long-term and short-term) storage and groundwater recharge changes in the resource (e.g. to monitor the effects of short-term or long-term climatic variations);
- To provide data for the evaluation of groundwater – surface water interactions (influent/effluent conditions; seasonal variations thereof and as a consequence of groundwater development);
- To design, implement and monitor the effects of any activities which may lead to water level changes, such as groundwater abstractions, injections into groundwater, land use changes, changes to surface water availability, etc. (e.g. to monitor the success of mine dewatering or artificial recharge, the effect of irrigation schemes, dams, deforestation, etc. often as part of environmental impact assessments);
- To provide data for the evaluation of the success of aquifer restoration programs (e.g. functionality of hydraulic barriers); and
- To provide input data for the development and validation of hydraulic models and for the establishment of a prognosis for expected long-term water level changes in correlation with certain possible development schemes.

The time period of continuous records and the frequency of record registration depend on the intended use (see below). Long-term water level monitoring data are an essential part of (ground)water resources management plans and should be used for all related management decisions. Especially in respect to the evaluation of the sustainability of water resources management such long-term data are fundamental.

Since changes in the water level may have serious consequences not only for the available amounts of groundwater but also for groundwater quality, monitoring data are important for groundwater protection, resource preservation and aquifer restoration programs. Because the number of sites and activities which are possibly hazardous to groundwater is continuously rising, the need for a proactive (preventive) groundwater protection is increasing. Monitoring of the groundwater resources downstream of such groundwater hazards is an important part of groundwater protection strategies.

Water level changes in the groundwater system may influence the flow pattern in the surface water system and vice versa.

Over the past decades, groundwater monitoring data have become increasingly important for environmental impact assessments. They are essential for any large scale alterations to the surface water flow, such as dams and diversions, or to the groundwater system, such as e.g. dewatering for mine operations, which cause water level declines and may result in the drying-up of springs, lakes or wetlands. Other major land use changes may have considerable effects on groundwater recharge and discharge and thus the water levels.

Groundwater levels measured at monitoring wells usually show a natural cyclic pattern which reflects the varying climatic conditions, i.e. the seasonal variations in recharge and discharge over the year. The range and timing of natural seasonal water level fluctuations depends on the source of recharge and the physical and hydraulic properties of the aquifer. Apart from such annual water level fluctuations water level changes over longer time periods may occur, which reflect long-term climatic changes, such as meso- and microclimatic changes induced by large dams, the drying-up of lakes or swamps or deforestation.

Annual variations in groundwater abstraction, water injection or surface water – groundwater interactions are also reflected in the water level recordings of a monitoring well. Effects of abstraction are often anti-cyclic to the 'natural' fluctuation and are often difficult to quantify and to distinguish from the latter. The stresses on the natural system must be evaluated carefully in order to be able to evaluate their relative impact on the groundwater system.

An effective monitoring network is required for water resources management decisions. Most important in this respect is the appropriate design of the monitoring network. Not only the number but also the location, screened depth interval and type of construction must be chosen appropriately. Often monitoring networks are not designed in such a way that they would provide sufficient data. Therefore, before establishing (a) monitoring network(s), a comprehensive concept needs to be established that states the monitoring purposes of each individual network, lists the proposed monitoring sites with all details about their position within an aquifer system, the frequency and duration of monitoring and the type of registration, data storage and transfer, as well as the intended field campaign schedule, the estimated costs, the staff qualification program, and the reporting procedures.

Written procedures must exist to provide for appropriate collection and storage of monitoring data. Such procedures should be the basis for an internal auditing which should be conducted every few years in order to be able to recognize problems and to define solutions. If problems still remain, external auditing should be envisaged.

If groundwater monitoring is conducted by several independent agencies, it is important to reach an agreement for coordination and full cooperation concerning all related work. This helps saving personnel and money, but also helps to obtain better monitoring results.

The regular maintenance of the equipment and the availability of sufficiently well trained staff and sufficient funds are very important. It is recommendable to evaluate the monitoring data at fixed time intervals, for instance on a monthly or quarterly basis, in order to be able to detect undesired impacts on the groundwater system or malfunctions of the monitoring system at an early stage. The results of groundwater monitoring should be published in annual reports so that they could be used for (ground)water resources management decisions.

2 Methods of Water Level Recording

Unfortunately, the terminology used for water level monitoring data recording, storage and transmission equipment is not uniform and largely varies among the companies producing them.

Various devices are used for water level recordings :

- For manual measurements:
  - Water level meters (contact meters; contact gauges; dip meters; dippers).
- For manual or automatic measurements:
  - Radar sensors;
  - Ultrasonic sensors;
  - Acoustic resonance sensors.
- For automatic measurements:
  - Mechanical water level recorders (using chart registration systems and floats);
  - Encoders for mechanical recorders (converting measurements of mechanical water level recorders into digital data);
  - Mechanical floats with built-in encoders and data loggers;
  - Sensors using the bubble principle;
  - Pressure probes (pressure transducers).

Water Level Meters

Description: An electric circuit is closed when the probe gets in contact with water and a light or sound signal is emitted.

Examples: SEBA KLL/KLM/PV (cable lengths between 10 and 1,000 m) or KLL-T/KLL-Q (combined with measurements of temperature or various water quality sensors; cable lengths between 30 and 500 m); OTT KL 010 (cable lengths between 15 and 750 m); SOLINST Model 101 (cable lengths between 10 and 1,500 m) or Model 102 (cable lengths between 30 m and 300 m).

Costs: around 300 EUR for standard water level meter with 100 m measuring range.

Application: Most frequently use method when manual groundwater level measurements are required.

Advantages: Quick and easy manual water level and total depth measurements for depths up to 750 m. Optionally with integrated temperature measurements, e.g. for temperature profiles. Its small external diameter allows inserting the probe into small diameter or inclined boreholes or tubes.

Disadvantages: When repaired by shortening the cable, misreadings may occur if repairs are not clearly indicated on the instrument.

Recommendations: Manual readings should be used in addition to other methods to calibrate or confirm the correctness of the other measurement. When measuring water levels deeper than 100 m the weight of cable and probe becomes heavy. A motor operated rolling-up mechanism facilitates such measurements. When pulling up the cable, the cable or probe might get stuck, e.g. when inserting the equipment into a well fitted with a pump. Spare parts, such as light bulbs and batteries should be added to field equipment. Broken cables could be mended even in the field when taking along a soldering gun and suitable plastic tape. Tape should only be cut at 1 or 10 m marks. Repairs should be marked on drum mentioning the missing depth intervals.

Radar Sensors

Description: A radar ('radio aircraft detecting and ranging') microwave (electro-magnetic wave) is transmitted from a fixed position perpendicular to the water surface. The reflected microwave is registered by a receiver and the signal processed to determine the exact distance. Microwave frequency and energy depend on the distance to the water level.

Examples: OTT Kalesto (surface water); SEBA Pulse.

Costs: unknown

Application: So far mainly used in surface water due to large dimensions and high weight of transmitter/receiver and problems with signal reflection by borehole wall. A new system is in the process to be developed for groundwater level measurements by OTT-Hydrometrie (guided wave principle).

Advantages: None so far.

Disadvantages: Problems with signal scattering; high energy consumption.

Recommendations: None.

Ultrasonic Sensors

Description: An ultrasonic impulse is emitted to the air/water interface. At the interface the signal is reflected back. Since the propagation velocity of ultrasonic waves is known the time lag between signal emission and first registration of reflected signal multiplied with the velocity yields the length of way.

Application: Very shallow water levels; boreholes of large diameter and very straight inner walls.

Advantages: None (rarely used).

Disadvantages: High energy consumption; temperature-dependent results; strong scattering of reflected signals if inner walls of borehole not straight.

Recommendations: Not recommended for groundwater level monitoring.

Acoustic Resonance Sensors

Description: Acoustic resonance in the air column in the borehole can be reached when the length of air column is equal to an uneven multiple of λ / 4 (with λ = wave length) of the corresponding overtone. The sound signal is generated using a frequency stable low-frequency generator emitting waves between 0.1 and 100 Hz.

Application: In not straight boreholes and such with small diameter and large depth; rarely used.

Advantages: No introduction of equipment into borehole required; applicable in not straight boreholes and such with small diameter and large depth.

Disadvantages: Temperature and humidity dependant; high energy consumption.

Mechanical Water Level Recorders

Description: The cable connecting a float, which is in permanent contact with the water surface, with a counterweight is mounted on a wheel that turns a drum (in vertical or horizontal direction). The rise and fall of the float, i.e. the changes of the water level is registered by a pen on a sheet of paper mounted on the drum. The pen runs with a constant speed in the direction perpendicular to the depth scale. Registration lasts until the pen has reached the end of the time scale. An alternative registration method uses strip charts, where the time scale follows the direction of the rolling motion of the paper, so that registration may last for longer time intervals than using drum charts.

Costs: between 2,000 and 5,000 EUR.

Examples: SEBA Vertical Water Level Recorder ALPHA for 180-days operation (*Figure 3*; outside max. diameter of float: 75 mm; suitable for 4” boreholes); SEBA Strip Chart Water Level Recorder DELTA for 333-days operation (outside max. diameter of float: 90 mm; suitable for 4” boreholes); Stevens A-71 for recording on a strip chart for a time period of up to 4 years, float size between 6” and 14”; Stevens Type F for recording on a drum chart for a time period of up to 32 days may be combined with a data encoder and data logger, float size between 2.5” and 8”. All types of mechanical water level recorders may be combined with a data encoder and data logger.

Application: Gauging of streams, canals and other surface waters, groundwater level measurements.

Advantages: Continuous water level records; low installation and maintenance costs.

Disadvantages: Charts must be replaced usually every month (in the case of drum charts; i.e. high costs for field work). Floats might become stuck when water level is rising if inner borehole wall is not entirely straight and even.

Recommendations: Functionality of system must be checked during every field visit. Additional manual measurements must be made every time the drum/strip chart is replaced in order to correlate the first and last readings.

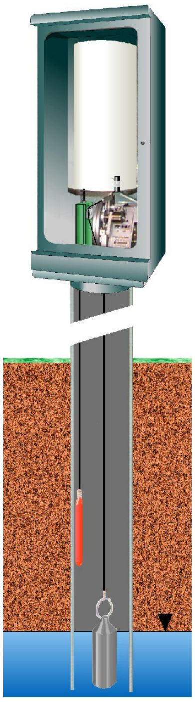


Figure 3: Mechanical Water Level Recorder – here Combined with Data Logger (Courtesy SEBA: Water Level Recorder ALPHA with SURFLOAT)

Encoders for Mechanical Recorders

Description: Converts the motion of the float cable into digital water level data. Data are stored in a data logger; can be mounted onto any conventional mechanical chart recorder.

Costs: between 500 and 1,000 EUR.

Examples: SEBA Potentiometer PS113; SEBA Surfloat Sensor; SEBA MDS-Surfloat; OTT Thalimedes optional for data transfer using GSM technology;

Application: Fitting of any preexisting mechanical water level recorder.

Advantages: Low additional costs; easier readout than using strip or drum charts.

Disadvantages: Like in all mechanical recorders, the inner borehole wall must be adequately smooth and straight to avoid the float becoming stuck.

Recommendations: when drilling wells for and installing equipment of this type special attention has to be given to straightness of the borehole and smoothness of the inner casing wall.

Mechanical Floats with built-in Encoders and Data Loggers

Description: Using the same principle as conventional mechanical recorders. No data registration on strip or drum charts but only by data logger.

Costs: approx. 600 EUR.

Examples: SEBA MDS Surfloat; SEBA MDS-Floater (*Figure 4*): installation down to max. 150 m hooking-in depth in 2” boreholes, accuracy ≤ 1 cm.

Application: Suitable for most applications.

Advantages: Low installation costs (comparable to traditional mechanical recorder), low maintenance and field work costs. Best cost-effectiveness ratio.

Disadvantages: Floats might become stuck when water level rises at places where the borehole is not straight and even.

Recommendations: when drilling wells for and installing equipment of this type special attention has to be given to straightness of the borehole and smoothness of the inner casing wall.

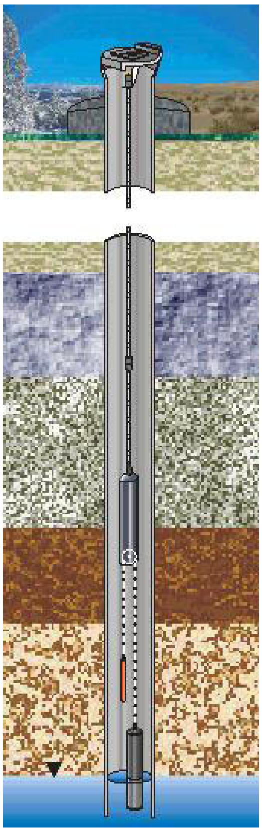


Figure 4: Water Level Recording using a Float in Combination with an Encoder (Courtesy SEBA: Water Level Recorder FLOATER)

Pressure Probes

Description: Pressure probes register the pressure of the water column, as the product of the length of the water column and the water density, and the pressure of the air column. In order to exclude influences from the air column, the air pressure is registered separately. This is done in the probe itself, using a small tube which extends from the atmosphere to the probe or using a separate registration or both in separate instruments.

Recorders often assume a constant water density which is used for calibration. Over longer observation periods changes in hydrochemical water composition may, however, lead to changes in the water density and thus lead to wrong water level readings.

Costs: between 600 and 2,500 EUR.

Examples: SEBA MDS Dipper, SEBA MDS Insider (*Figure 5*) for fitting with 1 additional sensor (temperature or multiparameter sensor: measurement of up to 7 quality parameters); SEBA MDS-III with multiparameter sensor; OTT ODS 4-K with 42 mm external diameter; OTT Orpheus-K for additional registration of temperature and electric conductivity; Van Essen Instruments Diver (distributed by SOLINST as Levellogger Model 3001 or by Eijkelkamp as Diver) with simple wireline or direct-read cable connection, combination with registration of dissolved oxygen (3001 LTDO) or electric conductivity possible, barometric pressure must be recorded separately, external diameter 7/8", cable lengths up to 500 m; STEVENS-GREENSPAN Pressure Sensors PS210 and PS310 with 45 or 48 mm outside diameter.

Application: Increasingly frequent application in remote areas or to reduce field work. Often used in combination with telemetry stations. Accuracy: ≤0.1 % of measuring range. Temperature range: - 5° to + 45° C. Cables with Kevlar cores provide longitudinal stability of cable.

Advantages: In combination with data loggers (either integrated or separate units) large amounts of data can be collected unattended over long time periods (usually more than 50,000 data). Data may be transmitted from the station using a telemetry station. Data collection intervals can be set individually between a few seconds and a few hours. Lithium batteries in the data logger provide that the system can be operational for more than 10 years without maintenance. Units with integrated measurement of water level, electric conductivity and temperature are available.

Whereas in the beginning the equipment was rather expensive and sensitive to a number of parameters such instruments are now affordable, easy to install and operate and most error sources have been eliminated.

Disadvantages: Lower life-expectancy; sensitive to impacts of lightning (if nor fitted with lightning protection), mechanical damage, intrusion of humidity into probe (if not provided with humidity absorber), and external temperature changes (if not fitted with temperature compensation); instrumental drift. Some instruments acquire pressure data (hydrostatic and air pressure) by two separate sensors at two different locations. Water level data have then to be corrected later on (e.g. after data have been read out from the logger, in the case of the Diver/Levellogger).

Recommendations: It must be provided that the instrument shows no drift or is otherwise sensitive to external factors as described above. Manual measurements should be conducted from time to time in order to make sure that the recorded data are accurate. If not, instrument must be maintained.

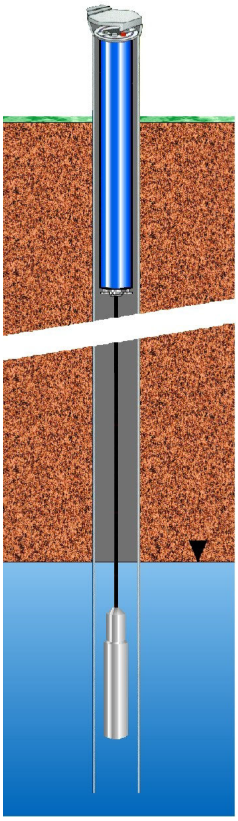


Figure 5: Water Level Recording using a Pressure Probe in Combination with a Data Logger (Courtesy SEBA: Water Level Registration Unit INSIDER and DS30)

Sensors using the Bubble Principle

Description: A piston pump inside the measuring device generates compressed air. The air flows through a pipe into the bubble chamber at fixed intervals and releases bubbles into the groundwater (or surface water). Inside the measuring tube an air pressure equal to the hydrostatic pressure is established. If groundwater density is constant, there is a linear correlation between the water level and the air pressure in the measuring tube. The hydrostatic pressure is equal to the difference between bubble-line pressure and barometric pressure. Both are measured by the instrument.

Costs: around 1,000 EUR.

Examples: SEBA PS-Light; OTT Orphimedes for installation in boreholes ≥ 2”; OTT Nimbus.

Application: Mainly applied in surface water and groundwater with shallow water levels; measuring range: 20 m; installation depth: max. 150 m.

Advantages: Not sensitive to humidity and condensation effects.

Disadvantages: High energy consumption.

Recommendations: None.

Data Loggers

Data loggers are able to store large quantities of data. These data may then be downloaded to a notebook or other data storage units when required. Data loggers can therefore considerably reduce the costs for field work since it may be necessary to visit monitoring stations equipped with data loggers only every few months. Data loggers can be programmed to record data at specific time intervals which can range between a few seconds and a few hours, depending on the intended use of monitoring data. They may even be programmed to set off an alarm when exceeding or dropping below a certain value.

The use of data loggers has significantly increased over the past decade. Loggers are often used in combination with telemetric data transfer in order to obtain real-time monitoring data at the head quarter.

Costs: mostly integrated into pressure probes; if additional installation: starting from 500 EUR.

Stations

The construction type of the monitoring station depends on the type of equipment that needs to be fitted. For loggers without telemetric data transfer and manual measurements no special construction measures are required, except that the well head has to be protected from flooding and vandalism. It is recommended to use well caps which can be opened by a special key only. Any other equipment which is installed above ground should be protected by a fence or located in a suitable locked building. Compact stations and telemetry stations are difficult to protect from vandalism and should therefore only be envisaged if permanent protection by a guard is possible.

Data Transfer using Telemetry

Monitoring stations equipped with a telemetry system need their own power supply which is mostly provided by a solar panel connected to a battery pack. Data can be transmitted from the data logger using :

- RS232/RS485/RS422 serial connections (over a maximum of 21 km using a fixed network cable);
- Modems (requires the availability of a telephone network);
- GSM (Global Mobile System; requires the availability of a countrywide GSM network with adequate signal quality in all monitoring areas);
- Radio signals (frequency can be chosen to suit the local conditions and regulations) or
- Satellite links (e.g. to Meteosat/EUMETSAT: geostationary satellite, data can be transmitted free of charge with the permission of the local meteorological service, frequency and time slot for transmission will then be allocated, data will be received by email or similar means; Inmarsat; Argos; GEOS; GMS; etc.).

Costs: due to the large range of prices costs are not specified in this document.

There is a large variety of systems presently on the marked and technology changes rapidly. Instead of listing individual systems, it is therefore directly referred to the providers of telemetry systems, such as :

- SEBA Hydrometrie, Kaufbeuren/Germany; *www.seba.de*;
- OTT Messtechnik, Kempten/Germany; *www.ott-hydrometry.de*;
- Stevens, Beaverton/USA; www.stevenswater.com;
- Solinst, Georgetown/Canada; *www.solinst.com*;
- Eijkelkamp, Giesbeek/The Netherlands; *www.eijkelkamp.com*.

Digital recorders and data transmission via telemetric stations are increasingly used in remote areas or when real-time data are needed in order to be able to instantly react to certain critical situations, such as extended drought periods (or contaminations). Only in this case limitations to groundwater use could be imposed (or lifted) within short time periods. Adequate protection of telemetry stations from vandalism is a must.

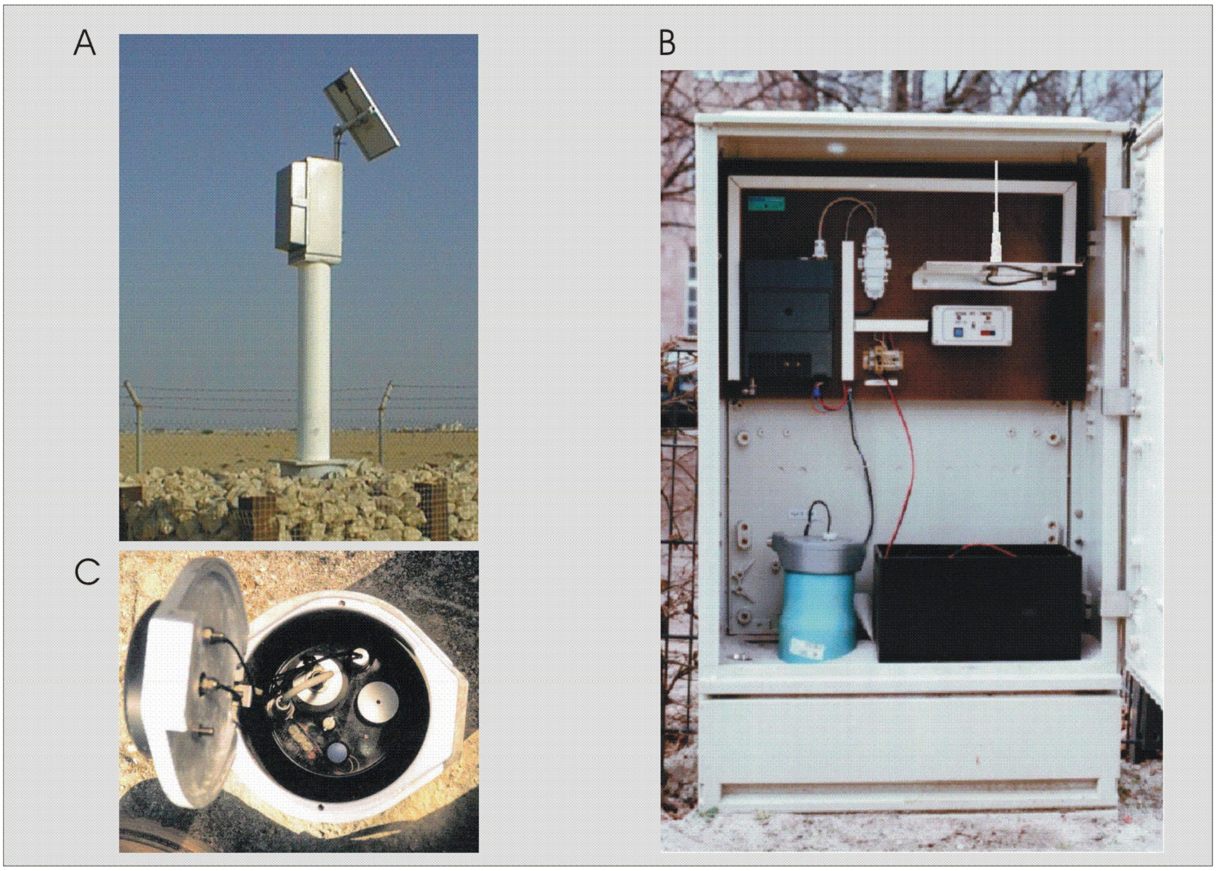


Figure 6: Examples of Telemetric Data Transfer from Groundwater Monitoring Stations using a) GSM Data Transfer in Combination with a Solar Panel, b) Radio Signals; Power supplied by the Local Power Grid or c) GSM Data Transfer in Combination with Standard Battery Packs (Courtesy SEBA)

Special Conditions in the Arab Region

Many monitoring sites in the Arab region are located in remote areas, often several hundred km away from the offices of the agency in charge. In such cases data loggers are highly recommended in order to reduce costs for field work. They should, however, be installed in such a way that the risk of vandalism is reduced. Often data transfer by telemetry from remote stations is difficult especially when transmission by standard techniques, such as radio signals (which often require permission from the military), GSM or modem, is not possible (e.g. due to incomplete network coverage). Also vandalism of the telemetry station may frequently occur, if there is no guard to take care of the site. Depending on the local regulations, data transmission via radio signals may require permission from the army or other government authorities. Energy consumption of the data transfer process also is an issue that has to be taken into consideration for the planning of a monitoring network. Using standard batteries data can be transferred at least once a day. Commonly the status of the batteries is transferred together with the water level data, so that batteries can be exchanged in time. A continuous data transfer is only possible if solar panels and rechargeable battery packs are being used.

It should be considered to install an alarm annunciator.

3 Installation of a Groundwater Level Monitoring Network

Extensive preparations are required before a groundwater level monitoring network is being set up. The locations need to be carefully selected, the frequency and overall duration of monitoring must be determined for each individual site, the required field work must be pre-planned (route planning, required equipment, staff training, etc.), the involved costs have to be calculated and money has to be made available. A monitoring handbook should be written, where all procedures are laid down in detail, such as data collection, maintenance, data transfer, data storage and data evaluation.

TAYLOR & ALLEY (2001) present a number of examples from the USA which give some valuable indication on how monitoring networks should be designed for their individual purpose.

The following strategy for setting up a groundwater monitoring network is proposed.

Table 1: Flow Chart for the Design Process of a Groundwater Monitoring Network

Phase	Main Task	Sub-Tasks
Initial Proposal	Feasibility Study	Management Tasks • Define monitoring objectives, data requirements and regulatory perspectives • Analyze tasks & organizational structure • Analyze staff capabilities • Propose organizational responsibilities • Propose basic design of network • Propose training concepts • Evaluate costs • Make budget available
Data Analysis (Preliminary Investigation and Conceptual Model)	Description of Aquifer System	Geology & Hydrogeology: • Topography • Geology (lithology, facies, thickness, distribution, etc.) • Structure (bedding structure, tectonics) • Aquifers & aquitards (hydraulic & hydrochemical character, boundaries) • Recharge & discharge • Other inflow & outflow components • Vulnerability of aquifers to pollution • Hazards to groundwater
	Description of Groundwater Flow Pattern	Groundwater Flow Directions and Amounts of Flow • Piezometric head maps • Relative hydraulic head differences between units • Interconnection of aquifers • Rates of groundwater movement

Phase	Main Task	Sub-Tasks
Design	Selection of Target Monitoring Zones	Depending on Monitoring Purpose: • Background wells (representative wells for natural undisturbed conditions) • Downgradient wells (at different distances and depth intervals to identify impact of exploitation or polluting activity)
	Proposal of Station Designs	• Well locations &screened intervals • Drilling types &drilling fluids • Types of materials for casing and measuring equipment • Type of measuring equipment • Data storage and transfer procedures • Constructional station design at land surface
	Verification of Locations	Do the proposed stations fulfill all selection criteria ?
	Cost Plan	Final Evaluation of Monitoring Budget
Implementation	Installation of Monitoring Wells	• Drilling & installation of equipment • Borehole testing (pumptests, geophysical logs, hydrochemical sampling, tightness, etc.)
	Testing of System	Final Acceptance Procedure
	Operation of System	• Data acquisition • Data storage • Data processing • Reporting • Maintenance • Rehabilitation • Training • Audits

A monitoring network may be established in several steps in order to distribute the costs over a longer time period.

Drilling and installation of monitoring equipment should follow (international) acknowledged practices. It must be provided that the well is correctly recording the hydraulic head at the specified depth, i.e. the well must be appropriately developed, the casing must be checked for tightness and the positions and tightness of the annular sealants must be controlled. Rehabilitation of monitoring wells is required after certain time periods. Therefore the functionality of the monitoring wells must be checked at regular intervals.

DVGW (2001) suggest the use of the following techniques for drilling of monitoring wells:

Unconsolidated rocks:

- All Rotary drilling methods; cable-tool drilling; driven wells (rammed filters or direct-push wells);

Consolidated rocks:

- Direct-Rotary drilling; cable-tool drilling; hammer down-the-hole.

EPA (1994) propose the use of the following drilling methods for monitoring within the framework of the RCRA program (*Table 2*). They also list a number of application examples and limitations to each drilling method (*Annex A-3*).

Table 2: Suitability of Selected Drilling Methods for the Drilling of Groundwater Monitoring Wells

Geologic Setting	Drilling Methods							
	Air Rotary	Water/ Mud Rotary	Cable Tool	Hollow-Stem Continuous-Flight Auger	Solid-Stem Continuous Auger	Jet Percussion	Dual-Wall Reverse-Circulation	Driven Wells
Unconsolidated or poorly consolidated materials less than 125 feet deep	♦	♦	♦	♦	♦	♦	♦	♦
Unconsolidated or poorly consolidated materials more than 125 feet deep	♦	♦	♦				♦	
Consolidated rock formations less than 500 feet deep	♦	♦	♦				♦	
Consolidated rock formations more than 500 feet deep	♦	♦	♦				♦	

ALLER et al. (1989) propose to consider the following factors when selecting an appropriate drilling method and well design:

- Versatility of drilling method;
- Relative drilling costs;
- Accessibility of drilling site;
- Sample reliability;
- Availability of equipment;
- Time;
- Ability of the technology to comply with the monitoring requirements (collection of undisturbed samples/data);
- Ability to install the desired casing and equipment (material stability, depth, diameters);
- Relative ease of well completion and development.

They also list some general recommendations what has to be considered when selecting an appropriate drilling method and well design:

- Drilling should be performed in a manner that preserves the natural properties of the subsurface materials;
- Contamination and/or cross-contamination of groundwater and aquifer materials during drilling should be avoided;
- The drilling method should allow for the collection of representative samples of rock, unconsolidated materials and soils;
- The drilling method should allow the owner/operator to determine when the appropriate location for the screened interval has been encountered;
- The drilling method should allow for proper placement of the filter pack and annular sealants. The borehole should be at least 4 inches larger in diameter than the nominal diameter of the well casing and screen to allow adequate space for placement of the filter pack and sealants;
- The drilling method should allow for the collection of representative groundwater samples. Drilling fluids (including air) should be used only when minimal impact to the surrounding formation and groundwater can be ensured;
- Drilling fluids, drilling fluid additives, or lubricants that impact the analysis of water constituents in groundwater samples or impede the hydraulic connection of the well to the aquifer should not be used;
- The materials of all construction components and equipment to be installed in a monitoring well, such as casings, screens, filter packs, sealants, and centralizers should not cause any alterations to the constituents in groundwater samples or impede the hydraulic connection of the well to the aquifer.

The well casing and screen material should meet the following requirements (EPA 1994):

- They should maintain their structural integrity and durability in the environment in which they are used over the entire operating lifetime;
- They should be resistant to chemical and microbiological corrosion and degradation in contaminated and uncontaminated waters;
- They should be able to withstand the physical forces acting upon them during and following their installation, and during their use;
- They should not chemically alter groundwater samples;
- They should be easy to install during the construction of a monitoring well and the material itself or its stability (tensile strength, compressive strength, and collapse strength) should not alter after installation.

More details about aspects relevant for the drilling, design, development, and materials used in groundwater monitoring wells are documented in *Annex A-3* and

Part B, chapters 4.2 and 5.1 of this report.

Further details are given in EPA (1991), EPA (1994) and the DVGW W 121 standard (DVGW 2002).

It is emphasized that groundwater level monitoring wells must be designed and equipped in such a way that monitoring yields reliable data at all times without major constructional modifications. This especially pertains to wells where the measuring range is changing due to long-term water level changes.

The monitoring wells must be marked appropriately to allow undoubted retrieval of the location.

3.1 Selection of Monitoring Location

Due to the large variety of objectives of a groundwater level monitoring network it is difficult to make general proposals concerning the positioning of wells. The locations chosen for groundwater level monitoring wells should provide representative data for groundwater flow in the considered aquifer system(s). This concerns the natural as well as altered conditions such as those resulting from groundwater (or surface water) exploitation.

When selecting monitoring locations all influencing factors must be taken into account, such as: topography, geology (geological units, facies changes, bedding structure, tectonics), climatic variations and variations in groundwater recharge (concerning amount and type: direct/indirect), land use characteristics, boundaries and limits of saturation of the aquifer systems, aquifer types (unconfined/ confined/leaky/artesian), and all locations and amounts of surface and groundwater abstractions, injections and discharges.

The collection of other hydraulic data, such as rainfall, evaporation, streamflow or spring flow data are required for the correct interpretation of the water level monitoring data. In some cases, especially when the groundwater level monitoring well is located in a remote place and there are no such data collected in the vicinity of the site, it may be necessary to establish meteorological and hydrological monitoring stations in order to provide such supplementary data for the interpretation of groundwater monitoring data.

Mostly monitoring networks are established in several consecutive phases (*Figure 7*).

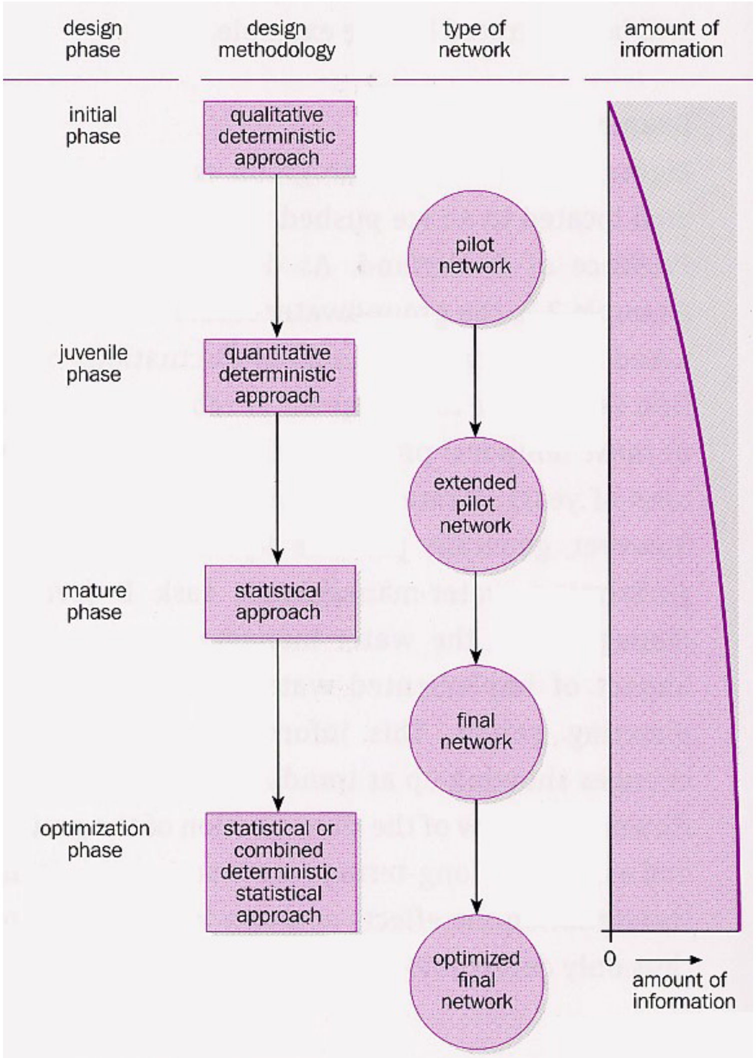


Figure 7: Phases in the Monitoring Network Design Process (from Van BRACHT 2001)

In general, monitoring wells have to be fitted with screens positioned only in one aquifer and not across aquifers, as is often observed. In aquifers with strong vertical differences in the hydraulic conductivity it may even be necessary to monitor the water level at different depth intervals, since the water level in such aquifers might strongly depend on upward or downward leakage. In such case, or when water levels of different aquifers shall be monitored at the same location, it is recommended to install a multi-level monitoring station (cluster wells) where individual wells are drilled at short horizontal distance from one another. For monitoring wells less than 50 m deep the distance between the individual wells should be at least 3 m, for those deeper than 50 m it should not be less than 5 m. If multi-level monitoring wells have to be installed in the same well, as sometimes is the case in mountainous and hilly areas, hydraulic cross-communication between aquifers must be prevented by suitable means.

In areas of new large-scale groundwater development, groundwater monitoring sites should be installed before development is started in order to be able to recognize the effects of abstraction. The same accounts for all other major alterations to the water budget that may have a considerable impact on water levels.

It is strictly advised against the use of abandoned abstraction wells for groundwater monitoring purposes as is presently the case in many countries of the Arab region. One reason is that their functionality is mostly not guaranteed – quite the contrary, their lacking functionality is often the reason for them being abandoned. Another reason is that they are mostly not appropriately designed for monitoring purposes and the specific monitoring target.

Due to the often very long time durations of monitoring, future developments and possible future data needs should be anticipated as far as possible when selecting monitoring locations.

In practice, limitations of the present monitoring network and further monitoring needs often only become evident when the data are used to calibrate groundwater models.

Often there is only limited knowledge of the lithology at the selected drilling location. In such cases an exact description of the lithology is needed in order to position the screens correctly. Such descriptions should be based on descriptions made by the responsible geologist from the cuttings taken from the borehole, aided by borehole geophysical logs, if possible.

NIELSEN (1991) presents a number of useful examples for site selection for different kinds of geological settings, focusing on groundwater quality monitoring of hazards to groundwater. This handbook for groundwater monitoring was prepared subsequently to the adoption of the Resource Conservation and Recovery Act (RCRA) in 1976 and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) in 1980 which considerably promoted the installation of groundwater monitoring networks in the USA. The interested reader is referred to this standard reference for groundwater quality monitoring.

In order to detect contamination in a complex aquifer system, different types of monitoring wells could be used, depending on the expected contaminants and flow paths. In general, the installation of monitoring stations with monitoring at different depth intervals is recommended (*Figure 8*). Possible well types are:

- Single boreholes which are fully screened;
- Single boreholes with multiple screens which are monitored using permanent or removable packers;
- Multi-level wells (cluster wells; multiple wells down to different depths near to one another);
- Single borehole multi-level wells (a single borehole suiting multiple wells which are screened at different depths and which must be hydraulically separated by suitable means);
- Multi-level wells (or monitoring ports) with direct burial (e.g. Waterloo/Solinst system);
- Direct wells (so-called monitoring pipes, rammed filters, driven wells, wellpoints, or direct-push system) which are mechanically driven in (for monitoring of shallow groundwaters; e.g. Eijkelkamp groundwater monitoring pipes; compare ASTM standards: D 6001-96, D 6724-01 and D 6725-01).

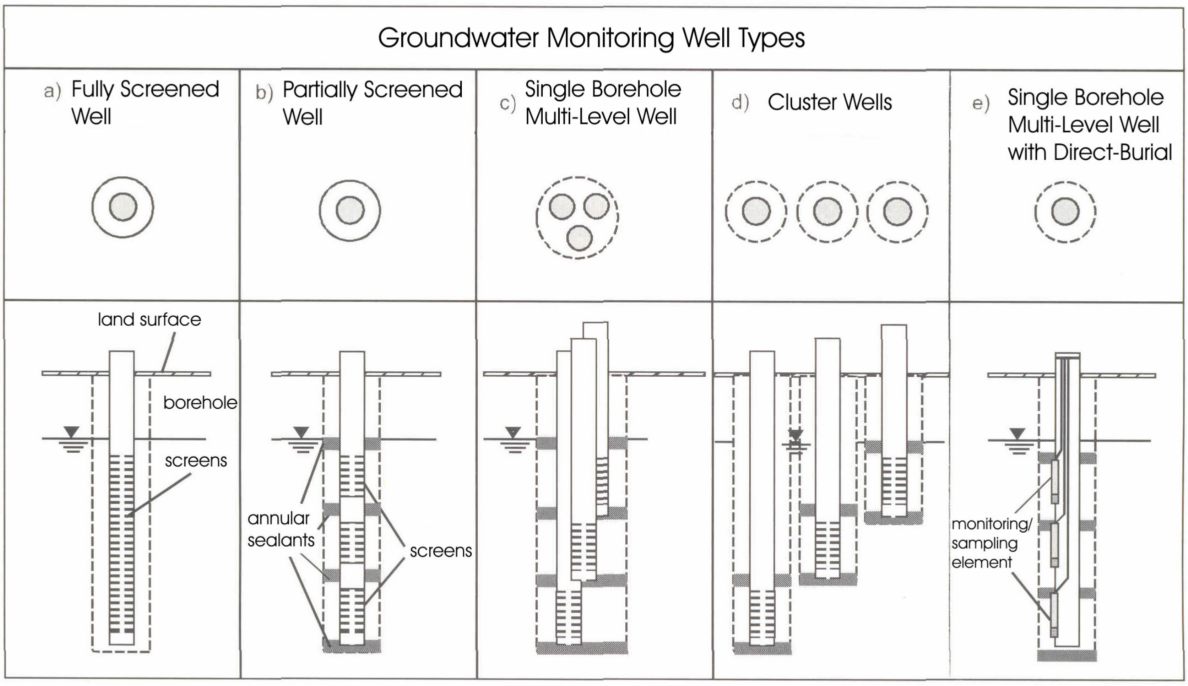


Figure 8: Groundwater Monitoring Well Types (modified after DVGW 1997)

NLÖ & NLWA (1997) present a zoning system for groundwater monitoring sites of contaminated land which is being used in Lower Saxony/Germany (*Figures 9 and 10*). This system differentiates four zones: upgradient (background or reference) wells – monitoring of natural undisturbed conditions/uncontaminated groundwater; near source downgradient wells – monitoring of altered conditions/contaminated groundwater at short distance from exploitation/contamination source (max. distance for contaminated land monitoring: 200 d travel time); downgradient control wells – monitoring of spreading of contamination in time and space (inner/outer control zones). For further detail concerning monitoring of contaminated land refer to *Part B* of this report.

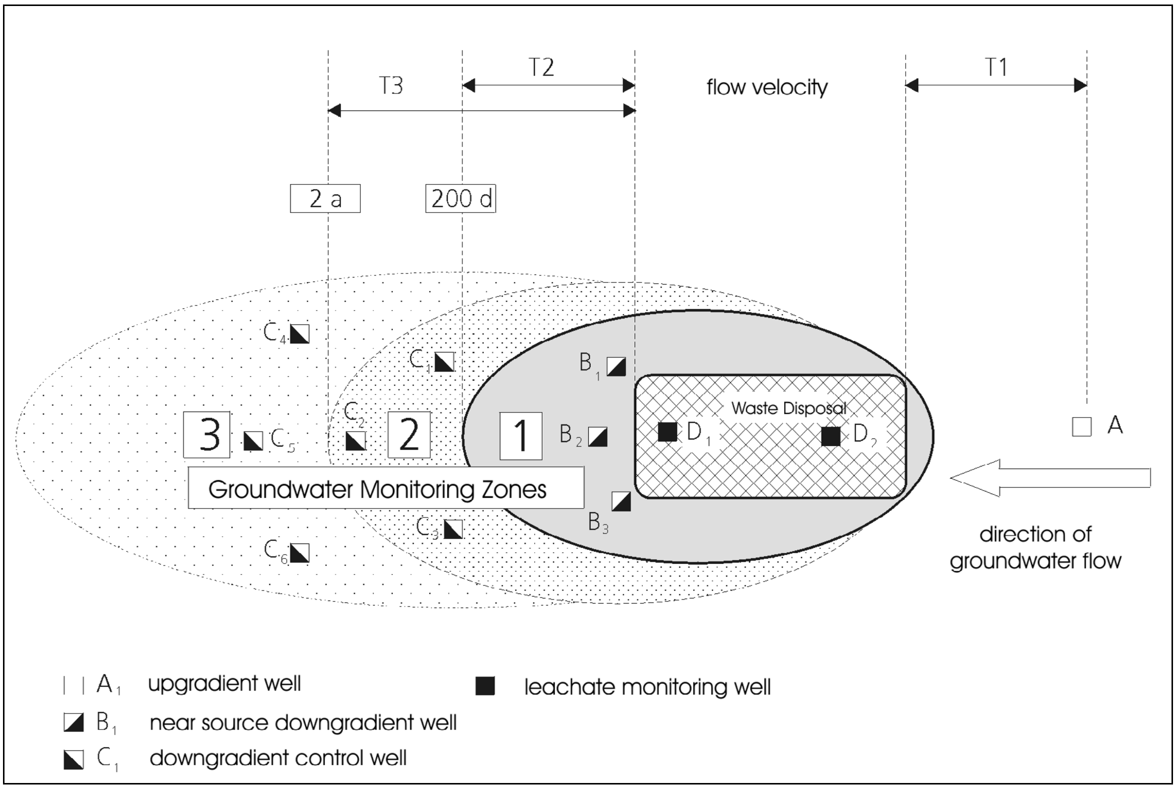


Figure 9: Proposed Zoning System for Monitoring of Contaminated Land (after NLÖ & NLWA 1997), plan view

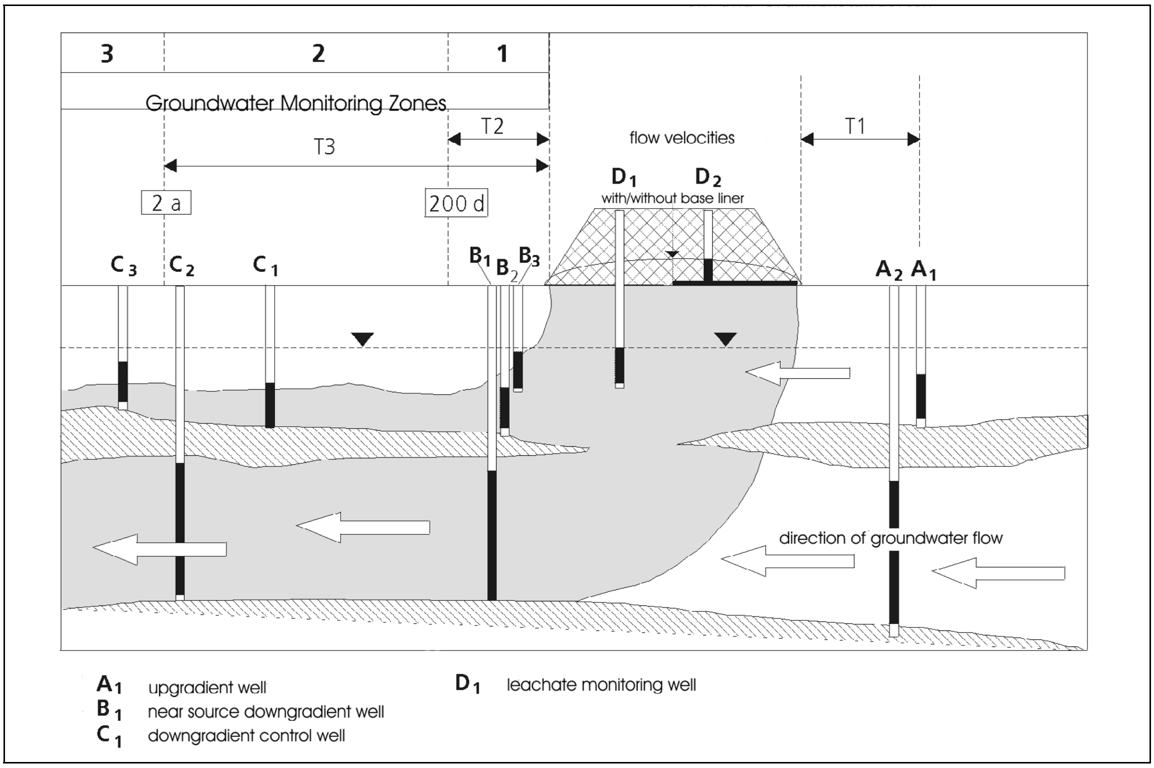


Figure 10: Proposed Zoning System for Monitoring of Contaminated Land (after NLÖ & NLWA 1997), typical schematic cross section

For the positioning and length of the well screens it must be taken into consideration that water levels may considerably fluctuate over the year and may show strong declining or rising long-term trends, depending on the level of groundwater exploitation or injection in the surrounding area. Moreover, hydraulic heads may considerably vary within an aquifer, depending on the vertical hydraulic gradient and the ratio of vertical to horizontal conductivity, so that heads measured in the lower part of the aquifer may significantly be different from those measured in the upper part. The fluctuation ranges of the water levels have to be estimated in order to be able to position the borehole screens appropriately.

In general, highly heterogeneous formations require shorter well screens to allow monitoring of discrete portions of the formation. The more homogeneous an aquifer is, the lesser are the vertical differences in hydraulic heads and chemical composition.

When designing a monitoring network in an area where little information about the groundwater system is available, it is often started with a pilot network which is later on expanded when more information becomes available.

For further details concerning the selection of the monitoring site compare also *chapter 4.1 of Part B* of this report.

3.2 Frequency and Duration of Monitoring

The frequency of monitoring should be determined before the actual installation and therefore is part of the preparation phase. Modern monitoring devices allow a more or less continuous recording of data. Data loggers could be set to record data every few minutes so that in this case even water level changes induced by barometric variations could be registered. In near coastal areas it may be important to set the frequency of data recording at such time intervals that water level changes induced by tidal fluctuations can be registered.

In general monitoring frequency will be higher in shallow aquifers with high flow velocities, while less in deeper and confined aquifers. This is due to the fact that natural influences such as from groundwater recharge or tidal variations become more damped with depth.

In many cases water level data are used to evaluate the time lag between major rainfall events and groundwater recharge. This time lag may vary, depending on the depth of the screened interval of the well and the lithological, structural and hydraulic characteristics, between a few hours and some weeks. Groundwater recharge often takes place not directly at the place where precipitation reaches the land surface but at some point further downstream, where infiltration is facilitated by soils or rocks which are more permeable (indirect recharge). This often occurs along the beds of wadis where the slope is becoming more gentle. Moreover there may be places along the course of wadis or permanent creeks or streams where surface water may be infiltrating into groundwater (loosing streams; effluent conditions) whereas at other places the surface water may receive water from the surrounding groundwater resources (gaining streams; influent conditions) during certain time periods or permanently.

It is important to include such locations of preferential infiltration and influent/effluent conditions in a monitoring network and to choose an appropriate monitoring frequency for them.

Throughout the Arab region manual monitoring still plays an important role because of risks of vandalism of remote automatic monitoring stations and lacking funds for the purchase of more sophisticated equipment, such as digital water level recorders and telemetry stations. Depending on the distance to the observation wells, monitoring is often being conducted on a monthly basis or even less frequently. It has to be taken into account, however, that the use of such monitoring data is very limited because the interpretation of hydrographs that are based on infrequently measured data bears significant uncertainties.

Often the monitoring frequency is strongly influenced by economic considerations or rather constraints. The duration of monitoring depends on the monitoring purpose. TAYLOR & ALLEY (2001) give the following recommendations (*Table 3*):

Table 3: Typical Duration of Water Level Monitoring in Correlation with the Intended Use of Data

Intended Use	**Typical Duration of Data Collection**			
	Days – Weeks	Months	Years	Decades
Determination of Hydraulic Properties (Aquifer Tests)	◆	◇		
Potentiometric Maps	◆	◇		
Evaluation of Short-Term Changes in Groundwater Recharge and Storage	◆	◆	◇	
Evaluation of Long-Term Changes in Groundwater Recharge and Storage			◆	◆
Effects of Climatic Variations			◆	◆
Regional Effects of Groundwater Development			◆	◆
Statistical Analysis of Water Level Changes			◆	◆
Evaluating Changes in Groundwater Flow Direction	◇	◆	◆	◆
Groundwater – Surface Water Interactions	◆	◆	◆	◆
Groundwater Modeling	◇	◆	◆	◆

◇ **less frequently used**

3.3 Planning of Field Work

Extensive field work is required for the collection of groundwater monitoring data. The amount of time and funds needed depends on the type of equipment used and the distance of the wells from the office. When readings are conducted manually and when data are collected from automatic recorders field work is more extensive as if measurements were being recorded in digital form (e.g. by pressure probes connected to data loggers) and transferred via telemetric systems over satellite or other telecommunication links (modem/GSM/radio signals). In the latter case, the data collection and data evaluation process may be completely automated and data may be directly uploaded to a database and displayed as real-time data on the supervisor’s computer screen or even made available on the internet.

Field work must be thoroughly planned and the requested resources must be timely made available so that data collection can be successful. The functionality of all instruments to be used for field measurements must be checked and calibrations have to be performed, if required (e.g. pH-meters). Since it may be necessary to conduct some basic repair works in the field, it is recommendable to have all possibly required tools available.

Upon arrival at a monitoring site the status and functionality of the monitoring site needs to be controlled and recorded and the necessary repair and maintenance work has to be performed. It is also important to have all relevant data about the station at hand in the field. All relevant data to a monitoring station should be kept in a monitoring station file. This kind of record-keeping facilitates the identification of the reasons for problems at a monitoring station.

4 Operational Aspects of a Groundwater Level Monitoring Network

4.1 Monitoring Handbook

When collecting monitoring data in the field, distinct procedures must be followed to ensure good quality and integrity of the data collected. This procedure must be laid down in a monitoring handbook. Such a handbook is different for each individual monitoring purpose and is therefore not included in this guideline.

4.2 Monitoring Station File

A monitoring station file of each well must be available that contains all important information (name, coordinates and elevation, location sketch, photos, well drilling and design information, previous monitoring records, etc.; *Annex A-1*).

A copy of the monitoring station file should be taken to the field in order to be able to identify the causes of problems.

4.3 Field Reports

Upon arrival at the site, a form sheet must be filled out that contains all relevant information about the field work conducted, such as for instance weather conditions, status of monitoring site, field measurements of T, pH, EC, etc., or maintenance works (see *Annex A-2*).

Before conducting the measurements or taking the readings from the recorder the intactness of the well has to be checked and documented.

4.4 Audits

There are a large number of reasons which may cause problems in groundwater level monitoring data collection and their interpretation. In order to minimize such problems it is useful to analyze at regular intervals the entire monitoring procedure and the causes for failures.

The most frequent reasons for failures in the Arab region are (modified after MARGANE 1995):

- The status and functionality of a monitoring site is not always thoroughly checked;
- Hand measurements are not always conducted when required (e.g. when the float was stuck);

- Unreliable recordings of manual and other measurements (due to writing/reading mistakes, wrong reference points, wrong use of or faulty measuring devices, etc.);
- Irregular and untimely field measurements and maintenance (e.g. untimely exchange of batteries: the dates batteries were last exchanged should be marked on the power pack and noted in the field report; only high quality batteries should be used);
- Vandalism (e.g. due to ineffective protection);
- Missing or lost field reports;
- Measurements are out of measuring range of installed equipment.

Adequate solutions for these problems must be found and addressed. Internal or external audits may help in detecting and solving problems in groundwater monitoring.

5 Costs

The installation and operation of a groundwater level monitoring network is a costly and time consuming task. The overall costs depend on the purpose of monitoring, the type of data recording and transfer, the monitoring frequency, the duration of operation, and other factors, e.g. the chemical composition of the water and its aggressiveness towards certain materials.

The following different costs have to be distinguished:

- Drilling costs including well fittings;
- Costs for monitoring data recording equipment including its installation;
- Costs for topographic survey (determination of coordinates and elevations);
- Costs for field surveys (including field equipment, cars, field allowances, etc.);
- Maintenance costs;
- Training costs (internal, external);
- Costs for data management, analysis, interpretation and reporting (hardware, software, personnel, etc.);
- Costs for audits (internal, external).

According to Van BRACHT (2001) the costs for groundwater monitoring in the Netherlands are distributed as follows: data acquisition: 48%, maintenance: 18%, data management: 18%, depreciation: 16%. This calculation does, however, not take into account the installation and personnel costs.

Tables 4 - 6 list a number of such costs referring to prices in Germany. They give an overview about the cost positions involved, but some positions are of course locally different.

Table 4: Costs for Groundwater Level Monitoring (4-6“ wells, different depths): Part A: Drilling and Well Fitting Costs

Item	***Costs in Euro***
Mobilization (0-50 km, 50-100 km, 100-200 km)	1500, 2500, 3250
Installation of/demobilization from drilling site	750, 1500, 3000
Drilling costs, rotary, drilling depth 0-50 m, per m	35
Drilling costs, rotary, drilling depth 50-100 m, per m	40
Drilling costs, rotary, drilling depth 100-400 m, per m	40-50
Casing, galvanized steel, per m, 5 cm/10 cm/12.5 cm/15 cm diameter	10/27/55/70
Casing, stainless steel, per m, 10 cm/12.5 cm/15 cm diameter	180/200/220
Casing, PVC, per m, 5 cm/10 cm/12.5 cm/15 cm diameter	10/20/30/36
Screens, galvanized steel, screen slot openings 0.5 mm wide, per m, 5 cm/10 cm/12.5 cm/15 cm diameter	

Item	***Costs in Euro***
Screens, stainless steel, screen slot openings 0.5 mm wide, per m, 10 cm/12.5 cm/15 cm diameter	210/230/260
Screens, PVC, screen slot openings 0.5 mm wide, per m, 5 cm/10 cm/12.5 cm/15 cm diameter	11/34/47/57
Cementation, per m³, incl. installation	40
Centralizers, per piece, material & installation)	20 (every 20 m)
Gravel pack, per m, incl. installation	20
Seals (clay), per m, incl. installation	40
Counter filter, per m	20
Well development (clean-pumping)	500 + (depending on water level)
Bottom plug	15

The drilling of a standard groundwater level monitoring well in Germany of 100 m depth fitted with 4" PVC casing/screens at a location of up to 100 km from the drilling company's office thus would cost around 12,000 Euro.

Table 5: Costs for Groundwater Level Monitoring (4-6" wells, different depths): Part B: Costs for Monitoring Equipment and Installation

Item	***Costs in Euro***
Well head	depending on type of installation
Automatic water level recorder (chart), unencoded	2,000 – 5,000 EUR
Automatic water level recorder, with encoding equipment	600 – 5,000 EUR
Pressure probes	600 – 2,500 EUR
Notebook/data readout device	1,000 – 1,500 EUR
Telemetry system using radio signal	
Telemetry system using GSM	
Telemetry system using satellite link	
Construction Costs	depending on type of construction

Table 6: Costs for Groundwater Level Monitoring (4-6" wells, different depths): Part C: Costs for Field Equipment

Item	***Costs in Euro***
Water Level Meters 50 m/100 m /200 m/ 300 m/ 500 m	250/300/450/600/900 EUR
Micro Filters 0.45 µm (100 pieces) incl. syringe	depending on type of material: 50 – 500 EUR
Electrical Conductivity Meter	from approx. 700 EUR to approx. 1,400 EUR (for instrument with 100 m cable)
pH Meter (with integrated ORP measurement; ORP – oxidation-reduction potential)	from approx. 400 EUR to approx. 1,600 EUR (for instrument with 100 m cable)
Oxygen Meter (dissolved oxygen)	from approx. 700 EUR to approx. 1,400 EUR (for instrument with 100 m cable)
ISE Meters (ISE – ion selective electrode)	between 200 and 700 EUR
BOD Measurement (BOD – biochemical oxygen demand)	
Portable Photometer (for measurement of selected parameters; compare *chapter 5.3.5* of *Part B* of this report)	between approx. 1,000 and 4,000 EUR

6 Interpretation of Results

Before any interpretation can be made the data must be checked for integrity and consistency. This is required because many mistakes may be made already in the field (faulty equipment, incorrect reading, incorrect reference point, wrong monitoring station, etc.), or when data are transferred to a database (writing/reading mistakes, typing mistakes).

For the correct interpretation of the monitoring data all relevant other information must be taken into consideration, such as the hydrogeological setting and hydraulic parameters, meteorological data, hydrological data, abstraction data of nearby wells and from nearby surface water bodies, the status of the monitoring site, reasons for termination or suspension of monitoring. Only in case all these additional data are available, a meaningful interpretation of the reasons for water level changes can be reliably conducted.

However, even then the interpretation may be ambiguous, especially if different factors may be responsible for changing water levels and the influence of these factors cannot be reliably estimated. Certain factors may influence the long-term trend only over a short time period and in many cases these time periods may be difficult to determine (such as e.g. the durations and exact amounts of abstractions from nearby groundwater wells). As mentioned before it is therefore important to locate monitoring wells in areas where the influence of such factors is minimal.

Since the number of factors and the degree and scale of their impact may considerably vary from place to place, it is difficult to give standard recommendations concerning the interpretation procedure. In case where the number of influencing factors is low, a statistical approach may be used. In case the situation is more complex, hydraulic modeling may be applied. However, experience shows that many people trend to overestimate the use of such models. Often the match between observed and calculated hydraulic heads is rather poor due to the limited data availability or understanding of the hydrogeological system.

From the time lag between distinct rainfall events and the rise of water levels some general conclusions about the groundwater recharge process can be drawn. Spatial variability of recharge may, however, be significantly different from place to place, depending on whether recharge occurs as direct recharge, as indirect recharge or in a mixed form and depending on how long the individual pathways are. An overview of methods used for groundwater recharge estimation based on water level data and examples are given in HEALY & COOK (2002), GIBBONS (1994), and HOBLER et al. (2001).

For the interpretation the availability of hydraulic parameters, especially the effective porosity (specific yield) or storage coefficient is very useful. It can only be obtained from pumping tests using water level monitoring in nearby wells (and not only in the pumped well itself, which is rather common throughout the Arab region).

It may be useful to correlate water level monitoring of groundwater wells and the discharge of nearby springs in order to identify whether trends are identical (throughout the year) or substantially different. However, spring discharge measurements are mostly not conducted as continuous recordings.

The main results of groundwater level monitoring should be published in annual groundwater level monitoring reports. These should show the long-term trends and the trends within the reporting period at all monitoring stations. They should indicate what the reasons for the observed water level changes are and what (counter)measures need to be undertaken. In groundwater level monitoring this mainly concerns groundwater resources management decisions, such as specific amounts of water which can be withdrawn at a specific location from a certain aquifer. Critical limits for groundwater levels (or other suitable indicators for sustainable groundwater resources management) may be defined at which certain actions need to be taken, such as imposing abstraction bans for irrigation wells during certain times of the year. Such management options, however, depend on the national policy for water resources management.

Statistical interpretations using auto-correlation, spatial correlation or temporal and spatial standard deviation of the hydraulic head may be used. One has to bare in mind, however, that wrong conclusions may be drawn if basic data for such correlations are not available in sufficient quality.

Some examples of evaluations and presentations of groundwater level monitoring data are shown in *Annex A-4*.

7 Summary and Recommendations

From the aforesaid the following conclusions can be drawn:

- The **planning of a groundwater level monitoring network** must be carefully conducted and the monitoring sites have to be chosen in such a way that the collected data are representative for the monitored aquifer and that they can be reliably interpreted;
- The **knowledge and understanding of the setup and the hydraulic properties of the monitored groundwater system** has to be sufficient;
- The **availability of meteorological, hydrological and hydrogeological data** considerably facilitates the interpretation of the monitoring data. These additional data have to be collected appropriately;
- The entire monitoring procedure needs to be documented in a **monitoring handbook**. **Monitoring station files** should be established for each monitoring station. **Field reports** have to be filled out during the visits at each site. This way the reasons for mistakes may be identified and necessary countermeasures may be undertaken in time;
- The results should be documented in **annual groundwater monitoring reports**;
- **Audits** should be conducted at regular intervals.

8 References and Related Literature

ASTM (1999): Ground Water and Vadose Zone Investigations: Drilling, Sampling, Geophysical Logging, Well Installation and Decommissioning. – 2nd edition, 576 p.; West Conshohocken/PE/USA.

ASTM (2002): Standard Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers. – American Society for Testing and Materials, Standard D5092-02, 14 p.; West Conshohocken/PE/USA.

BAUMANN, K., BURDE, B. & GOLDBECK, J. (2003): Die gläserne Messstelle: Fortschritte bei der Bohrlochgeophysik. – BBR, 7/03, p. 24-32; Bonn/Germany.

DRISCOLL, F.G. (1989): Groundwater and Wells. – 2nd Edition, 1098 p.; St. Paul/USA (Johnson Filtration Syst. Inc.).

DVGW (2001): Technische Regel – Arbeitsblatt W115: Bohrungen zur Erkundung, Gewinnung und Beobachtung von Grundwasser. – 27 p.; Bonn/Germany (Wirtschafts- und Verlagsgesellschaft mbH).

DVGW (2002): Technische Regel – Arbeitsblatt W121: Bau und Ausbau von Grundwassermessstellen. – 25 p.; Bonn/Germany (Wirtschafts- und Verlagsgesellschaft mbH).

DVGW (2003): Technische Regel – Arbeitsblatt W 108: Messnetze zur Überwachung der Grundwasserbeschaffenheit in Einzugsgebieten von Trinkwassergewinnungsanlagen. – 19 p.; Bonn/Germany (Wirtschafts- und Verlagsgesellschaft mbH).

DVWK (1989): Grundwasser – Redoxpotentialmessung und Probennahmegeräte. – Schriften, 84, 172 p.; Hamburg, Berlin/Germany (Parey).

DVWK (1990a): Manual for Water Level Gauging and Discharge Measurements. – Guidelines, 301, 274 p.; Bonn/Germany.

DVWK (1990b): Einflüsse von Messstellenausbau und Pumpenmaterialien auf die Beschaffenheit einer Wasserprobe. – Mitteilungen, 20, 141 p.; Bonn/Germany.

DVWK (1994): Grundwassermessgeräte. – Schriften, 107, 241 p.; Hamburg, Berlin/Germany (Parey).

DVWK (1997): Tiefenorientierte Probennahme aus Grundwassermessstellen. – Merkblätter zur Wasserwirtschaft, 254, 14 p.; Bonn/Germany (Wirtschafts- und Verlagsgesellschaft mbH).

EPA (1989): Ground-Water Monitoring in Karst Terranes – Recommended Protocols and Implicit Assumptions. – Report No. 600/X-89/050, 79 p.; Las Vegas/NV/USA.

EPA (1991a): Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells. – Report No. 600/4-89/034(Rev), 221 p.; Washington/USA.

EPA (1991b): Site Characterization for Subsurface Remediation. – Report No. 625/4-91/026, 268 p.; Washington/USA. [*http://www.epa.gov/swerust1/cat/sitchasu.pdf*]

EPA (1993): Subsurface Characterization and Monitoring Techniques – A Desk Reference Guide, Vol.1: Solids and Groundwater. – Report No. 625R93003, 448 p.; Washington/USA.

EPA (1994): RCRA Ground Water Monitoring – Draft Technical Guidance. – 220 p.; Rockville/USA (Gov.Inst.Inc.).

GIBBONS, R.D. (1994): Statistical Methods for Groundwater Monitoring. – 304 p.; New York/USA (J. Wiley);

HEALY & COOK (2002): Using Groundwater Levels to Estimate Recharge. – Hydrogeology Journal, 10, 1, 91-109; Heidelberg (Springer).

HOBLER, M., MARGANE, A., ALMOMANI, M. & SUBAH, A. (2001): Groundwater Resources of Northern Jordan, Vol.4: Hydrogeological Features of Northern Jordan. - BGR & WAJ, Technical Cooperation Project 'Advisory Services to the Water Authority of Jordan', BGR archive no. 112708, 84 p.; Amman.

HOMRIGHAUSEN, R. & LÜDEKE, U. (1990): Dichtigkeit von Ausbaumaterialien und Wirksamkeit von hydraulischen Barrieren im Ringraum. – BBR, 7, 376-383; Bonn/Germany.

IGRAC (2003): Inventory of existing guidelines and protocols for groundwater assessment and monitoring. – International Groundwater Resources Assessment Centre, 25 p.; Utrecht/The Netherlands.

ISO (1980): International Standard ISO 5667/1: Water Quality – Sampling – Part 1: Guidance on the Design of Sampling Programmes. – International Organization for Standardization, 13 p.; Switzerland.

KEYS, W.S. (1989): Borehole Geophysics Applied to Ground Water Investigations. – USGS, Techniques of Water-Resources Investigations (TWRI), book 2, Chapter E2, 150 p.; Denver/CO/USA.

KOTERBA, M.T., WILDE, F.D., and LAPHAM, W.W. (1995): Ground-water data-collection protocols and procedures for the National Water-Quality Assessment Program—Collection and documentation of water-quality samples and related data – U.S. Geological Survey, Open-File Report, 95–399, 113 p.; Denver/CO/USA.

KÜHN, F., MARGANE, A., TATONG, T. & WEVER, T. (2004): InSAR-Based Land Subsidence Map for Bangkok/Thailand. – Zeitschrift für Angewandte Geologie (ZAG), 50, 104; Stuttgart/Germany (Schweizerbart).

LAWA (1999a): Empfehlungen zu Konfiguration von Messnetzen sowie zu Bau und Betrieb von Grundwassermessstellen (qualitativ). – 32 p.; Berlin/Germany (Kulturbuchverlag).

LAWA (1999b): Empfehlungen zur Optimierung des Grundwasserdienstes (quantitativ). – 36 p.; Berlin/ Germany (Kulturbuchverlag).

LfU (1996): Grundwasserüberwachungsprogramm – Ergebnisse der Beprobung 1995. – Landesanstalt für Umweltschutz Baden-Württemberg, 57 p.; Karlsruhe/Germany.

LUCKNER, L. & NITSCHE, C. (1999): Repräsentative Grundwassermessstellen – Eine Einführung. – in: Begleitmaterial zur Veranstaltung "Weiterbildung im DGFZ e.V.: Bewertung der Repräsentativität und des technischen Zustandes von Grundwassermessstellen" am 22./23.10.1999, Dresden/ Germany. [internet download]

MANSUY, N. (1999): Water Well Rehabilitation – A Practical Guide to Understanding Well Problems and Solutions. – 174 p.; Boca Raton (Lewis Publ.).

MARGANE, A. (1995): Groundwater Resources of Northern Jordan – Vol.2 Part 2: Monitoring of Groundwater Levels in Jordan. – Unpubl. Report, Technical Cooperation Project ‘Advisory Services to the Water Authority of Jordan’, BGR archive no. 112708, 71 p.; Amman.

MARGANE, A. & SUNNA, N. (2002): Proposal for a National Guideline for the Delineation of Groundwater Protection Zones. - Report prepared by WAJ & BGR, Technical Cooperation Project ‘Groundwater Resources Management‘, Technical Report No. 1, 161 p.; Amman.

MARGANE, A. (2003a): Guideline for the Preparation of Groundwater Vulnerability Mapping and Risk Assessments for the Susceptibility of Groundwater Resources to Contamination. – Technical Report Vol. 4, prepared by ACSAD & BGR, Technical Cooperation Project ‘Management, Protection and Sustainable Use of Groundwater and Soil Resources in the Arab Region‘, 177 p.; Damascus.

MARGANE, A. (2003b): Guideline for the Delineation of Groundwater Protection Zones. – Technical Report Vol. 5, prepared by ACSAD & BGR, Technical Cooperation Project ‘Management, Protection and Sustainable Use of Groundwater and Soil Resources in the Arab Region‘, 329 p.; Damascus.

MARGANE, A. (2003c): Guideline for Sustainable Groundwater Resources Management. - Technical Report Vol. 6, prepared by ACSAD & BGR, Technical Cooperation Project ‘Management, Protection and Sustainable Use of Groundwater and Soil Resources in the Arab Region‘, 235 p.; Damascus.

MOORE, J.E. (2002): Field Hydrogeology – A Guide for Site Investigations and Report Preparation. – 208 p.; Boca Ratton/USA (Lewis Publ.).

MORRIS, B.L., LAWRENCE, A.R.L., CHILTON, P.J.C., ADAMS, B. CALOW, R.C. & KLINCK, B.A. (2003): Groundwater and its Susceptibility to Degradation. – Report RS.03-3 prepared by BGS for UNEP, 126 p.; Nottingham/UK, Nairobi/Kanya.

MUELLER, P. & MANGER, V. (1993): Modernes Grundwassermonitoring in der Wasserversorgung. – Wasserwirtschaft, 83, 1, 28-34; Wiesbaden/ Germany (Vieweg).

NIELSEN, D.M. (1991): Practical Handbook of Ground-Water Monitoring. – 717 p.; Boca Ratton/USA (Lewis Publ.)

NFESC (2000): Guide to Optimal Groundwater Monitoring. – Interim Final Report prepared by Radian International for the Naval Facilities Engineering Service Center, 59 p.; Port Hueneme/CA/USA. [internet download]

NLfB & NLWA (1991): Deponieüberwachungsplan Wasser – Beweissicherung an Deponien – Grundwasser, Oberirdische Gewässer. – Niedersächsisches Landesamt für Bodenforschung und Niedersächsisches Landesamt für Wasser und Abfall, 46 p.; Hannover, Hildesheim/Germany.

NLÖ & NLfB (1997): Altlastenhandbuch des Landes Niedersachsen – Geologische Erkundungsmethoden. – Niedersächsisches Landesamt für Ökologie und Niedersächsisches Landesamt für Bodenforschung, 198 p.; Berlin/Germany (Springer).

SMITH, S. A. (1995): Monitoring and Remediation of Wells – Problem Prevention, Maintenance, and Rehabilitation. – 183 p.; Boca Raton/USA (Lewis Publ.).

TAYLOR, C.J. & ALLEY, W.M. (2001): Groundwater-Level Monitoring and the Importance of Long-Term Water-Level Data. – USGS, Circular 1217, 68 p.; Denver/CO/USA.

UNECE (1999): State of the Art on Monitoring and Assessment of Groundwaters.- 83 p.; Lelystad/The Netherlands. [internet download]

UNECE (2000): Guidelines on Monitoring and Assessment of Transboundary Groundwaters.- 64 p.; Lelystad/The Netherlands. [internet download]

UNECE (2002): Guidance to Operation of Water Quality Laboratories.- 89 p.; Lelystad/The Netherlands. [internet download]

Van BRACHT, M. J. (2001): Made to Measure – Information Requirements and Groundwater Level Monitoring Networks. – PhD thesis, Univ. Amsterdam, 210 p.; Amsterdam.

WILDE, F.D., RADTKE, D.B., GIBS, J. & IWATSUBO, R.T. (1998): National Field Manual for the Collection of Water-Quality Data. – USGS, Techniques of Water-Resources Investigations (TWRI), book 9, 765 p.; Reston/VA/USA. [internet download]

WOLTER, R., ROSENBAUM, S. & HANNAPPEL, S. (2000): The German Groundwater Monitoring Network. – Proceedings MTM-III Conference, p. 277-282; Nunspeet/The Netherlands.

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9 Selected Standards for Groundwater Monitoring

Standard	Issue
ASTM Standard D 1293-99	Standard Test Methods for pH of Water
ASTM Standard D 3864-96 (2000)	Standard Guide for Continual On-Line Monitoring Systems for Water Analysis
ASTM Standard D 4128-01	Standard Guide for Identification and Quantitation of Organic Compounds in Water by Combined Gas Chromatography and Electron Impact Mass Spectrometry
ASTM Standard D 4448-01	Standard Guide for Sampling Ground-Water Monitoring Wells
ASTM Standard D 4547-98	Practice for Sampling Waste and Soils for Volatile Organic Compounds
ASTM Standard D 4696-92	Guide for Pore-Liquid Sampling from the Vadose Zone
ASTM Standard D 5092-02	Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers
ASTM Standard D 5173-97 (2001)	Standard Test Method for On-Line Monitoring of Carbon Compounds in Water by Chemical Oxidation, by UV Light Oxidation, by Both or by High Temperature Combustion Followed by Gas Phase NDIR or by Electrolytic Conductivity
ASTM Standard D 5244-92 (1998)	Standard Practice for Recovery of Enteroviruses from Waters
ASTM Standard D 5254-92	Standard Practice for Minimum Set of Data Elements to Identify a Ground-Water Site
ASTM Standard D 5299-99	Standard Guide for Decommissioning of Ground Water Wells, Vadose Zone Monitoring Devices, Boreholes, and Other Devices for Environmental Activities
ASTM Standard D 5314-92	Standard Guide for Soil Gas Monitoring in the Vadose Zone
ASTM Standard D 5408-93	Standard Guide for Set of Data Elements to Describe a Ground-Water Site: Part 1-Additional Identification Descriptors
ASTM Standard D 5409-93	Standard Guide for Set of Data Elements to Describe a Ground-Water Site: Part 2-Physical Descriptors
ASTM Standard D 5410-93	Standard Guide for Set of Data Elements to Describe a Ground-Water Site: Part 3-Usage Descriptors
ASTM Standard D 5434-97	Guide for Field Logging of Subsurface Explorations of Soil and Rock
ASTM Standard D 5474-93	Standard Guide for Selection of Data Elements for Ground-Water Investigations
ASTM Standard D 5521-94	Standard Guide for Development of Ground-Water Monitoring Wells in Granular Aquifers
ASTM Standard D 5544-94 (1999)e1	Standard Test Method for On-Line Measurement of Residue After Evaporation of High-Purity Water
ASTM Standard D 5717-95	Standard Guide for Design of Ground-Water Monitoring Systems in Karst and Fractured-Rock Aquifers
ASTM Standard D 5739-00	Standard Practice for Oil Spill Source Identification by Gas Chromatography and Positive Ion Electron Impact Low Resolution Mass Spectrometry
ASTM Standard D 5753-95	Guide for Planning and Conducting Borehole Geophysical Logging
ASTM Standard D 5782-95	Standard Guide for Use of Direct Air-Rotary Drilling for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices
ASTM Standard D 5783-95	Standard Guide for Use of Direct Rotary Drilling with Water-Based Drilling Fluid for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices
ASTM Standard D 5784-95	Standard Guide for Use of Hollow-Stem Augers for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices

Standard	**Issue**
ASTM Standard D 5787-95	Standard Practice for Monitoring Well Protection
ASTM Standard D 5851-95 (2000)	Standard Guide for Planning and Implementing a Water Monitoring Program
ASTM Standard D 5872-95	Standard Guide for Use of Casing Advanced Drilling Methods for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices
ASTM Standard D 5875-95	Standard Guide for Use of Cable-Tool Drilling for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices
ASTM Standard D 5876-95	Standard Guide for Use of Direct Rotary Wireline Casing Advancement Drilling for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices
ASTM Standard D 5903-96	Standard Guide for Planning and Preparing for a Groundwater Sampling Event
ASTM Standard D 5978-96	Standard Guide for Maintenance and Rehabilitation of Ground-Water Monitoring Wells
ASTM Standard D 5980-96	Standard Guide for Selection and Documentation of Existing Wells for Use in Environmental Site Characterization and Monitoring
ASTM Standard D 5997-96 (2000)	Standard Test Method for On-Line Monitoring of Total Carbon, Inorganic Carbon in Water by Ultraviolet, Persulfate Oxidation, and Membrane Conductivity Detection
ASTM Standard D 6001-96	Standard Guide for Direct-Push Water Sampling for Geoenvironmental Investigations
ASTM Standard D 6089-97	Standard Guide for Documenting a Ground-Water Sampling Event
ASTM Standard D 6145-97 (2002)	Standard Guide for Monitoring Sediment in Watersheds
ASTM Standard D 6146-97 (2002)	Standard Guide for Monitoring Aqueous Nutrients in Watersheds
ASTM Standard D 6232-03	Standard Guide for Selection of Sampling Equipment for Waste and Contaminated Media Data Collection Activities
ASTM Standard D 6238-98	Standard Test Method for Total Oxygen Demand in Water
ASTM Standard D 6282-98	Standard Guide for Direct Push Soil Sampling for Environmental Site Characterizations
ASTM Standard D 6286-98	Standard Guide for Selection of Drilling Methods for Environmental Site Characterization
ASTM Standard D 6312-98	Standard Guide for Developing Appropriate Statistical Approaches for Ground-Water Detection Monitoring Programs
ASTM Standard D 6317-98	Standard Test Method for Low Level Determination of Total Carbon, Inorganic Carbon and Organic Carbon in Water by Ultraviolet, Persulfate Oxidation, and Membrane Conductivity Detection
ASTM Standard D 6452-99	Standard Guide for Purging Methods for Wells Used for Ground-Water Quality Investigations
ASTM Standard D 6502-99	Standard Test Method for On-Line Measurement of Low Level Particulate and Dissolved Metals in Water by X-Ray Fluorescence (XRF)
ASTM Standard D 6538-00	Standard Guide for Sampling Wastewater With Automatic Samplers
ASTM Standard D 6564-00	Standard Guide for Field Filtration of Ground-Water Samples
ASTM Standard D 6634-01	Standard Guide for the Selection of Purging and Sampling Devices for Ground-Water Monitoring Wells
ASTM Standard D 6698-01	Standard Test Method for On-Line Measurement of Turbidity Below 5 NTU in Water
ASTM Standard D 6724-01	Standard Guide for Installation of Direct-Push Ground Water Monitoring Wells
ASTM Standard D 6725-01	Standard Practice for Direct-Push Installation of Prepacked Screen Monitoring Wells in Unconsolidated Aquifers
ASTM Standard D 6771-02	Standard Guide for Low-Flow Purging and Sampling for Wells and Devices Used for Ground-Water Quality Investigations

Standard	**Issue**
DVGW Standard W 101 - 02/95	Richtlinien für Trinkwasserschutzgebiete; I. Teil: Schutzgebiete für Grundwasser *Guidelines for Drinking Water Protection Zones; Part I: Protection Zones for Groundwater*
DVGW Standard W 102 - 04/02	Richtlinien für Trinkwasserschutzgebiete; II. Teil: Schutzgebiete für Talsperren - Arbeitsblatt *Guidelines for Drinking Water Protection Zones; Part II: Protection Zones for Drinking Water Dams*
DVGW Standard W 104 - 12/02 – draft	Beste verfügbare Umweltpraxis in der Landbewirtschaftung - Arbeitsblatt *Environmental-Friendly Best Agricultural Practice*
DVGW Standard W 105 - 03/02	Behandlung des Waldes in Wasserschutzgebieten für Trinkwassertalsperren - Merkblatt *Treatment of Forests in Protection Zones for Drinking Water Dams*
DVGW Standard W 106 - 04/91	Militärische Übungen und Liegenschaften der Streitkräfte in Wasserschutzgebieten - Merkblatt *Military Exercises and Military Installations in Water Protection Zones*
DVGW Standard W 107 - 06/03 – draft	Aufbau und Anwendung numerischer Grundwassermodelle in Wassergewinnungsgebieten -Arbeitsblatt *Preparation of Numerical Groundwater Models for Water Protection Zones*
DVGW Standard W 108 - 12/03	Messnetze zur Überwachung der Grundwasserbeschaffenheit in Wassergewinnungsgebieten - Arbeitsblatt *Network for Monitoring of Groundwater Quality in Water Exploitation Zones*
DVGW Standard W 109 - 12/02 – draft	Planung, Durchführung und Auswertung von Markierungsversuchen bei der Wassergewinnung -Arbeitsblatt *Planning, Execution and Interpretation of Tracer Tests in Water Exploitation Zones*
DVGW Standard W 110 - 06/90	Geophysikalische Untersuchungen in Bohrlöchern und Brunnen zur Erschließung von Grundwasser *Geophysical Investigation of Boreholes and Wells used for Exploitation of Groundwater*
DVGW Standard W 111 - 03/97	Planung, Durchführung und Auswertung von Pumpversuchen bei der Wassererschließung - Arbeitsblatt *Planning, Execution and Interpretation of Pumping Tests in Water Exploitation Wells*
DVGW Standard W 112 - 07/01	Entnahme von Wasserproben bei der Erschließung, Gewinnung und Überwachung von Grundwasser -Merkblatt *Sampling of Groundwater for Exploration, Exploitation and Monitoring Purposes*
DVGW Standard W 113 - 03/01	Bestimmung des Schüttkorndurchmessers und hydrogeologischer Parameter aus der Korngrößenverteilung für den Bau von Brunnen - Merkblatt *Determination of the Size and Composition of Sand Filters and of Hydrogeological Parameters for the Construction of Wells based on Grain Size Analysis*
DVGW Standard W 114 - 06/89	Gewinnung und Entnahme von Gesteinsproben bei Bohrarbeiten zur Grundwassererschließung - Merkblatt *Extraction of Rock Samples during Drilling of Groundwater Exploitation Wells*
DVGW Standard W 115 - 03/01	Bohrungen zur Erkundung, Gewinnung und Beobachtung von Grundwasser *Boreholes for Exploration, Exploitation and Monitoring of Groundwater*
DVGW Standard W 116 - 04/98	Verwendung von Spülungszusätzen in Bohrspülungen bei Bohrarbeiten im Grundwasser - Merkblatt *Use of Drilling Additives for Drilling in Groundwater*
DVGW Standard W 117 –	Entsanden und Entschlammen von Bohrbrunnen (Vertikalbrunnen) im

Standard	**Issue**
12/75	Lockergestein und Verfahren zur Feststellung überhöhten Eintrittswiderstandes *Removal of Sand and Mud from Boreholes in Unconsolidated Rocks and Methods for Determination of Excessive Intake Resistance in Well Screens*
DVGW Standard W 119 - 12/02	Entwickeln von Brunnen durch Entsanden - Anforderungen, Verfahren, Restsandgehalt *Well Development by Sand Removal – Requirements, Methods, Residual Sand Content*
DVGW Standard W 120 - 07/01	Qualifikationskriterien für Bohr-, Brunnenbau- und Brunnenregenerierunternehmen - Arbeitsblatt *Qualification Criteria for Companies Performing Drilling and Rehabilitation of Water Wells*
DVGW Standard W 121 - 07/03	Bau und Ausbau von Grundwassermessstellen -Arbeitsblatt *Construction and Design of Groundwater Monitoring Facilities*
DVGW Standard W 122 - 8/95	Abschlussbauwerke für Brunnen der Wassergewinnung - Arbeitsblatt *Closure Structures for Water Exploitation Wells*
DVGW Standard W 123 - 9/01	Bau und Ausbau von Vertikalfilterbrunnen - Arbeitsblatt *Construction and Design of Groundwater Wells*
DVGW Standard W 124 - 11/98	Kontrollen und Abnahmen beim Bau von Vertikalfilterbrunnen - Merkblatt *Control and Acceptance Procedures during the Construction of Groundwater Wells*
DVGW Standard W 125 - 06/03 – draft	Brunnenbewirtschaftung - Betriebsführung von Wasserfassungen - Arbeitsblatt *Management of Water Extraction Facilities*
DVGW Standard W 130 - 07/01	Brunnenregenerierung *Rehabilitation of Groundwater Wells*
DVGW Standard W 132 - 12/80	Algen-Massenentwicklung in Langsamsandfiltern und Anlagen zur künstlichen Grundwasseranreicherung - Möglichkeiten zu ihrer Vermeidung - Merkblatt *Possibilities for the Avoidance of Mass Algal Growth in Sand Filters and in Installations for Artificial Groundwater Recharge*
DVGW Standard W 135 - 11/98	Sanierung und Rückbau von Bohrungen, Grundwassermessstellen und Brunnen - Merkblatt *Rehabilitation and Abandonment of Boreholes, Wells and Monitoring Facilities in Groundwater*

The ISO standards which are relevant for groundwater quality monitoring are documented in *Part B, chapter 8* of this report since most of them are related to groundwater quality monitoring.

10 Internet Links

For further links, see *Part B*, *chapter 11* of this report.

ASTM – American Society for Testing and Materials: *www.astm.org/*

DVGW – Deutsche Vereinigung des Gas- und Wasserfaches: *www.dvvgw.de*

EPA – Comprehensive State Groundwater Protection Program: *http://www.epa.gov/OGWDW/csgwppnp.html*

ISO – International Organization for Standardization: *www.iso.ch/*

USGS - Ground-Water Monitoring Network Design (National Research Program): *http://water.usgs.gov/nrp/proj.bib/wagner.html*

World Bank Water Resources Management Group: *www.worldbank.org/water*

11 Abbreviations

ACSAD	Arab Center for the Studies of Arid Zones and Dry Lands, Damascus/Syria, *www.acsad.org*
ADB	Asian Development Bank, Manila/Philippines, *www.adb.org/*
ASTM	American Society for Testing and Materials, *www.astm.org/*
BCM	Billion cubic meters
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe – Federal Institute for Geosciences and Natural Resources, Hannover/Germany, *www.bgr.de*
BMZ	Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung – Federal Ministry for Economic Cooperation and Development, Bonn/Germany, *www.bmz.de*
BOD	Biochemical oxygen demand
CERCLA	Comprehensive Environmental Response, Conservation and Liability Act (US, 1980)
COD	Chemical oxygen demand
DNAPL	Dense non-aqueous phase liquid
DSS	Decision Support System
DVGW	Deutsche Vereinigung des Gas- und Wasserfaches, *www.dvgw.de*
DVWK	Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall (ATV-DVWK); *http://www.atv.de/*
EEA	European Environment Agency, Copenhagen/Denmark, *www.eea.eu.int/*
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency, Washington/USA, *www.epa.gov/*
ESCWA	United Nations Economic and Social Commission for Western Asia, Beirut/Lebanon, *www.escwa.org.lb/*
ESCAP	United Nations Economic and Social Commission for Asia and the Pacific, Bangkok/Thailand, *www.unescap.org/*
EUR	Euro
FAO	Food and Agriculture Organization, Rome/Italy, *www.fao.org*
GEMS	Global Environmental Monitoring System, Burlington/Ontario/Canada *www.gemswater.org*
GIWA	UNEP' s Global International Water Assessment, Kalmar/Sweden, *www.giwa.net/*
GRDC	Global Runoff Data Center, Koblenz/Germany *www.bafg.de/grdc.htm*
GSM	Global System for Mobile Comunications
GTZ	Gesellschaft fuer Technische Zusammenarbeit, Corporation for Technical Cooperation, *www.gtz.de*
GWP	Global Water Partnership *www.gwpforum.org/*
IADB	Inter-American Development Bank, Washington/USA, *www.iadb.org/*
IETC	International Environmental Technology Center, Osaka/Japan, *www.unep.or.jp/ietc/*
IGRAC	International Groundwater Resources Assessment Center, Utrecht/The Netherlands, *http://igrac.nitg.tno.nl/*
IISD	International Institute for Sustainable Development, Winnipeg/Manitoba/CDN, *www.iisd.org/*
IRC	International Research Center for Water Supply and Sanitation, Delft/The

	Netherlands, *www.irc.nl/*
ISE	Ion selective (or sensitive) electrode
ISO	International Organization for Standardization, /Switzerland; *http://www.iso.ch/iso/en/ISOOnline.frontpage*
IWRM	Integrated Water Resources Management
IWMI	International Water Management Institute, Colombo/Sri Lanka, *www.iwmi.cgiar.org/*
JICA	Japan International Cooperation Agency, Tokyo/Japan, *http://www.jica.go.jp/english/index.html*
LAWA	Länderarbeitsgemeinschaft Wasser, *www.lawa.de*
LfU	Landesanstalt für Umwelt, Baden-Württemberg/Germany, *http://www.lfu.baden-wuerttemberg.de/*
LNAPL	Light non-aqueous phase liquid
MCM	Million cubic meters
NLfB	Niedersächsisches Landesamt für Bodenforschung, Lower-Saxony/Germany, *www.nlfb.de*
NLÖ	Niedersächsisches Landesamt für Ökologie, Lower-Saxony/Germany, *www.nloe.de*
NLWA	Niedersächsisches Landesamt für Wasser und Abfall, Lower-Saxony/Germany (disbanded)
ORP	Oxidation-reduction potential (or redox potential)
RCRA	Resource Conservation and Recovery Act (USA, 1976) *http://www.epa.gov/rcraonline/*
SAGE	Schéma d' Aménagement et de Gestion des Eaux (France ; Water Management Plan)
T	Temperature
TDS	Total Dissolved Solids
UNCED	United Nations Conference on Environment and Development, Dublin/Ireland (1992)
UNCSD	United Nations Commission on Sustainable Development (Division for Sustainable Development, Department of Economic and Social Affairs), New York/USA, *www.un.org/esa/sustdev/csd.htm*
UNDP	United Nations Development Program, New York/USA, *www.undp.org*
UNECE	United Nations Economic Commission for Europe, Geneva/Switzerland, *www.unece.org/*
UNEP	United Nations Environment Program, Nairobi/Kenya, *www.unep.org*
UNIDO	United Nations Industrial Development Organization
USGS	United States Geological Survey, Reston/Virginia/USA, *www.usgs.gov/*
USBR	United States Bureau of Reclamation, Washington/DC/USA *www.usbr.gov/main/*
WHO	World Health Organization, Geneva/Switzerland, *www.who.int*
WWAP	World Water Assessment Program
WWDR	World Water Development Report

12 Units

acre	4,047 m²
feet or ft	0.3048 meter
gallon or gal	3.785412 liter (1 gallon/minute = 1gpm = 6.309E-2 l/s)
ha	10,000 m² (hectare)
inch or “	2.54 cm
µS/cm	micro (1E-6) Siemens per centimeter (standard unit for measurements of electric conductivity)

Annex A-1: Groundwater Level Monitoring – Monitoring Station File

The following basic data should be made available for each groundwater level monitoring well. These data should be kept in a file in the office. The monitoring wells should be unmistakably marked in the field. It is recommended to include a sketch and photos of the site to facilitate retrieval of location.

Item	Unit	Remark
Name		
Well Identification No.		Unique code system for easy and unmistakable data retrieval using basin/area codes
Monitoring ID No.		Ditto
Name of Well		
Owner of Well		
Location		
East Coordinates	m	Local grid system
North Coordinates	m	Local grid system
Source of Data		Where data were obtained from
Type of Coordinate Determination		Acquired by leveling, single instrument GPS, Differential GPS, etc.
Elevation	m	
Source of Data		Where data were obtained from
Type of Elevation Determination		Acquired by leveling, single instrument GPS, Differential GPS, etc.
Governorate		
District		
Town/Village		
Location Name		
Location Description		
Location Sketch(es)		
Photo(s) of Location		
Drilling Data		
Drilling Rig(s)		
Drilling Type(s)		
Drilling Company/-ies / Agency/-ies		
Drilling Fluids Used		
Date Drilling Started		
Date Drilling Completed		
Total Depth	m	
Water strikes encountered at	m	
Loss of circulation encountered at	m	
Drilling Diameters from/to	m; mm or inches	
Cementings from/to & Materials	m	
Backfillings from/to & Materials		
Casing/Screens x from/to	m	
Casing/Screens x Diameters	in/mm	
Casing/Screens x Type & Materials & Slot Sizes		
Centralizers Positions	m	

Item	Unit	Remark
Gravel Packs from/to	m	
Gravel Packs Types		
Well Development		
Date of Development		
Type of Development		
Duration of Development		
Equipment/Fluids used		
Volume and Source of Water (if applicable)		
Result of Development		
Company		
Geophysical Borehole Logging		
Geophysical Log x from/to	m	
Date of Logging		
Logging by (Company/Agency)		
Data available at		
Pumping Test		
Test x		
Type of Testing		Hydraulic Parameter Characterization / Capacity Test
Date of Testing		
Depth of Pump Installation		
Pump Type/Model Name		
Discharge at Step x		
Duration of Discharge x		
Distance to Aquifer Boundaries		
Distance to Nearest Other Well		Well that was monitored during pumping test
Static Water Level	m	
Reference Point		e.g. land surface/well head, etc.
Dynamic Water Level	m	
Other Parameters Monitored		
Well Loss		
Aquifer Loss		
Proposed Maximum Discharge	m^3/h	depending on the locally used units
Specific Capacity	m^2/h	depending on the locally used units
Results: Transmissivity	m^2/h	depending on the locally used units
Results: Hydraulic Conductivity	m/s	depending on the locally used units
Method of Evaluation		
Results: Storage Coefficient		
Method of Evaluation		
Results: Specific Yield	m^2/h	depending on the locally used units
Results: Leakage Factor	l/s	depending on the locally used units
Method of Evaluation		
Geology/Lithology		
Section x from/to	m	
Rock/Sediment Description		
Lithostratigrahic Classification		
(Age)		
Hydrogeology		
Aquifer x		
Aquifer Classification		Aquifer Name
Aquifer Type		Confined/unconfined/leaky/artesian
Penetration		Complete/partial
Top		
Bottom		

Item	**Unit**	**Remark**
Hydrochemical Composition		
Data of Sampling		
Sample No.		
Laboratory No.		
Sampled by		Name/Agency
Field Measurements: pH	-	
Field Measurements: EC	µS/cm at reference temperature	
Field Measurements: T	°C	
Field Measurements: O_2	mg/l	
Analysis Results: All Analyzed Parameters		
Monitoring Equipment		
Name/Model x for Data Registration		
Type of Data Registration		
Date of Installation		
Installed by		
Installation Depth	Meters	
Type(s) of Material		
Service Agency		Name, phone no., etc.
Name/Model x for Data Storage		
Service Agency		Name, phone no., etc.
Name/Model x for Data Transfer		
Service Agency		Name, phone no., etc.
Constructions		
Name/Type of Well Cap		
Type of Construction		e.g. Building/Fence/Telemetry Station with Solar Panel/etc.
Date of Construction		
Well Rehabilitation		
Rehabilitation x		
Date		
Method		
Duration		
Conducted by		
Specific Capacity before Rehabilitation		
Specific Capacity after Rehabilitation		
Maintenance		
Maintenance x		
Date		
Description of Problem		
Description of Solution		
Conducted by		

In addition a standard lithological log and a standard design diagram (as-built) has to be added to the file.

Annex A-2: Groundwater Level Monitoring – Monitoring Field Report

Each time a groundwater level monitoring well is visited a monitoring field report should be filled out.

Groundwater Monitoring Program "xyz"	
Name of Agency and Responsible Division/Section	
Well Identification No.	
Monitoring Well No.	
Name of Well	
(Other Basic Data)	(e.g. coordinates, etc.)
Date of Visit	
Visited by	
Status of Monitoring Site	concerning borehole, equipment, construction, etc.; e.g. flooding of borehole (during a certain rainfall event) likely, float stuck during (dates), batteries empty, solar panel damaged, etc.
Last Maintenance	date
Maintenance conducted	
Description of Problem	
Description of Solution	
Last Rehabilitation	date
Water Level Indicated by Instrument	in m below reference point
Manual Measurement of Water Level	in m below reference point
Measured by Water Level Meter No.	ID no. of instrument
Data File Downloaded to	e.g. notebook xyz
File Name	unique file name
Remarks	e.g. maintenance/repair works required, water level corrected, instrument calibrated, etc.
Other Field Parameters	e.g. EC, pH, T, O_2
Water Quality Sampling	yes/no, sample id no.

If a water sample is taken at the same time, a separate protocol should be completed (see *Annex B-2*).

Annex A-3: Groundwater Monitoring – Selection of Drilling Method

The following table describes the suitability of drilling methods used for the drilling of wells for groundwater monitoring purposes and is adopted from EPA (1994) with some minor modifications.

Driven Wells	
Applications and Advantages	*Limitations*
• Water level monitoring in shallow formations • Ease of water samples collection • Low cost, encouraging the installation of a larger number of monitoring facilities	• Depth limited to approx. 15 m • Small diameter casing • No soil sample recovery, i.e. no lithological interpretation possible • Steel casing may interfere with some hydrochemical constituents • Lack of stratigraphic details creates uncertainty regarding screened zones and/or cross-contamination • Cannot penetrate dense and/or some dry materials • No annular space for well completion
Solid-Stem Auger Drilling	
Applications and Advantages	*Limitations*
• Shallow soil investigations • Soil sampling • Vadose zone monitoring wells • Monitoring wells in saturated, stable soils • Identification of depth to bedrock • Fast and mobile	• Unacceptable soil samples, unless split-spoon or thin-wall samples are taken • Soil sample data limited to areas and depths where stable soils are predominant • Unable to install monitoring wells in most unconsolidated aquifers because of borehole caving upon auger removal • Depth capability decreases as diameter of auger increases
Hollow-Stem Auger Drilling	
Applications and Advantages	*Limitations*
• All types of soil investigations • Permits good soil sampling with split-spoon or thin-wall samplers • Water quality sampling • Monitoring well installation in all unconsolidated formations • Can serve as temporary casing for coring rock • Can be used in stable formations to set surface casing	• Difficulty in preserving sample integrity in heaving formations • Formation invasion by water or drilling mud if used to control heaving • Possible cross-contamination of aquifers where annular space not positively controlled by water or drilling mud or surface casing • Limited diameter of augers limits casing size • Smearing of clays may seal off aquifer to be monitored
Mud Rotary Drilling	
Applications and Advantages	Limitations
• Rapid drilling of clay, silt and reasonably compacted sand and gravel formations • Allows split-spoon and thin-wall sampling in	• Difficult to remove drilling mud and wall cake from outer perimeter of filter pack during development

unconsolidated materials • Allows core sampling in unconsolidated formations • Abundant and flexible range of drilling tool sizes and depth capabilities • Very sophisticated drilling and mud programs available • Ease of geophysical borehole logging	• Bentonite or other drilling fluid additives may influence quality of groundwater samples • Circulated (ditch) samples poor for monitoring well screen selection • Split-spoon and thin-wall samplers are expensive and of questionable cost effectiveness at depths greater than 50 m • Wireline coring techniques for sampling both unconsolidated and consolidated formations often not locally available • Difficult to identify aquifers • Drilling fluid invasion at permeable zones may compromise validity of subsequent monitoring well samples
Air Rotary Drilling	
Applications and Advantages	Limitations
• Rapid drilling of semi-consolidated and consolidated rock formations • Good quality reliable formation samples • Allows easy and quick identification of lithologic changes • Allows identification of most water-bearing zones • Allows estimate of yields in strong water-producing zones with short down-time	• Surface casing frequently required to protect top of hole • Drilling restricted to semi-consolidated and consolidated formations • Samples occur as small particles that are difficult to interpret • Drying effect of air may mask lower-yield water-producing zones, allowing only identification of significant water-bearing zones • Air stream requires contaminant filtration • Air may modify chemical or biological conditions and recovery time is uncertain
Air Rotary with Casing Driver Drilling	
Applications and Advantages	Limitations
• Rapid drilling of unconsolidated clays, silts and sands • Drilling in alluvial material • Casing supports borehole thereby maintaining borehole integrity and minimizing inter-aquifer cross-contamination • Eliminates circulation problems common with direct-mud rotary drilling • Good formation sample recovery • Minimal formation damage when pulling back casing	• Thin, low-pressure water-bearing zones easily overlooked if drilling not stopped at appropriate places to observe whether or not water levels are recovering • Difficult interpretation of rock samples due to pulverization • Air may modify chemical or biological conditions and recovery time is uncertain
Dual-Wall Reverse-Circulation Rotary Drilling	
Applications and Advantages	Limitations
• Very rapid drilling through both unconsolidated and consolidated formations • Allows continuous lithological sampling in all types of formations • Very good representative lithological samples can be obtained with minimal risk of contamination of sample and/or water-bearing zone • In stable formations, wells with diameters as large as 6 inches can be installed in open-hole completions	• Limited borehole size that limits diameter of monitoring wells • In unstable formations, well diameters are limited to approx. 4 inches • Air may modify chemical or biological conditions and recovery time is uncertain • Unable to install filter pack unless completed as open hole

Jet Percussion Drilling	
Applications and Advantages	Limitations
• Allows water level measurement • Sample collection in form of cuttings • Primary use in unconsolidated formations, but may be used in some softer consolidated rock formations • Best application is 4-inch borehole with 2-inch casing and screen installation	• Drilling mud may be needed to return cutting to surface • Diameter limited to 4 inches • Installation slow in dense, bouldery clay/till or similar formations • Disturbance of the formation possible if borehole not immediately cased
Cable Tool Drilling	
Applications and Advantages	Limitations
• Drilling in all types of geologic formations • Almost any depth and diameter range • Ease of monitoring well installation • Ease and practicality of well development • Excellent samples of coarse-grained materials	• Slow drilling advancement • Heaving of unconsolidated materials must be controlled

Annex A-4: Groundwater Level Monitoring – Examples for Graphic Presentation of Water Level Data

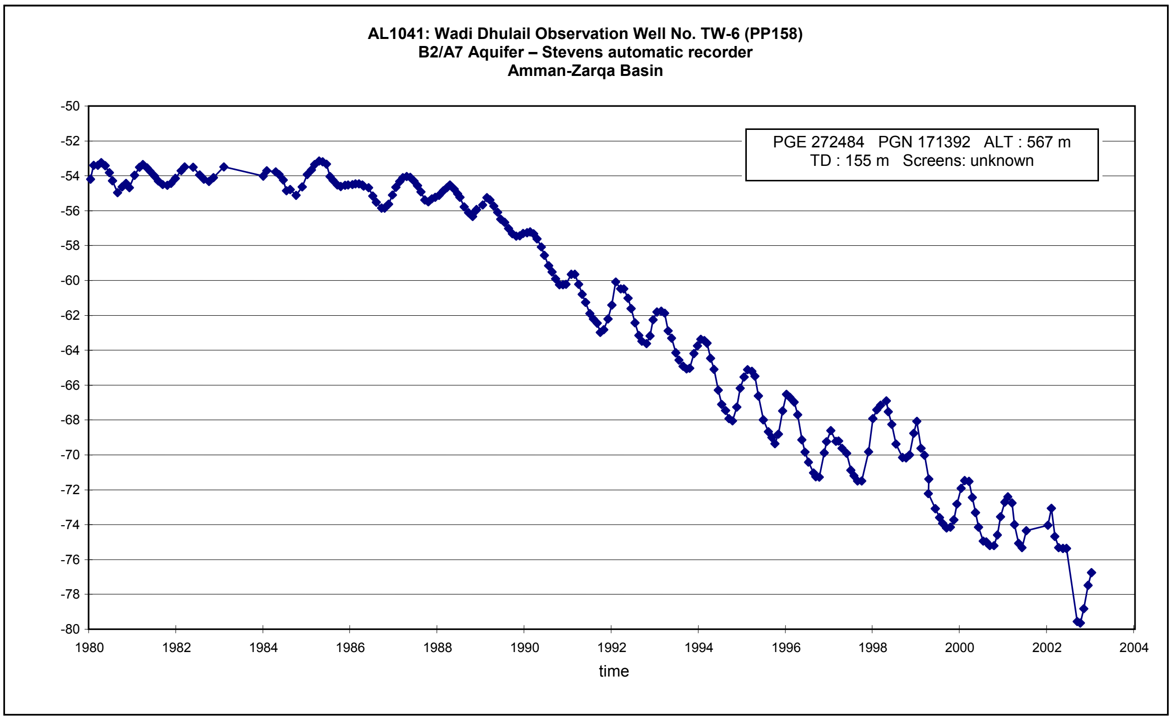


Figure 11: Hydrograph of a Piezometer in Jordan (courtesy MWI)

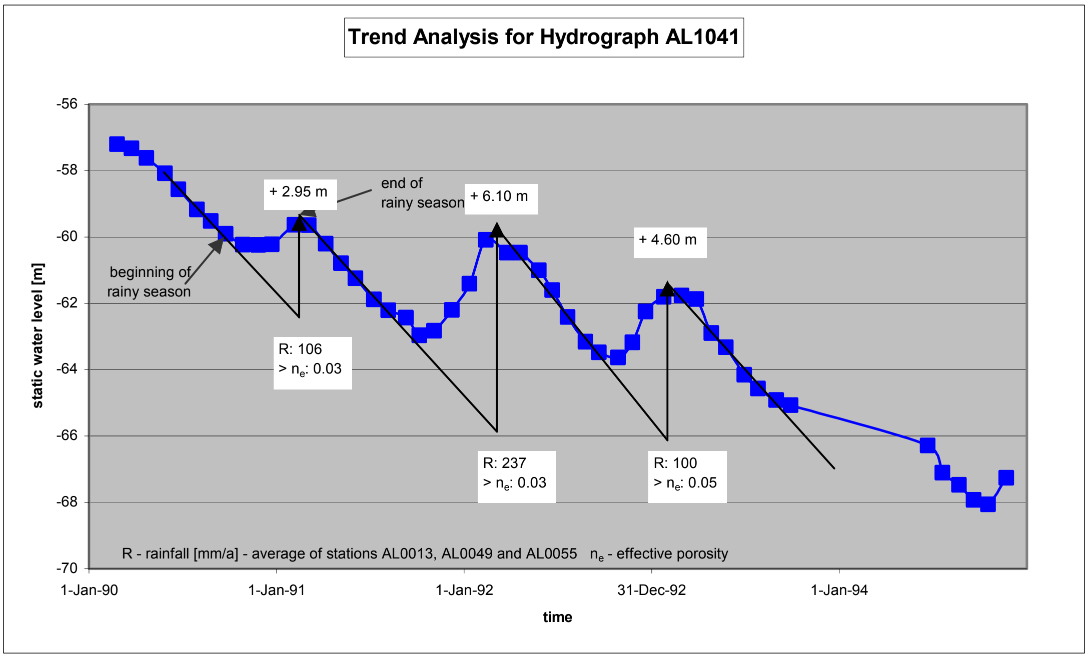


Figure 12: Example for a Simple Trend Analysis of a Piezometer

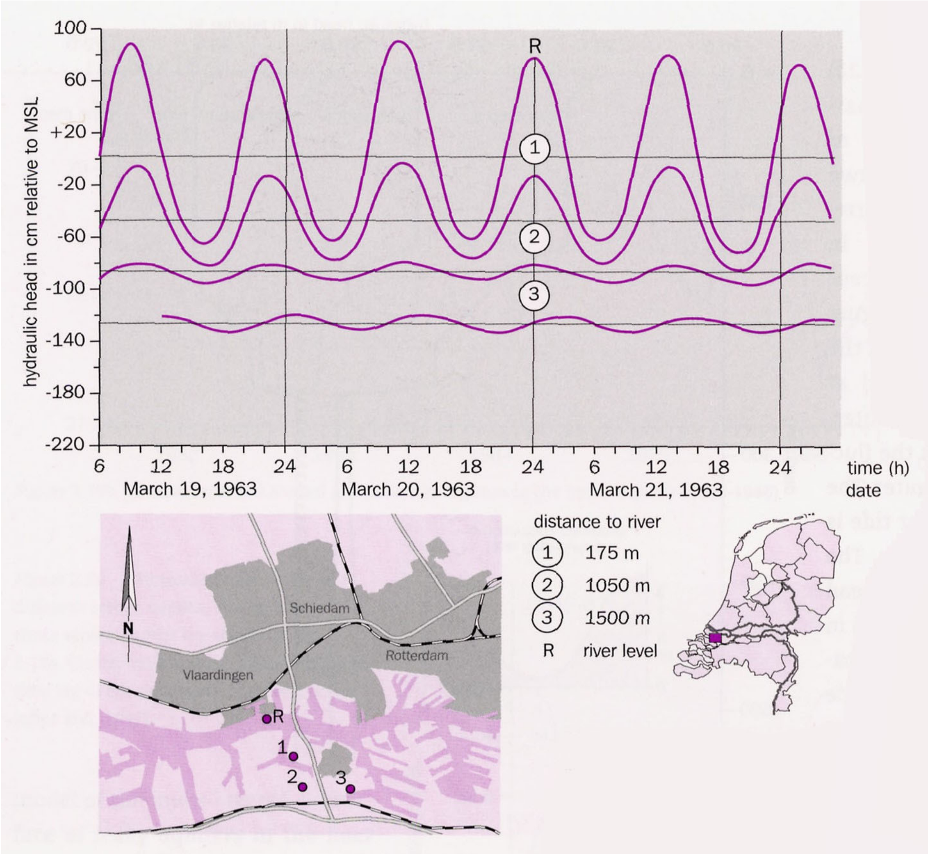


Figure 13: Dampening of Pressure Propagation of Tidal Waves with Distance from the Sea, Monitored near the City of Rotterdam/The Netherlands (from Van BRACHT 2001)

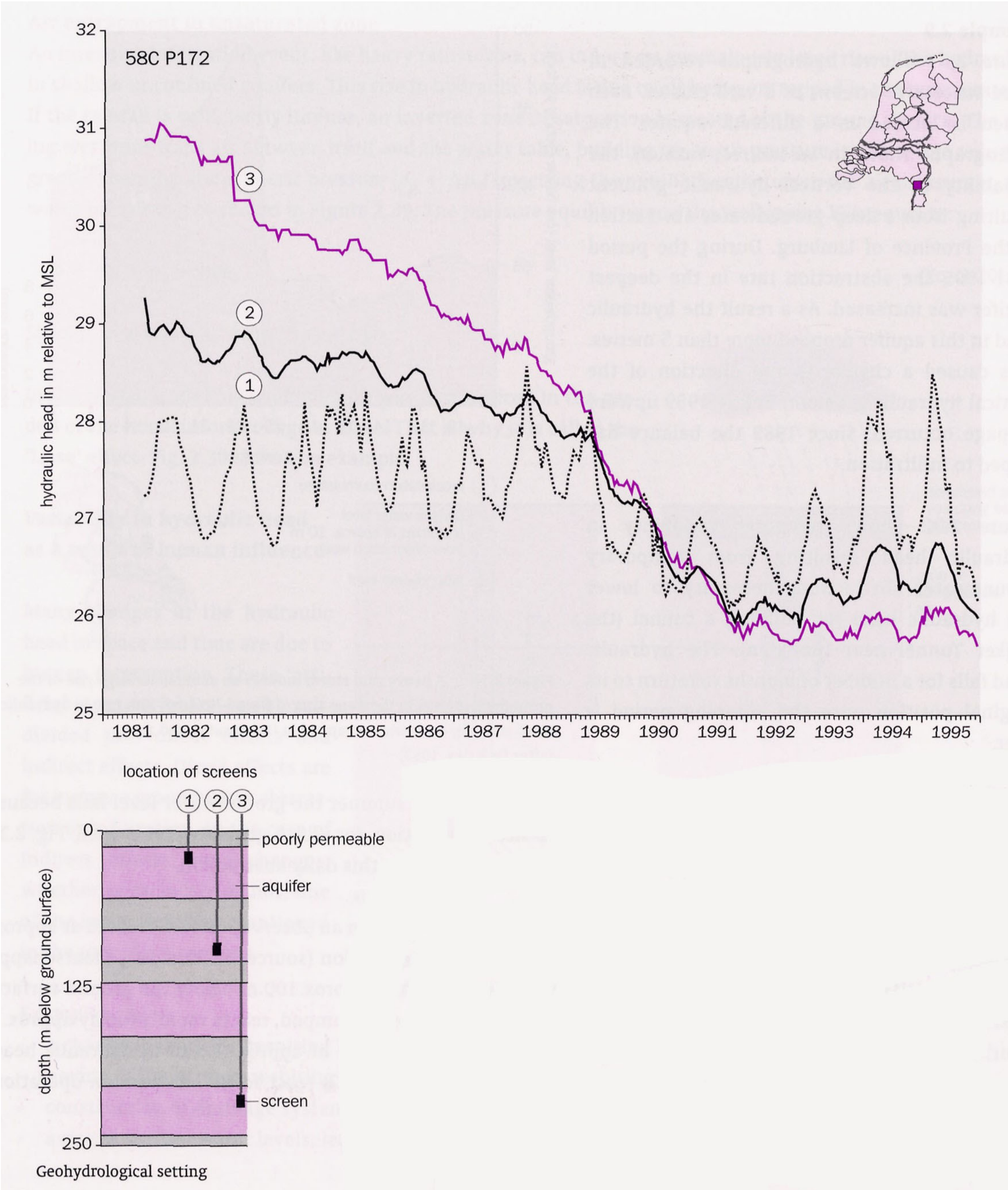
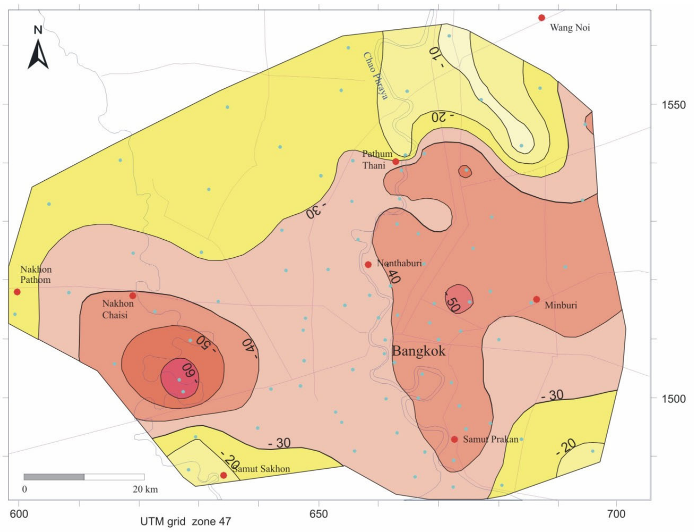
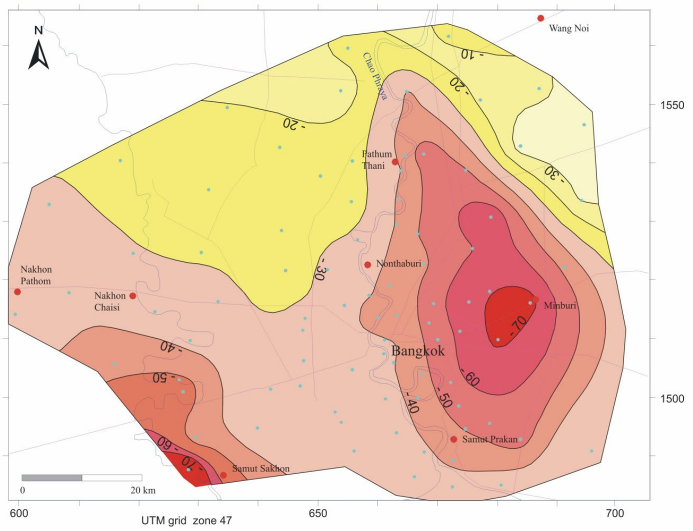


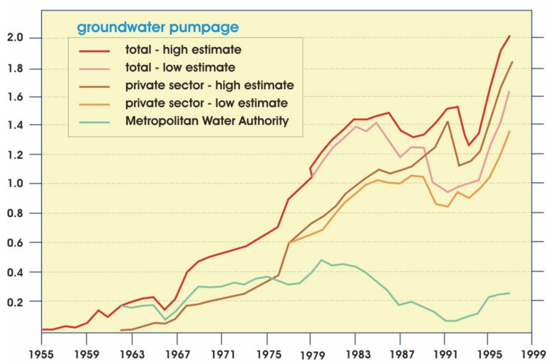
Figure 14: Hydrographs of a Cluster Well in the Roer Graben near Limburg/The Netherlands showing Response to High Groundwater Abstraction in Deepest Aquifer (from Van BRACHT 2001)



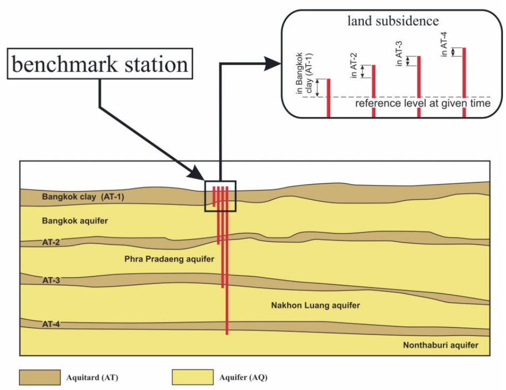
Groundwater Contour Map of the Nonthaburi Aquifer (NB), based on Wells Screened from 200 to 250 mm below m.s.l.



Groundwater Contour Map of the Nakhon Luang Aquifer (NL), based on Wells Screened from 150 to 200 mm below m.s.l.



Groundwater Abstraction in the Greater Bangkok Area in MCM/d



Schematic Sketch of Benchmark Stations for Land Subsidence Monitoring in the Greater Bangkok Area

Figure 15: Monitoring of Land Subsidence and Groundwater Levels in Bangkok; Groundwater Abstraction is Highest in the Nakhon Luang Aquifer (after KÜHN et al. 2004)

Part B – Groundwater Quality Monitoring

1 Objectives and Strategies

There are different objectives for groundwater quality monitoring:

- Meeting regulatory requirements (e.g. sampling of drinking water);
- Site characterization;
- Monitoring of possible impact of sites and activities (point sources) which are possibly hazardous to groundwater, such as waste disposal sites, waste water treatment plants, oil/chemical substances storage sites, etc., or
- Assessment of degree and spreading of contamination where contamination has already been detected and locating of emission source;
- Monitoring of possible impact of widespread contamination from non-point sources (e.g. pesticide and fertilizer application);
- Monitoring of general groundwater quality in individual aquifers or regions/catchment areas (e.g. determination of natural groundwater quality in the framework of EIAs);
- Monitoring of rate and composition of artificially infiltrated water (hydro-chemical interactions with natural groundwater);
- Monitoring of saltwater intrusion phenomena (change of position of interface over time and space;
- Monitoring for specific or research purposes (e.g. nitrate decomposition, tracer tests, etc.);
- Monitoring of groundwater quality in catchment area of water works;
- Monitoring of aquifer restoration success.

CHILTON & FOSTER (1997) distinguish the following kinds of monitoring objectives:

- Trend monitoring: to indicate trends in groundwater quality and or quantity changes derived from natural causes, the impact of diffuse pollution sources, and changes in the hydraulic regime;
- Baseline monitoring: to provide background information on groundwater quality so that the impacts of future, as yet undefined, human activities can be detected;
- Spatial distribution monitoring: to provide information on the three-dimensional distribution of groundwater quality within aquifers;
- Early-warning systems: to provide early-warning information on the impacts of

diffuse sources of pollution on water sources.

UNECE (2000) differentiate the following types of monitoring networks:

- Basic/reference monitoring: to provide data on a background situation which enables to determine trends;
- Compliance monitoring: serving to protect the population from violations of regulations, laws and directives (concerning soil and groundwater pollution);
- Special monitoring networks, such as for
    - Water supply wells: establishment of protection zones; monitoring of impact of groundwater extraction and compliance with restrictions in groundwater protection zones; early-warning monitoring (e.g. monitoring system proposed for Germany (DVGW 2003);
    - The investigation and implementation of groundwater remediation and restoration measures;
    - The investigation of the interrelation between groundwater and surface water;
    - The development of scenarios for contaminant migration; and
    - The investigation of the behavior and spatial distribution of specific contaminants (compliance/research);
- Early-warning monitoring: to determine public health hazards related e.g. to accidental spills possibly affecting the public water supply, impacts from waste disposal sites and contaminated land, etc.

Monitoring networks designed for the above mentioned purposes may be in operation only temporarily (i.e. several months) or permanently (several years).

For each individual objective there are different methods for well drilling, well design, and sampling being used. A monitoring program needs to be carefully planned in order to achieve adequate and interpretable results. The selection of suitable locations and depth intervals is crucial for this matter. However, a number of other factors also have a strong influence on the results, such as: drilling method, well design, materials used, sampling conditions (e.g. hydraulic conditions, weather), sampling method, sample conservation and storage method, analysis method.

In most cases, the availability of sufficiently trained staff and of the financial resources, however, are the main constraints for groundwater quality monitoring. If financial resources are limited, the program should be downsized in such a way that the objectives are still achievable. The training of the staff must be a key component in monitoring programs.

It must be kept in mind that the properties of water change immediately after its extraction from the aquifer. Along the pathway from extraction to analysis the sample may be subjected to numerous changes concerning these properties (especially as a result of exposure to or variations of temperature, pressure, light, access to oxygen, access to bacteria and other chemical substances). Water quality may change considerably if not protected from such influences. It is very important to follow the necessary treatment procedures for analysis of individual parameters. The time span between sampling and analysis should be as short as possible.

When complying with all the below mentioned criteria, water quality monitoring may become rather expensive. A careful balance needs to be stricken between the costs of these measures and the overall benefits. However, when neglecting some of these measures, one has to be aware of the consequences and the implications on the results.

There are a substantial number of references and guidances on the issue of water quality monitoring. The most extensively used ones are:

- EPA (2001): Environmental Investigations Standard Operating Procedures and Quality Assurance Manual; and
- WILDE, F.D., RADTKE, D.B., GIBS, J. & IWATSUBO, R.T. (1998): National Field Manual for the Collection of Water-Quality Data, prepared by the USGS.

2 Methods of Water Quality Monitoring

Concerning the sampling mode, it must principally be distinguished between spot samples, periodic samples, continuous sampling, series sampling and composite samples.

Spot samples are taken randomly in time to determine the existence of a parameter, e.g. a pollutant, in the water.

Periodic samples are taken at specific time intervals, e.g. once a day/month/year, or when water levels reach their minimum and maximum.

Continuous sampling is achieved by sampling devices which allow for the continuous recording of on-site measurements, such as pH, EC, T, O_2, or others. Individual elements may be determined by ion selective probes. For this purpose, the probe has to be installed at a specific depth in a well. Such continuous measurements have the disadvantage that calibration of the probe is difficult and that the water being measured is not truly representative. Probes for continuous sampling are available from various companies for borehole diameters as small as 2 inches (e.g. the SEBA multi-parameter probe MPS-D for recording of water level, pH, redox potential, temperature, dissolved O_2; www.seba.de). The USGS has been testing an automated groundwater monitoring system called Robowell (GRANATO & SMITH, 2002; http://ma.water.usgs.gov/automon/default.htm) since 1994 that records a number of parameters at preprogrammed intervals, and automatically notifies the operator and increases the frequency of measurements if a certain limit is exceeded. Commonly the system performs the following steps: (1) activation at the time intervals programmed; (2) performing self-tests; (3) measurement of water level; (4) calculation of purge volume; (5) measurement and recording of a number of water quality parameters during purging; (6) determination of parameter constancy and recording of final monitoring values; (7) return to inactive mode. The Robowell automated monitoring was tested in six different monitoring programs in the Cape Cod area, Massachusetts (http://ma.water.usgs.gov/automon/spie2001.pdf) for different purposes, such as e.g. salt water intrusion.

Series sampling may be carried out in a well to monitor the content in a specific parameter over depth or to determine the spatial distribution of contents in a specific parameter over a larger area. For the latter, samples are being taken from a specific aquifer horizon or depth.

Composite samples are taken automatically (or manually) to obtain the average composition of a sample over a specific amount of time.

Concerning the well design it is distinguished between (compare chapter 3.1 of *Part A*):

- Single boreholes which are fully screened;
- Single boreholes with multiple screens which are monitored using permanent or removable packers;

- Multi-level wells (cluster wells; multiple wells down to different depths near to one another);
- Single borehole multi-level wells (a single borehole suiting multiple wells which are screened at different depths and which must be hydraulically separated by suitable means);
- Multi-level wells (or monitoring ports) with direct burial (e.g. Waterloo/Solinst system);
- Direct wells (so-called monitoring pipes, rammed filters, driven wells, wellpoints, or direct-push system) which are mechanically driven in (for monitoring of shallow groundwaters; e.g. Eijkelkamp groundwater monitoring pipes; compare ASTM standards: D 6001-96, D 6724-01 and D 6725-01).

The position of the wells and their screened depth interval depends on the following criteria:

- Direction of groundwater flow;
- Thickness of the aquifer;
- Relative position and distance to possible/proven hazards to groundwater and to wells for water abstraction;
- Homogeneity of the aquifer (vertical/horizontal differences in permeability, sediment type and components or hydrochemical composition ?);
- Possibility of upward downward leakage from other aquifers into the aquifer to be monitored;
- Position of faults/fault zones possibly influencing groundwater flow and chemical composition;
- Chemical properties (e.g. density, solubility, adsorption capacity, etc.) of sediment/rock and contaminants and assumed transport path.

If an emission from a point-source of contamination is assumed/proven, the monitoring network should encompass monitoring stations for

- Monitoring of natural background levels;
- Monitoring of emissions (early-warning system);
- Monitoring of spatial distribution (transport path and velocity of movement in horizontal and vertical direction);
- Monitoring of water supply wells (immediately upstream of the well: late-warning system).

3 Requirements to Laboratory Analyses

Often regulations require that the samples be taken by trained and accredited staff of the laboratory which is in charge of the analyses. Regulations of analytic quality control have considerably increased over the past two decades. In most European countries it is required that laboratories obtain accreditation by an acknowledged institute (mostly institutes for standardization and norms) and regularly participate in round-robin tests. Only then they may be awarded public contracts.

It is recommendable to use only accredited water laboratories for sample analysis since these laboratories underlie strict controls of the supervising bodies. Guidance for the operation of water quality laboratories may be obtained from UNECE (2002), EPA (2001), FAO (1998), ISO 17025 (2000), and WILDE et al. (1998).

During sampling campaign blank samples should be taken to test the laboratory's capability, the appropriate choice of the container and its cleanliness.

The design of a monitoring program has to specify the analytic demands, i.e. the targeted parameters, the analytical accuracy, the detection limits, and the sampling procedures. The responsibilities have to be clear. Mostly the water samples are taken by the staff of the agency that is responsible for monitoring, whereas the analysis is carried out by staff of the laboratory. In such a case it has to be provided that the responsible staff applies the appropriate methods for sampling and analysis. The schedule and procedure for sampling, treatment, storage and analysis of water samples has to be coordinated with the laboratory. If analyses are conducted by different laboratories it has to be ensured that the same analytical procedures are applied so that the results are comparable.

For the selection of parameters the following criteria should be used:

- Relevance: does the parameter reflect the monitoring objective ?
- Validity: does the parameter respond to changes in the environment ?
- Diagnostic value: does the total amount or the amount of change significantly reflect changes in the environment ?
- Responsiveness: does the measurement enable decision makers to react to a detected contamination early enough to be able to respond to it ?
- Reliability: the procedures for monitoring and hydrochemical analysis must be suitable to obtain reliable results;
- Appropriateness: is the measurement appropriate (does the parameter occur at this specific site and depth at this specific time period) ?

When preparing a parameter list, it has to be taken into consideration that many substances underlie a number of physical and chemical processes which may alter the original substance, such as natural parameters influencing the solubility and chemical reactivity (temperature, pressure, etc.), dispersion/diffusion, chemical complexation, sorption and precipitation, degradation (chemical/biological/radiological transformation, hydrolysis, etc.).

Therefore, especially during monitoring of contaminants, the specific behaviour of the expected individual chemical substances in the underground has to be evaluated. Contaminants can be transformed by geochemical, radiological, and microbiological processes as they are transported through various environments within the groundwater system. Some chemical transformations can change harmful contaminants into less harmful chemical species, while other processes can produce compounds that are more harmful to ecosystems or human health than the parent compound. The natural decay of some radionuclides can produce daughter products with different transport properties and health effects than the parent product. In some cases, transformation products are found in the environment more often than parent compounds. For example, groundwater remediation programs are increasingly focused on natural attenuation processes controlled by mixing, advection, and biodegradation as these processes serve to decrease concentrations and/or viability of contaminants. Similarly, some chemical transformations can change relatively immobile compounds into highly mobile compounds, and change parent compounds to transformation products. Knowledge of the path and timing of groundwater movement as well as the chemistry and biology relevant for the contaminant present is important in determining the fate and transport of a contaminant and its associated transformation products. This is important for contaminants that rapidly change to other chemicals in the environment particularly when transformation or daughter products are more persistent than the parent compound. In addition, the vulnerability of a groundwater supply facility to many contaminants is dependent on the solubility and subsequent mobility of the contaminant as influenced by the specific mineralogy and associated geochemical conditions within the aquifer and pumped well. The chemical properties of a contaminant are important in the unsaturated zone as well as the aquifer itself. For example, some (hydrophobic) compounds strongly attach to soils in the unsaturated zone (as well as the saturated zone) before reaching the water table, and these compounds are attached until released by geochemical or other changes such as when the binding capacity of the soil is exceeded.

Some examples for contaminants that are possibly associated with certain activities are documented in *Annexes B-6 and B-7*. From these substances the hydrogeologists and the hydrochemists have to develop the list of parameters taking into consideration the possible by-products which may occur.

When the parameter list is established a number of other parameters have to be determined:

- Parameter;
- Minimum likely level of interest (= lowest concentration considered likely to be encountered);
- Principal level of interest (= range of concentration that is anticipated to be encountered in most monitoring wells);
- Limit of detection (= mostly one third of the minimum level of interest);
- Tolerance indices (= largest allowable analytical error).

Based on this matrix the analytical methods may be selected.

Analysis inaccuracies are acceptable up to a certain limit. Normally the accuracy of an analysis result is controlled by the ion balance, where the sums of anions should equal the sum of ions. For low mineralized waters a difference in this balance of up to 5% is acceptable (up to 2 meq/l), for higher mineralized water (above 2 meq/l) it should be less than 2% (DVWK 1992). The ion balance error is determined by the following equation :

$$\text{ion balance error [\%]} = \frac{\Sigma \text{ cations [meq/l]} - \Sigma \text{ anions [meq/l]}}{\Sigma \text{ cations [meq/l]} + \Sigma \text{ anions [meq/l]}} \cdot 2 \cdot 100$$

Laboratory reports should clearly state the used analytical methods and the detection limits.

The lists of parameters to be analyzed and the monitoring frequencies should be reviewed at fixed intervals in order to determine whether monitoring of the parameters at present monitoring frequencies is still relevant and necessary. This way overall costs may be reduced significantly.

4 Installation of a Groundwater Quality Monitoring Network

In many countries of the Arab region it is common to use abandoned groundwater abstraction wells for groundwater quality monitoring. Usually theses wells were abandoned for some specific reason, mainly due to poor yield. Since such wells are mostly not representative for the natural conditions in the aquifer, it is strictly advised not to use such wells for groundwater quality monitoring. Even with extensive rehabilitation measures it is mostly difficult to obtain/regain near to natural conditions. Moreover, the monitoring of some parameters may not be possible, if drilling or design methods have been used which are incompatible with the monitoring purpose.

Networks for monitoring of global groundwater quality aspects in particular aquifers or catchment areas require different site selection criteria than the monitoring of a contaminated aquifer or of the remediation success.

Concerning the site selection of global groundwater quality networks, the monitoring stations should be spaced more or less evenly over the entire aquifer in horizontal as well as in vertical direction. Monitoring should, however, focus on those areas intensively exploited or where individual landuses occur that may cause contamination, such as agriculture, industrial sites, waste disposal sites, wastewater collection and treatment facilities, etc. In order to protect exploitation wells from becoming polluted, upgradient control wells have to be erected in the area immediately upstream of the exploitation wells.

The monitoring of contaminated aquifers or potential contaminations has to focus on the detection of the possible spreading of contaminant plumes. The direction and velocity of spreading depends on the flow regime (unsaturated/saturated zone), the aquifer type, the sediment or rock type and the properties of the contaminants (compare MARGANE 2003a).

Recordkeeping is of utmost importance in groundwater monitoring. All processes during the installation and operation of the monitoring sites must be appropriately documented.

4.1 Selection of Monitoring Sites

The selection of monitoring sites first and foremost depends on the monitoring purpose.

Groundwater quality may be monitored at springs, wells or shafts. Monitoring of springs has the advantage that the sample integrates the groundwater quality within a larger area, the catchment area of the spring.

Factors that play a major role in the selection process are: costs, suitability for overall objective (detection of pollution, overall groundwater quality, etc.), representative-ness, ease of access (roads, tracks), ease of transport (maximum transport duration before analysis), availability of or possibility to purchase or rent land.

The representativeness of a monitoring site mainly depends on the hydrodynamic flow regime in the regarded groundwater system. This in turn depends on the topography, the hydraulic properties of the geological units, the homogeneity/ heterogeneity of the geological units, the geological structure (tops and bottoms of geological units, tectonics), the groundwater recharge process, the interrelation and connection with other aquifers, the different components of groundwater flow (inflow, outflow) and their variability in time and space, etc.

In general, the seasonal variability of groundwater composition decreases with depth. Furthermore, the lower the hydraulic conductivity, the lower are the flow velocities. In groundwater recharge areas groundwater flow is generally directed downwards, whereas in groundwater discharge areas groundwater flow is directed upwards. Monitoring in the groundwater recharge zone may be suitable for the determination of the natural, uninfluenced background levels of hydrochemical constituents, whereas global groundwater quality monitoring often focuses on the groundwater discharge zones.

Concerning the installation of early-warning monitoring stations in the upstream area of water supply wells, DVGW (2003) proposes the placement of such wells at a distance of:

$$\text{distance} = (\text{early-warning time} + \text{sampling interval}) \bullet \text{flow velocity}$$

where

distance : distance of monitoring station from water supply well

DVGW (2003) considers an early warning time of 1 to 3 years as appropriate.

Some proposals for the selection of monitoring sites in standard hydrogeological conditions are given in NIELSEN (1991).

When selecting a well site, the following needs to be considered:

- For wells monitoring the general groundwater quality:

  Does this site reflect the average composition of groundwater quality within the aquifer (no sites should be selected where permeability is lower than on average, where components could be preferably released or adsorbed due to differences in the lithological composition) ?

- For wells monitoring the contamination risk:

  Does this site detect the highest possible content in the specific pollutant ?

  How has the plume of contamination advanced in time and space (taking into consideration separation of phases, degradation of substances, adsorption, lithological heterogeneities, etc.) ?

The proposed monitoring zoning system for contaminated sites in Lower Saxony, Germany, is depicted in *Figures 9 and 10* of *Part A* of this report. The terminology for monitoring well locations used in the USA is shown in *Figure 16*.

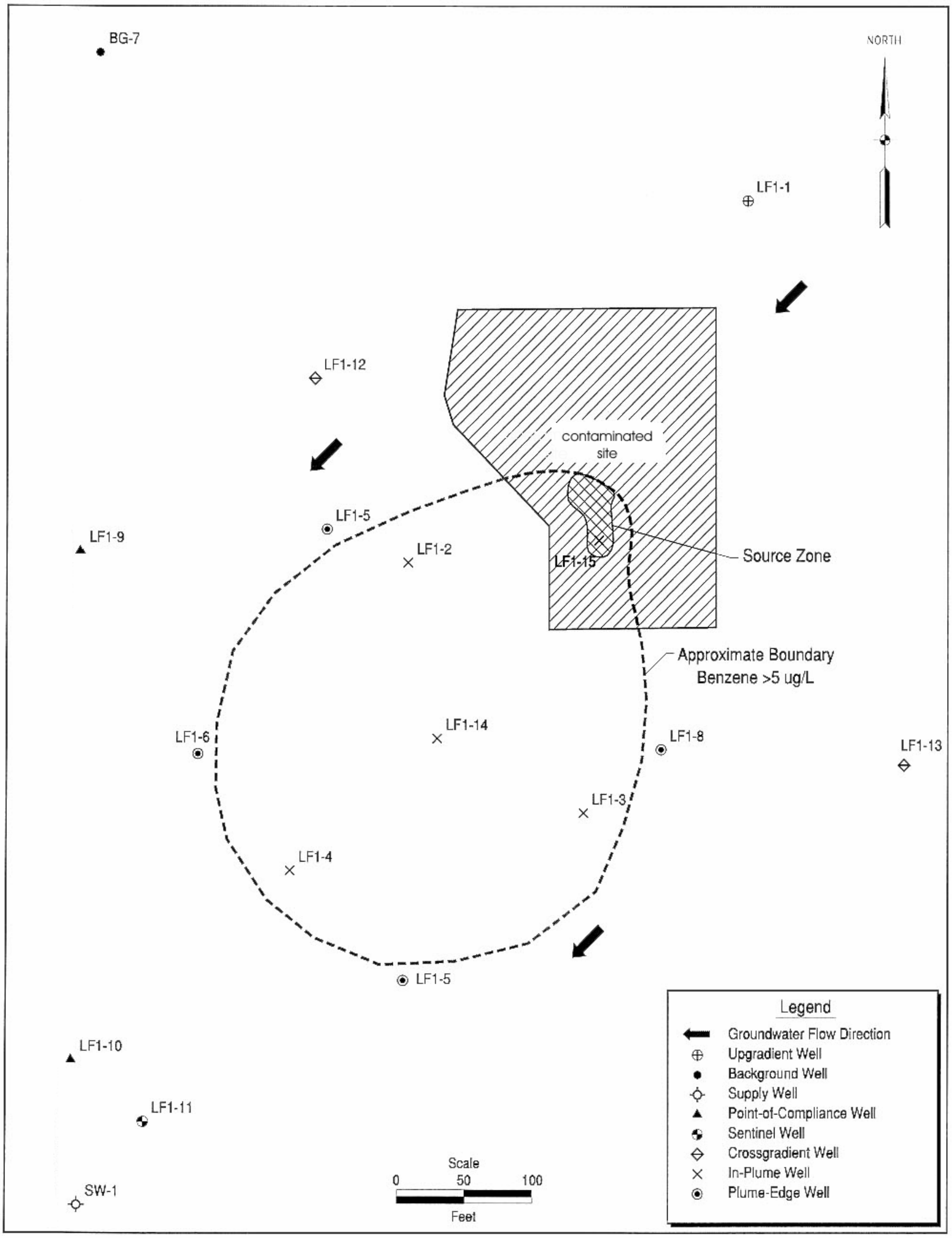


Figure 16: Idealized Monitoring Well Network, Terminology of Monitoring Well Locations in Relation to the Contaminant Plume (from NFESC 2000)

The behavior of a contaminant in the subsurface depends on its solubility/miscibility and density. The rate of movement is affected by physico-chemical and biological processes, such as retardation, hydrolysis/precipitation, sorption, cation exchange, dispersion (mechanical mixing and molecular diffusion), biochemical transformation, complexation, volatilization, etc. Seasonal alterations of the groundwater flow may affect lateral movement of a contaminant more than dispersion. The direction of movement strongly depends on the contaminant density. In general it is observed that where the density of the contaminant approximates that of water, it moves in the same direction and with the same velocity as water. Miscible contaminants of high density (DNAPLs) sink through the aquifer and accumulate at its bottom. The migration of such a contaminant then follows gravity and is solely determined by the topography at the bottom of the aquifer. If the contaminant is partly soluble, the plume of the dissolved fraction will develop around the undissolved fraction. The dissolved fraction, however, will move with groundwater flow (*Figure 17*). Contaminants of low density (LNAPLs) will accumulate at the top of the water table. The undissolved and the dissolved fraction will in this case move in the same direction but with different velocities (*Figure 18*). Residual amounts of the fluids may be retained in the vadose zone or in pore spaces in the aquifer. Volatile gas phase may develop in the unsaturated zone or in topographic highs at the top of confined aquifers.

Where monitoring of LNAPLs (such as e.g. hydrocarbons or fuels) or DNAPLs (such as e.g. chlorinated hydrocarbons) is involved, monitoring should focus in the case of LNAPLs (*Figure 18*) on the zone near to the aquifer top (confined) or water table/capillary zone interface (unconfined) or in the case of DNAPLs (*Figure 17*) on the zone near the bottom of the aquifer. It must be taken into consideration that DNAPLs follow, driven by gravity movement, the direction of the incline of the aquifer bottom and not the direction of groundwater flow and may be accumulated or trapped in structural depressions. The movement of DNAPLS may be deflected by low hydraulic conductivity lenses. LNAPLs may also be trapped at the bottom of aquitards by faults or domes. Migration of LNAPLs and DNAPLs or individual fractions thereof into deeper or higher aquifer horizons through geological windows or rocks may also be possible depending on the local geological conditions and the properties of the substance(s).

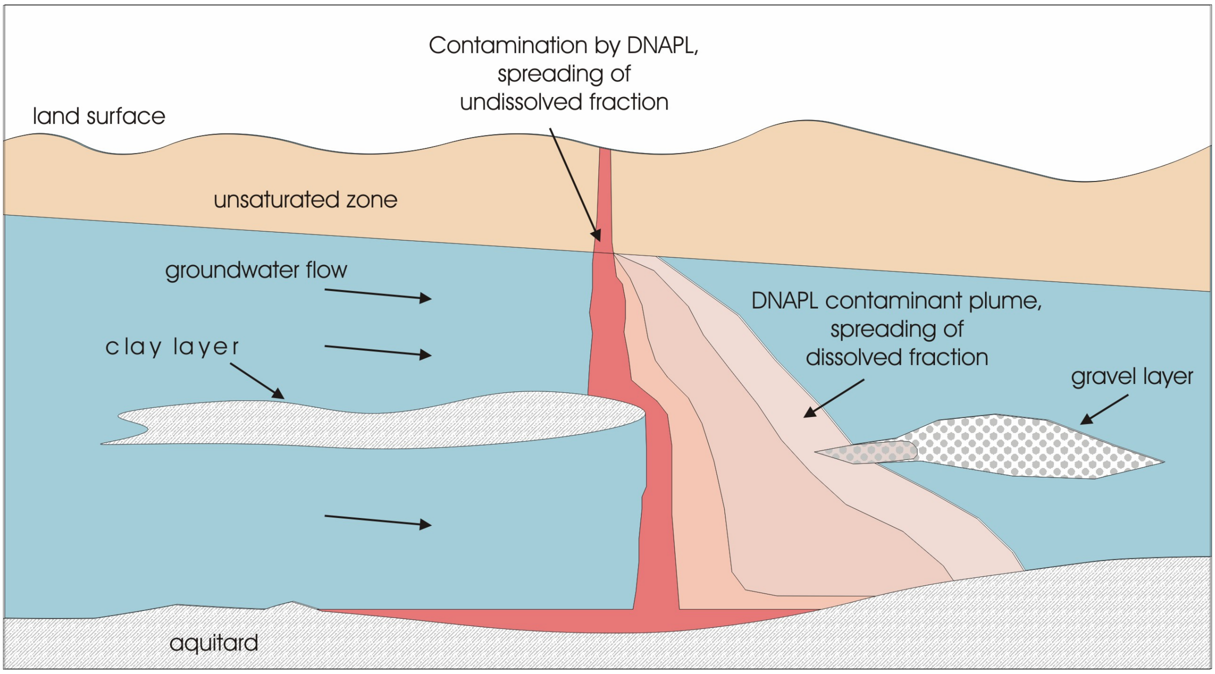


Figure 17: Migration of Contamination Plumes of miscible DNAPLs

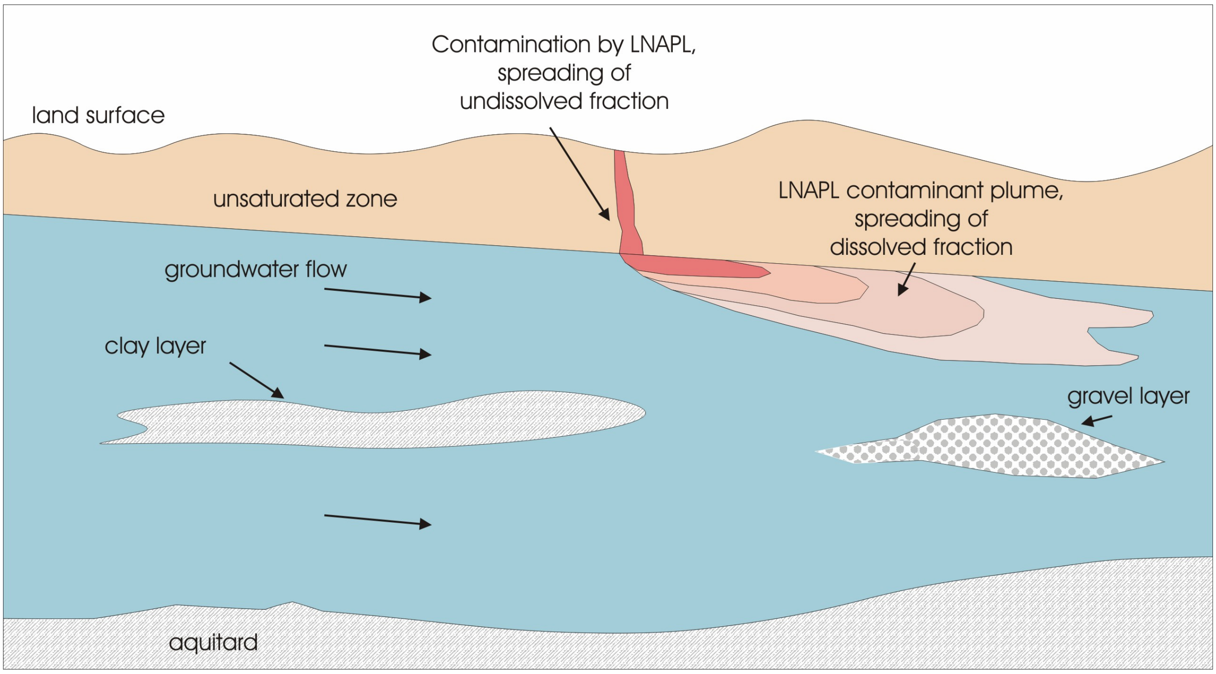


Figure 18: Migration of Contamination Plumes of miscible LNAPLs

Monitoring wells designed for the detection of such contaminants must take into consideration the densities, dispersion coefficients, aquifer configuration (top, bottom), hydraulic properties, lithological composition, and possible transfer processes of the contaminants. Monitoring of the dissolved, undissolved and volatile fractions has to be carried out at separate monitoring stations.

If contaminants have spread over an extended amount of time, e.g. at an industrial or military site, the investigation of the history of the site may be important. Certain chemical components may have been used only during certain time periods and at certain locations. Also the total amounts used may be important for the estimation of the estimation of the total amount of a contaminant which has leaked into the aquifer. Risk assessment procedures (compare MARGANE 2003a) for such sites commonly start with a historical evaluation.

For further details concerning the selection of the monitoring site compare also *chapter 3.1 of Part A* of this report.

The following types of groundwater monitoring wells are distinguished:

- Single boreholes which are fully screened;
- Single boreholes with multiple screens which are monitored using permanent or removable packers;
- Multi-level wells (cluster wells; multiple wells down to different depths near to one another);
- Single borehole multi-level wells (a single borehole suiting multiple wells which are screened at different depths and which must be hydraulically separated by suitable means);
- Multi-level wells (or monitoring ports) with direct burial (e.g. Waterloo/Solinst system);
- Direct wells (so-called monitoring pipes, rammed filters, driven wells, wellpoints, or direct-push system) which are mechanically driven in (for monitoring of shallow groundwaters; e.g. Eijkelkamp groundwater monitoring pipes; compare ASTM standards: D 6001-96, D 6724-01 and D 6725-01).

The density of monitoring networks differs considerably. According to LAWA (1999) the density of the state operated groundwater monitoring network in less populated areas varies between around 1 and 10 per 100 km², whereas higher populated areas obtain densities of more than 100 per 100 km². According to UNECE (2000) the density of groundwater level and quality monitoring networks in the EU is as follows:

Table 7: Density of Groundwater Monitoring Facilities in the EU

Country	Number of Groundwater Level Monitoring Wells per 100 km²	Number of Groundwater Quality Monitoring Wells per 100 km²
Sweden	0.11	0.04
Finland	0.02	0.02
Denmark	0.15	0.26
UK (England & Wales)		0.4
The Netherlands	10.7	1.07
Belgium (Flanders)	1.61	1.61
Germany (Bavaria)	1.0	0.47

Country	Number of Groundwater Level Monitoring Wells per 100 km²	Number of Groundwater Quality Monitoring Wells per 100 km²
Germany (New States)		0.33
Hungary	2.27	0.55
Spain	1.95	0.22

Well should be abandoned from monitoring networks if the following criteria are met:

- Monitoring results do not yield useful information;
- Monitoring well is damaged and rehabilitation is unlikely to yield improvement or is too costly;
- Monitoring well is temporarily or permanently dry;
- Monitoring well is not screened at appropriate level;
- Monitoring well possibly acts as a conduit for contamination.

Well abandonment procedures are documented e.g. in ASTM standard D 5299-99 and DVGW (1998).

Concerning the frequency of monitoring it is referred to *Part A*, *chapter 3.2* of this document. However, in groundwater quality monitoring, the frequency and overall duration of monitoring should be reviewed at fixed intervals in order to determine whether monitoring is still needed at the sites and to minimize costs. It is recommended to use optimization procedures similar to those proposed by NFESC (2000: 17-21).

4.2 Drilling and Installation of Monitoring Wells

The monitoring site must be safeguarded against damage and vandalism. If the well head is to be housed in an underground shaft, it must be ensured that the shaft is ventilated but can not be flooded. Preferable is the construction of a concrete building around the well head which is sufficiently protected. If the likelihood of damage is small, the well head may be protected only by a standard cap locked with a special key.

4.2.1 Well Drilling

The drilling method used depends on the types of sediments and rocks to be penetrated, the types of sediment/rock samples to be recovered, the total drilling depth and the type of casing to be installed (borehole stability). Most suitable are dry-coring drilling techniques which facilitate the accurate description of the lithological composition of sediments and rocks. Coring is, however, rather expensive and therefore rarely applied in the Arab region.

Concerning the suitability of individual drilling methods refer to *Part A, chapter 3* of this report.

In groundwater quality monitoring wells, no drilling methods or drilling fluids should be used that alter the natural chemical composition of the water or block natural groundwater flow. Drilling fluid additives such as clay additives, mineral/chemical additives, polymers, foam or others may considerably change the natural hydrochemical environment.

The drilling diameter must be large enough to install suitable seals, filter packs and casings. The annular space should be at least 8 cm (3 inches) wide so that seals and filter packs function properly. The casing diameter must be suitable to accommodate the well development, pumptesting, geophysical testing, purging, sampling, logging, rehabilitation and cleaning devices, avoiding that these devices become stuck in the borehole at places where the casing is not aligned sufficiently large and straight. For shallow boreholes up to 50 m deep, the inner casing diameter must be at least 2 inches. For greater depths commonly larger diameters of 4 to 6 inches are used since often pumps of larger diameter have to be used. However, the drilling diameter should not be much larger than necessary, since the stagnant water in the well has to be purged prior to collecting a water sample. The larger the borehole diameter, the larger is the volume of water that needs to be purged. Most commonly used water sampling devices fit into 2-inch casings. Since geophysical measurements are mostly required to be conducted in monitoring wells in order to accurately determine the lithological composition of the sediments or rocks, the tops and bottoms of lithological units and the tightness of the casing, the diameter has to be adapted to fit such equipment into the borehole and/or casing. Modern devices are also designed to fit into 2 inch boreholes.

It must be ensured that the borehole is drilled to the target horizon. Especially when drilling deep boreholes in inclined strata or strata of varying hardness a plumb and straight alignment of the borehole is difficult. This has to be controlled during and after drilling by geophysical methods (dip meter/inclinometer).

Borehole geophysical logs are a basic requirement for monitoring wells, in order to improve the lithological description, to determine the proper interval(s) for screen installation, and to control the correct drilling of the well and installation of casing and screens. There is a vast number of methods for this purpose (for details refer e.g. to ASTM standard D 5753-95 or other standard references).

A proper well completion report must be made available documenting all important data of the well, such as location name and description, coordinates, elevations, well drilling data (drilling methods, drilling fluids), well design data (drilling diameters, materials and depths of casings/screens; materials, depths and compositions of backfills/grouts/seals/gravel packs), drilling/fitting/pumptesting/sampling/logging dates with names of responsible persons, formation depths, lithological descriptions, water levels, pumping test data, etc.

More details with all advantages and disadvantages of the individual drilling methods are documented in ASTM standard D 6286 (1998).

For water well rehabilitation and maintenance it is referred to the standard literature, such as: DRISCOLL (1989), MANSUY (1999), and SMITH (1995).

4.2.2 Well Design

Appropriate well design diagrams have to be prepared for each individual monitoring well before the start of the drilling program. In may however become necessary to deviate from the projected design if the drilling reveals differences to the actual lithological composition of the aquifer.

Monitoring wells up to 50 m deep should be equipped with a casing with a minimum diameter of 65 mm, those deeper than 50 m of 100-125 mm (LUCKNER & NITSCHE, 1999). The main criterion is the fitting of the pumping and sampling equipment but also the minimization of the amount of water needed to be purged before sampling and the stability of the borehole.

The well screens should be positioned in such a way that an exchange of waters across aquifers or aquifer horizons may not occur. The mixing of water in an aquifer is often neglected even though vertical differences in the water composition may be considerable, especially when the vertical permeability is much lower than the horizontal. Therefore it is mostly better to monitor only a specific horizon in an aquifer and test the other(s) by separate monitoring wells. Testing of separate horizons in an aquifer by the use of packers has proven to be difficult in many cases. One reason is that annular sealants between aquifer horizons may not be completely functional. The other reason is that leakages through the casing (if only a single packer is used) and lifting pipe may occur. It is therefore recommended to drill separate monitoring wells at one station down to different depths.

Well casings and well screens materials should be inert to the water and contaminants being tested. The screen slot and filter pack design should enable maximum retention of filter pack material and of natural formation material as well as minimize plugging of filter pack or slots. The design should enable rapid sample recovery but also permit effective well development and rehabilitation. The strength, rigidity and durability of the casing and filter material must be high enough so that the well does not collapse within the projected life time of the well.

A number of different materials are used for casings and screens having different characteristics concerning the inertness, strength, durability, ease of handling and cost. The best suitable material has to be selected for each individual purpose.

The following material is presently most commonly being used:

- Low carbon steel;
- Galvanized steel;
- Coated steel (e.g. HAGULIT – 0.3 to 0.5 mm epoxy coated, *www.gwe-group.com*)
- Stainless steel;
- Polyvinylchloride (PVC);
- High-Density Polyethylene (HDPE);
- Acrylonitrile butadiene styrene (ABS);
- Fluorinated ethylene propylene (FEP);
- Fiberglass reinforced epoxy (FRE);

- Polypropylene and fiberglass reinforced plastic (FRP);
- Fluoropolymers or polytetrafluoroethylen (PTFE, such as e.g. Teflon).

Most commonly rigid PVC thermoplastic casings and screens are used in groundwater investigations. Their main advantage is their durability and resistance to corrosion, their light weight (ease of handling and installation as well as low shipping costs), their ease of workability (cutting, joining), and their low costs. The brittleness of this material may cause problems during installation. Thermoplastics are susceptible to physical degradation by certain organic solvents in high concentration (solvation caused by: certain ketones, aldehydes, amines, and chlorinated alkenes and alkanes; EPA 1991). Some additives used in the production of thermoplastics, such as plasticizers, stabilizers, fillers, pigments, and lubricants, as well as the basic monomers may cause chemical interference with certain parameters to be analyzed in monitoring wells.

PVC-U and similar materials, such as SBF-NORIP (*www.gwe-group.com*), are the most commonly used materials in groundwater monitoring in Germany, due to their high rigidity/stability, suitability for most hydrochemical parameters and low costs. They are recommendable for monitoring installations down to approx. 600 m (DN 65 under artesian conditions; other aquifer types: max. 400 m; DN 115: 185 m/110 m); *www.gwe-group.com*). Most commonly 65 mm or 115 mm casings and screens are used, which are suitable for most modern well purging and sampling pumps. They are available in standard lengths of up to 6 m (the longer the pipes, the lower the total price and the fewer connections are needed, resulting in lower risks of leakage). Commonly dual-sided couplings with two o-rings are used to connect such pipes.

HDPE casings and screens have a limited stability and may be used down to depths of less than around 60 m. HDPE is especially recommendable when conducting monitoring of highly contaminated waters, such as e.g. on waste disposal sites.

PTFE casings and screens have a number of potential advantages, such as their high temperature resistance (- 240 to + 260°C), very low friction coefficient, and almost complete chemical inertness. It is, however, more than 10 times more expensive than PVC, difficult to handle (heavier, less rigid than other thermoplastics), and compressive stresses may lead to failures at joints and intakes (EPA 1991). It is therefore recommendable only to depths of less than around 100 m.

Steel casings have some general advantages over thermoplastics, fluoropolymers, and fiberglass-reinforced epoxy materials, being less temperature sensitive and more rigid. Due to its strength and rigidity, metal casings and screens are suitable for almost all depths and rock types. They are, however, - even stainless steel casings – subject to corrosion. Installation in corrosive waters should therefore be avoided. The following indicators may be used to identify potentially corrosive conditions in groundwater (DRISCOLL 1989): low pH, high dissolved oxygen content (> 2 mg/l), presence of H_2S (> 1mg/l), high CO_2 contents (exceeding 50 mg/l), and high chloride contents (exceeding 500 mg/l).

Commonly stainless steel types 304 or 316 are used in groundwater monitoring. Whereas stainless steel 304 consists of around 72 % iron, 18% chromium, > 8% nickel, and < 0.08 % carbon, stainless steel 316 is composed of < 68 % iron, 18%

chromium, > 10 % nickel, 2-3 % molybdenum, and < 0.08 % carbon. Stainless steel 316 has therefore a higher resistance to reducing environments, such as indicated by the presence of sulfur species and sulfuric acids in the water.

Stainless steel or even better and less costly: epoxy coated steel, such as HAGULIT (*Figure 19;* ND 100 – ND 800; maximum length of casing pipes: 5m; maximum length of prepacked screens: 3 m; *www.gwe-group.com*), may be installed if higher strength (compressive strength, tensile strength and collapse strength) or higher resistance to specific contaminants or temperature is required. Such coated steel casings and screens are temperature resistant to + 50°C, highly inert to hydrochemical components, easy to install, resistant to bacteriological attacks, and, if using e.g. the HAGUESTA or HAGUDOSTA spline connections (*Figure 19*), excellently tight. Coated steel casings and screens are in use in Germany since more than 25 years with good experience. Such material is recommended for all monitoring wells deeper than approx. 250 m.

EPA (1991) gives a good overview on materials used in well design and their characteristics.

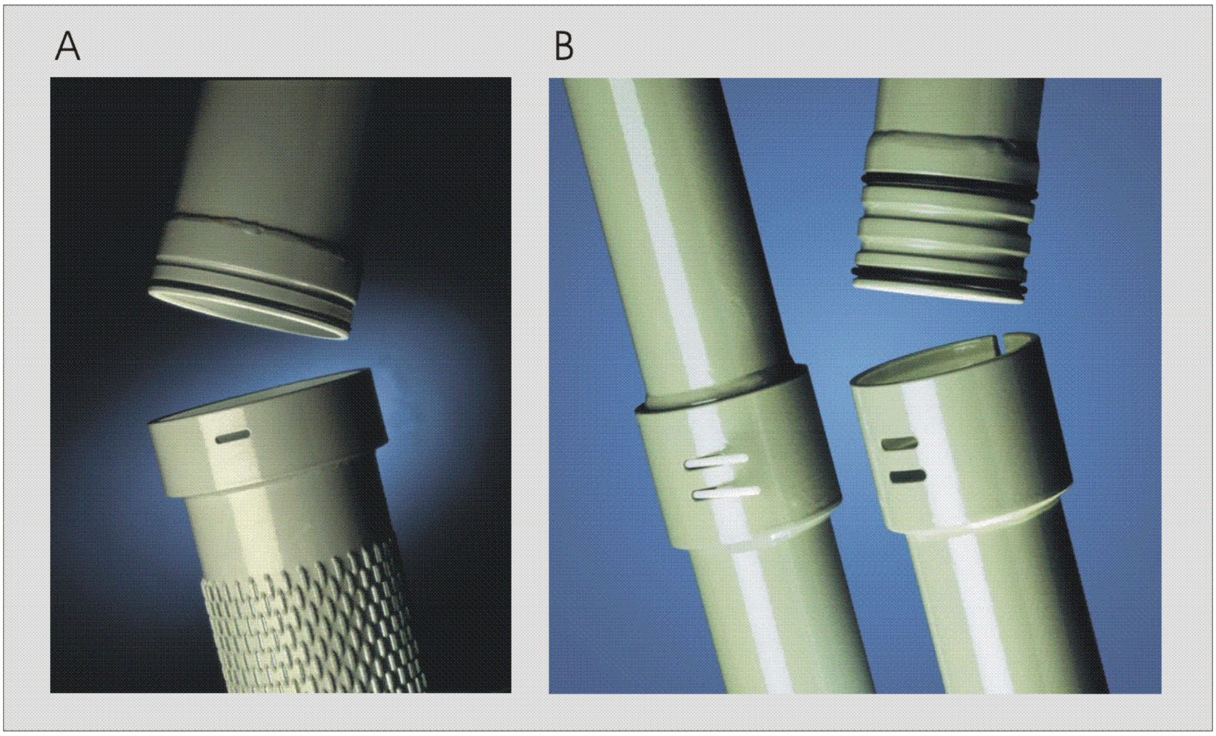


Figure 19: Epoxy-Coated Steel (HAGULIT) Casings and Filters (A) and Riser Pipes (B) with Spline Connections (Courtesy GWE Group)

All <u>couplings between casing and screen elements</u> need to be closed tightly in order not to allow water to enter the casing at any place other than the screens. Glued or solvent welded joints are not recommended. No fluids should be used for these joints which may alter the hydrochemical composition of the water. For such connections o-rings of materials that may not impact on the water sample may be used. It has to be provided that corrosion does not occur at these connections (or elsewhere).

The filter packs need to be put in place in such a way that there is no segregation of materials and that the projected top and bottom depths are maintained. At greater depths the use of prepacked filters is recommended, because only this way it is sufficiently ensured that the filter pack is properly located. The used filter pack material must be bacteriologically safe and during installation any bacteriological or other contamination must be avoided.

Top and bottom formation seals must be properly installed in order to avoid water reaching the casing through leaking annular sealants. Centralizers must be installed at proper distances so that the proper functioning of seals and gravel packs is guaranteed.

If an aquifer is to be monitored which is overlain by another aquifer, the annular space between borehole and casing needs to be sealed of completely from the base of the separating low permeable unit to the land surface. It must be tested that no leaks from the upper aquifer into the casing occur. During drilling, a contamination of the lower aquifer by the upper or vice versa has to be avoided. It is recommended to drill with large enough diameters down to the separating aquitard, cement the casing, and continue drilling with a smaller diameter in the lower aquifer. The cement must be of such a composition that no leaks into the upper part of the casing could occur.

To prevent the material used for sealing or cementing from entering the filter pack, a counter sand pack of at least 1 m length should be installed below and above the filter pack.

The well head must be designed ensuring that no surface water or runoff can enter the casing. If damage or vandalism poses a risk, the well head must be appropriately protected, either by placing it in a drained shaft, in a locked building or otherwise. Any kind of organism must be prevented from entering the casing (e.g. algae, bacteria, snails, worms, and insects).

A design diagram of a typical groundwater monitoring well is shown in *Figure 20*:

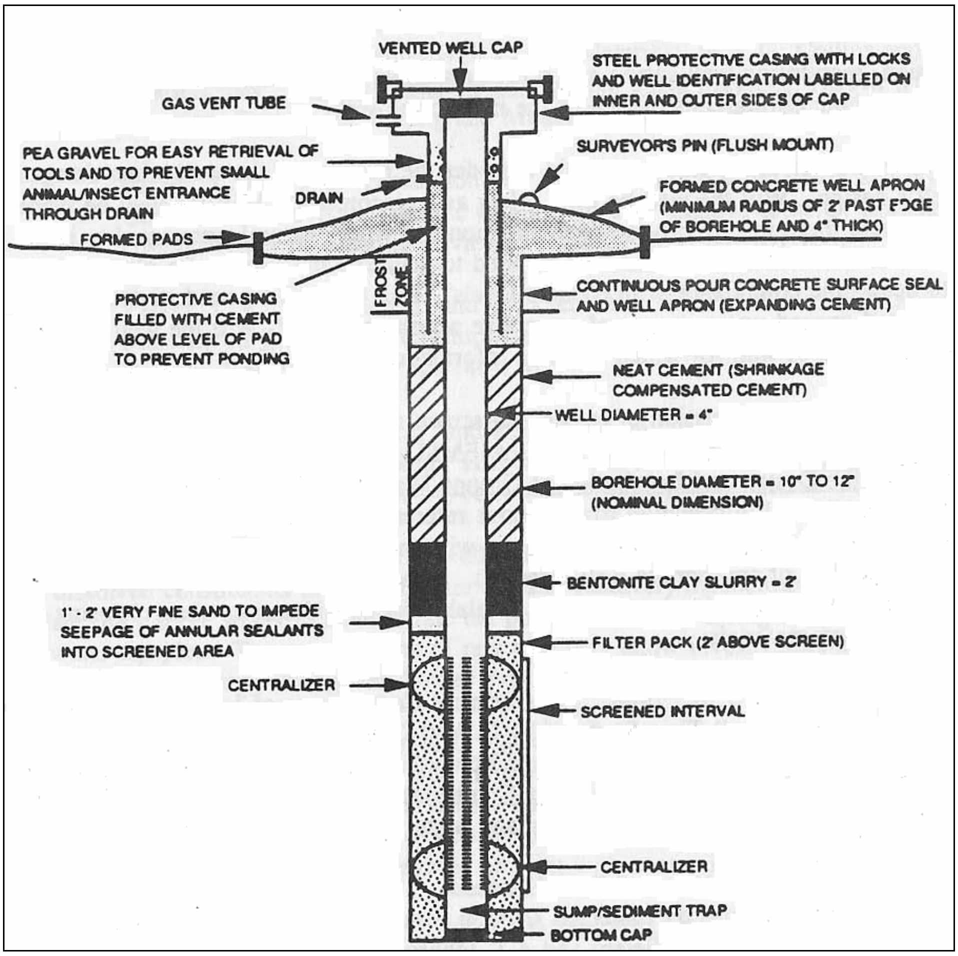


Figure 20: Design Diagram of a Typical Groundwater Monitoring Well (from EPA 1994)

Further details are documented in ASTM standard D 5092 (ASTM 2002).

4.2.3 Well Development

In general, well development can be regarded as one of the most crucial elements of well installation. It should be conducted thoroughly and immediately after well completion.

For groundwater exploitation wells, the purpose of well development is usually to maximize the yield of a well. With regard to groundwater quality monitoring, however, wells must be developed to ensure the proper (re)establishment of a hydraulic regime that is as close as possible to the natural one. A too aggressive development method (e.g. air jetting, etc.), should be avoided because it may cause deformations of the filter pack or unwanted leaks through seals or leaky joints. The general aim of well development is to test the functionality of the monitoring well. If possible, geophysical logs should be conducted after well development to test the integrity and tightness of the casing and to remove the finer grained material from casing and filter.

Well development should be conducted until all constituents introduced during the drilling and installation procedure are removed and the composition of the water becomes representative for the natural conditions in the aquifer. For this purpose some critical parameters, which may be used as indicators for the natural condition, have to be continuously recorded. Upon reaching parameter constancy for those parameters well development may be terminated (compare chapter 5.3.1: well purging).

A number of factors have to be considered for the selection of the appropriate development method, such as:

- The drilling method;
- The depth of the static water level;
- The pump setting (length of water column);
- The hydraulic properties of the aquifer;
- The lithological composition of the aquifer;
- The construction characteristics of the well (especially the material used);
- The constituents introduced into the well and aquifer during drilling and installation.

The well development equipment itself needs to be decontaminated and free of any substances which may impact on the water quality or the constituents to be analyzed, in order to avoid or minimize the effects of bacteriological or other contaminations.

Generally the following methods are used:

- Mechanical surging;
- Over-pumping and backwashing;
- Air lift pumping;
- High-velocity hydraulic jetting;
- High-velocity hydraulic jetting combined with simultaneous pumping.

A well development report has to be completed after termination of development. More details are documented in ASTM standard D 5521 (1994).

4.2.4 Geophysical Borehole Logging

Geophysical borehole logging should be conducted in all groundwater monitoring wells to:

- Obtain more reliable information on or check existing information (cuttings) on the lithological composition and vertical boundaries of geological units;

- Detect zones where the passage of certain equipment may be obstructed;
- Check the tightness of casings and detect the location of leaks;
- Control the existence, homogeneity and position of annular space fills, such as grouts, sealants, filter packs, etc.;
- Check the (hydraulic) functionality of a monitoring well;
- Check the verticality of a borehole.

Over the past decade, special geophysical logging equipment was developed to suit the requirements of groundwater monitoring. This pertains to the development of new methods as well as to the development of special equipment suitable for logging of small boreholes.

A good overview and examples on geophysical borehole logging methods for groundwater investigations are given in:

- DRISCOLL (1989);
- KEYS (1989);
- BAUMANN et al. (2003).

5 Operational Aspects of a Groundwater Quality Monitoring Network

5.1 Factors Affecting Groundwater Sampling Results

Besides the drilling method, the well design, and the well development, a number of other factors influence the results of groundwater quality sampling.

Groundwater samples have to be representative for their individual objective. In some cases it may be required to take representative samples from the entire aquifer, in others certain depths may be of special interest. It is important to adjust the drilling method, the installation design, the type of casing, the purging method, and the sampling method to this specific objective.

The representativeness is influenced by the character of groundwater and contaminant movement, and thus the lithological composition and heterogeneity, as well as the type of movement: advective and/or dispersive transport, the aquifer type(s) and hydraulic interrelations, the hydraulic properties, etc.

5.1.1 Materials used for Drilling, Well Design, Well Development, Well Purging, Sampling and Containment

The selection of appropriate materials for well design and sampling (pumps, sampling devices, tubes, connections, filters, etc.) is crucial for obtaining hydrochemical analysis results that are not influenced or changed due to the properties of those materials.

The following chemical reactions may take place (LfUG, 2003):

- Sorption of water constituents by the material;
- Desorption of water constituents from the material;
- Carry-over of water constituents to the next samples;
- Dissolution of material constituents to the water sample;
- Diffusion of gaseous compounds through the material, especially through tubes or connections;
- Corrosion;
- Contamination of the sample by chemical substances (oils, coolants, etc.);
- Growth of microorganisms, especially in tubes.

Sorption depends on the hydrophilic respectively lipophilic character of a water constituent. The higher the lipophilic character, the higher the tendency to sorption. For plastics the following ranking for sorption tendency has been observed:

Teflon < PVC soft < PE hard < PE soft < Silicon < PVC soft < Caoutchouc

For this reason, most plastic materials are unsuitable for sampling of organic compounds, except PTFE and in part HDPE.

Desorption from material components of soft PVC and silicon has been observed where volatile chlorinated hydrocarbons are present in the water.

Additives in plastic materials, such as plasticizers (e.g. phtalic acid ester), stabilizers, pigments containing metallic compounds, slip additives, filler materials, or anti-staticizers, may be transferred into the water sample. For tracer tests with fluorescent tracers, many tube materials are inappropriate for sampling because of their contents in fluorescents.

Gas diffusion through tubes can either lead to gases leaking out of or into the tube. Oxygen leaking into the tube can change the redox potential as well as parameters that may be oxidized, such as iron, manganese, nitrogen compounds, etc.

Tubes with high contents in plasticizers, such as soft PVC, facilitate the growth of algae and other microorganisms. It is recommended to clean and dry such material thoroughly. Rubber/caoutchouc, silicon or soft PVC is generally not suitable for tubes. It is recommended to use PTFE instead.

For the detection of boron, borate, sodium, potassium, fluoride and silicate, glass bottles should not be used since they contain traces of these elements which may be transferred into the water, react with the water, or adsorb elements contained in the water. The same counts for soda-lime glass which may increase silica or sodium contents.

Opaque containers or brown (non-actinic) glass can considerably reduce photolytic reactions and are therefore recommended for any constituents which may be affected by such reactions. If the material is unsuitable for sampling, containers should be kept in photoresistant boxes during transport and storage.

For containing the water samples, the general recommendation is to use glass bottles for determination of organic compounds and plastic bottles for inorganic compounds.

The use of disposable containers should be considered, especially when samples contain high concentrations of contaminants which may otherwise influence subsequent samples with low concentrations of the same component.

If new glassware is used, it should be rinsed with water containing a detergent, thereafter washing off the detergent with distilled water.

Flaks for determination of phosphate and boron should not be cleaned with detergents. Glass containers for determination of pesticides, herbicides and their residues should be cleaned with water and detergent, followed by thorough rinsing with distilled water. Thereafter they should be dried in an oven at 105°C for 2 h, cooled, then rinsed with the extraction solvent, and finally dried with purified air or nitrogen.

Containers used for microbiological examination must withstand sterilization temperature of 175°C for 1 h and not release any substances which would change the biological activity of the water. The same counts for the caps being used. Polycarbonate or heat-resistant polypropylene containers may be used when appropriate low-temperature sterilization is applied, such as steam sterilization.

Containers for microbiological analysis must be free of acidic, alkaline and toxic compounds. Glass containers have to be cleaned with water and detergent, then rinsed with distilled water, then rinsed with 10vol% nitric acid, and finally rinsed again with distilled water.

Since equipment made of stainless steel or Teflon is heavier and more costly, it has to be secured by an additional rope or wire against loss or becoming trapped in the casing, which in turn also needs to be made of material that does not have any negative influence on the water sample and needs to be cleaned every time after sampling.

The most adequate material for sampling devices used for the analysis of organic compounds is stainless steel with tubes and lifting pipe being made of PTFE, whereas for inorganic compounds Teflon is recommended.

Further detail concerning the suitability of materials for groundwater quality monitoring may be obtained from EPA (1985), EPA (1991), and DVWK (1990c).

5.2 Planning and Preparation

Prior to water sampling careful planning and preparation must be conducted. This encompasses:

- Preliminary description of the groundwater system with regards to groundwater flow and hydrochemistry (based on existing data);
- Selection of monitoring locations (locations, depths, number and spacing of sites);
- Determination of site specific well drilling and design data (drilling methods, position of screens, casing/screen/filter pack depths, diameters and materials, etc.);
- Determination of parameters to be analyzed;
- Determination of frequency of sampling;
- Determination of sizes (ml) and number of samples (commonly 2 or 3) for each site;
- Determination of sampling procedures (sampling devices, pumping/purging duration, sampling depths, position of pump, position of packers);
- Determination of on-site measurements (e.g. T, pH, redox, EC, O_2, etc.);
- Determination of sample containment methods (glass bottle, PVC-bottle, Teflon coated bottle, etc.)
- Determination of sample treatment methods (e.g. acidification), conservation (refrigerated/frozen), transport and storage (light protection);
- Sampling protocols;
- Field reports.

The technical preparation of a sampling campaign encompasses:

- Making available operational equipment for sample collection and on-site measurements (including calibration of instruments);
- Providing and preparing sampling bottles (name tags) and chemical substances;
- Preparation of sampling documents and field reports;
- Control of operational status and functionality of monitoring well;
- Conducting on-site measurements.

Water sampling campaigns must closely be coordinated with the laboratory in charge of carrying out the analyses. It must be consulted for the appropriate timing, the pretreatment procedures, the materials to be used for sampling, the protocol and data exchange, and the analysis methods with their respective levels of accuracy.

A time schedule should be prepared in advance of the field campaign. A checking list (*Annex B-1*) should be made, to make sure that all equipment is available, operational and calibrated.

Sampling protocols and labels need to be ready before the campaign. A typical example for a groundwater quality sampling protocol is enclosed as *Annex B-2*.

Groundwater quality sampling encompasses the following steps in the field:

- Inspection of the site;
- Recording the static water level;
- Determination of total depth of borehole;
- If necessary: dummy test, especially when conducting first measurement with this equipment at this site;
- Estimation of discharge amount and determination/preparation of point of discharge of purged water;
- Readying sampling equipment;
- Documentation of sampling layout;
- Well purging;
- Organoleptic examination (if required);
- Determination of discharge amount (using hydraulic or parameter constancy criterion);
- On-site measurements;
- Extraction of water sample(s);
- Treatment and conservation of water samples;
- Preparation of sampling protocol;

- Water level measurement of recovery phase;
- Demobilizing equipment;
- Transport of sample(s).

5.3 Sample Collection

5.3.1 Well Purging

For obtaining a representative water sample the stagnant water contained in the well itself has to be removed because the conditions in the well itself are different from those in the aquifer. The amount of water that has to be removed depends on the well diameter and the flow regime in the screened part of the aquifer. If the aquifer is heterogeneous, it has to be taken into consideration that water flowing from the higher permeable sections reaches the well earlier and in higher amounts than that from low permeable sections.

In case the assumed lowest pumping water level is less than 9 m below the well head, a centrifugal suction pump could be used which needs to be fitted with a foot valve at pumping depths exceeding 3 m. Water is commonly sucked through a textile-reinforced PVC tube, if compatible with the parameters to be analyzed. Suction pumps can have pumping rates of 1-2 l/s and are commonly operated by petrol-driven motors, so that the motor needs to be placed in such a way that exhaust fumes do not contaminate the sample.

Submersible pumps need to be used at depths exceeding 9 m. They can either be electrical pumps with vibrating pistons or motor pumps, both requiring the use of a generator. Submersible pumps with a vibrating piston have a maximum pumping lift of around 215 m (e.g. Grundfos MP-1: 95 m; Grundfos SQE-NE/SP-NE: 215 m). Its small largest outside diameter of only 45 mm makes it possible to fit the MP-1 pump into 2 inch casings (maximum outside diameter of SQE-NE: 74 mm; SP-NE: 131 mm). The MP-1 pump provides an output rate of up to 2.4 m^3/h and is suitable for temperatures of up to + 35°C. The Whale-Purger (*www.whale.ltd.uk*) pump may even be fitted into 1.5 inch casings but pumps only a maximum of 0.68 m^3/h from a maximum depth of 18 m.

Submersible motor pumps have a larger outside diameter of around 100 mm and are much heavier (> 18 kg). Usually they are fitted with a textile-reinforced PVC tube and an internal diameter of around 16 mm, which is strong enough to carry the pump and the cable. Other types of pumps, such as reciprocating pumps (maximum pumping lift: 50 m), water jet aspirators (maximum pumping lift: 30 m) or impulse pumps (maximum pumping lift: 50 m) may also be used (DVWK, 1985).

Packers may be used to take samples from individual screened horizons, provided that each of these horizons are separated by a sufficiently tight seal.

If possible, discharge should be possible to regulate by a valve (which is not possible when using suction pumps).

Throughout well purging no turbulent flow should occur. The pump should be positioned 1 m below the dynamic water level or 1 m below the top of the uppermost screen, respectively, in order to provide that no oxygen is introduced to the water sample. Drawdown of the water level should be between 1/10 and 1/3 of the water column in the well. The pumped water has of course to be disposed of in such a way that it does not return to the well.

The generator and any other fuel operated motors should be positioned in such a way that the exhaust fumes do not influence the water sample.

Sampling should commence after reaching:

- A certain hydraulic criterion or
- Parameter constancy.

Both criteria intend to ensure that the sample does not contain any water which was contained in the filter and casing before well purging, since this water may not represent the same conditions as in the aquifer.

The hydraulic criterion is met when x times the volume of the water column contained in the filter and casing is exchanged. Commonly a factor x > 1.5 is chosen (LfUG 2003; a factor of x > 2 is mentioned in LAWA 1999 and LfU 2001):

$$V = x * \pi/4 * d_{BL}^2 * l_F$$

Parameter constancy is determined by constantly measuring one or several of the standard parameters T, pH, and EC in a flowthrough-chamber, a closed glass bulb (e.g. Woulff’s cell), where water flows through a cell fitted with electrodes. A water sample is taken when the main (e.g. EC) or several of the on-site parameters remain constant. Often this is considered to be achieved if the following limits for parameter changes are not exceeded within a period of pumping 50 l of water volume :

- EC: ± 0.5%
- T: ± 0.1%
- pH: ± 0.1
- O_2: ± 0.1 mg/l

All equipment used for well purging must be cleaned and dried (and, if required, sterilized) thereafter. The type of cleaning to be applied depends on the material used.

Further guidance about the selection of purging and sampling devices is given in ASTM standard D 6634-01.

In the USA the low-flow purging method is frequently used (ASTM standard D 6771-02). Its objective is to remove a minimum amount of water from the screened interval without disturbing the stagnant water above the screen. Typically, flow rates in the order of 0.1 to 0.5 l/min are pumped. According to the ASTM standard, low-flow purging may be used to collect samples for all categories of aqueous-phase contaminants and naturally occurring analytes, including volatile and semi-volatile organic compounds (VOCs and SVOCs), metals and other inorganics, pesticides, PCBs, other organic compounds, radionuclides and microbiological constituents. It is not applicable to sampling of either light or dense non-aqueous phase liquids. ASTM standard D 6771-02 recommends to use a stabilization criterion of pH ± 0.2, EC ± 3%, dissolved oxygen content ± 0.2 mg/l or ± 10% (whichever is greater), or ORP ± 20 mV.

Also LAWA (1999a) recommends applying a pumping rate of between 0.1 and 0.5 l/min during purging.

5.3.2 Sampling Devices

Other than using the above-mentioned pumps, water may be extracted by bailers. Bailers are intended to be used for taking water samples from a specific depth. They may be simple, consisting of steel or plastic pipes being fitted with a valve at the bottom for letting water flow in and out when lowering the bailer and blocking through-flow at the bottom when lifting the bailer. The through-flow is, however, partly blocked by the bottom valve when lowering it, so that these types of bailers are not ideal for taking a representative water sample from a specific depth. Such bailers may have a diameter of less than 40 mm and lengths of 50 cm and more.

Another type of bailer is the Ruttner-bailer. It is made of Plexiglas and brass and has a diameter of 85 mm. When lowering the device it is flushed. When reaching a specific depth the cone valves at the top and bottom are shut using a drop weight. Similar types of bailers are available from several companies (e.g. SEBA: *www.seba.de*; EIJKELKAMP: *www.eijkelkamp.nl*, etc.).

Under certain circumstances devices for continuous monitoring of individual parameters may be installed in groundwater quality monitoring wells. This, however, is only recommendable if the screened part of the well is relatively short and the permanent exchange of water in the well casing is guaranteed by the relatively high hydraulic permeability of the screened part of the aquifer. Instruments, such as the SEBA MDS-D Multiparameter Sensor (SEBA: *www.seba.de*) can monitor up to seven parameters continuously in boreholes equipped with casings of at least 2 inch diameter (similar instruments are available from YSI: *www.ysi.com*; e.g. YSI's 6-series). Data may be read out using a notebook or a hand-held device at specified time intervals. Such devices are most commonly used for the detection of contamination plumes in the surrounding area of contamination sources, such as e.g. waste disposal sites or contaminated land or as early-warning systems in the upstream area of drinking water sources which are at risk.

5.3.3 Filtration

A 0.45 µm micro filter should be used to filter the water sample for fine particles contained in the water, such as suspended matter, sediment, algae and other microorganisms, before filling it into the collection bottle. Filtration could be achieved by filter papers, membrane filters or centrifugation. It is essential that the filter itself is not contaminated. Commonly single use filters are applied. If too costly, filters may be washed with a method that is compatible with the analysis parameters and analysis methods. Filters could be made of regenerated cellulose, PTFE, cellulose acetate, polyester, polycarbonate, nitrocellulose, or other material. The filter material should have no influence on the composition of the sample, and thus the material to be used for filtration depends on the hydrochemical components in the water and the parameters to be analyzed. Most commonly regenerated cellulose filters are used for water sample filtration. (CHROMAFIL/PORAFIL/NANOCOLR: *www.macherey-nagel.de/* or AQUATRON: *www.schleicher-schuell.de/*). Simple filters cost approx. 0.5 EUR/piece, whereas PTFE filters are rather expensive (approx. 2 EUR/piece).

Filters of 0.45 µm retain suspended solids and certain types of bacteria but smaller organisms such as viruses, proteins, and colloids may pass (*Figure 21*).

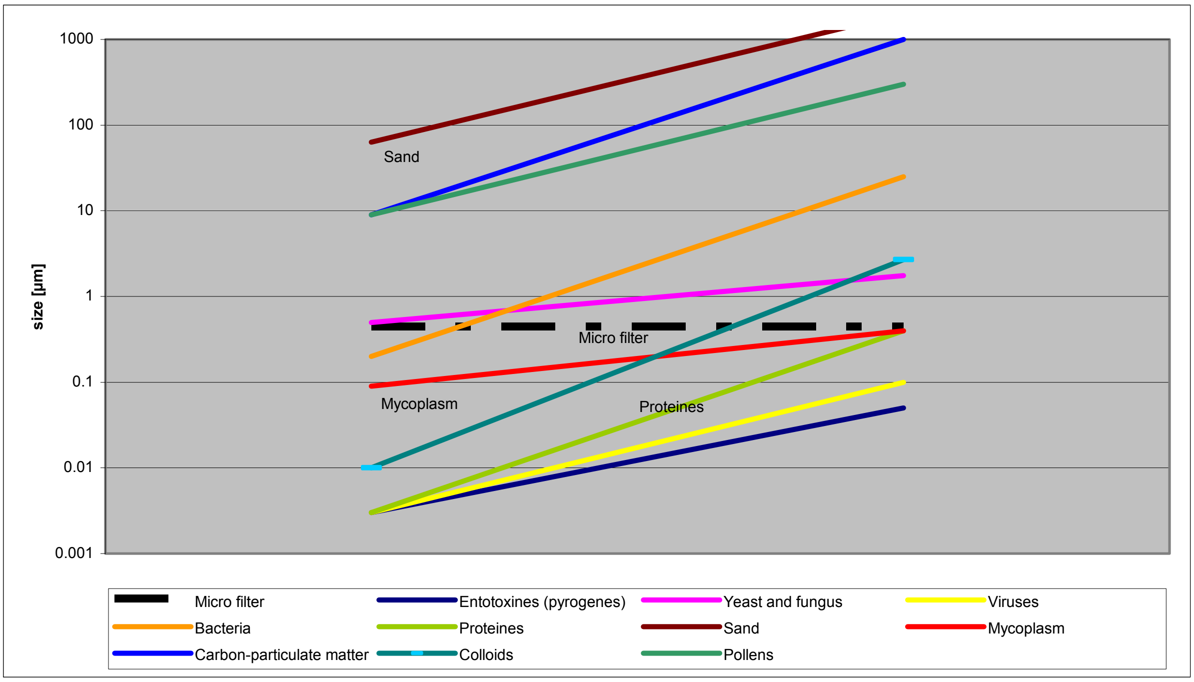


Figure 21: Size of Water Particles (Min/Max) and Filtering Effect of Micro Filters

Further details on sample filtration may be obtained from ASTM standard D 6564-00.

5.3.4 Sample Collection

When sampling springs and shafts it has to be taken into consideration that the physico-chemical conditions change where the water emerges. Samples should be taken immediately at the spot of emergence (i.e. not at those places where retention structures have been built).

The facilities available at water laboratories and the analysis method used vary considerably, and so do the sampling routines. Therefore, the laboratory needs to be consulted before the start of the field campaign for the specific details of containment material, sample size(s), preservation methods, storage, and transport.

After the well is purged and the water is filtered, the sample could be filled into one or more flasks, depending on the parameters to be analyzed and the laboratory requirements. The instruments used for filling the sample bottles must be of appropriate material (see above) and have to be cleaned thoroughly thereafter.

The flasks should be filled completely and closed with a stopper in such a way that there is no air trapped inside and that the flask remains airtight during the entire transport and storage. This avoids modifications in the CO_2 and O_2 content, which may result in changes of pH or iron or HCO_3/CO_3.

For bacteriological examination, however, an air space should be left, so that the sample may be shaken before examination. Also samples that need to be frozen should not be filled to the brim because the volume will expand and may cause the flask to blast.

The sample containers must be marked in such a way that the identification number, name, date and sequential no. of the sample are clearly readable. Preprinted labels using water proof ink or permanent overhead pens may be used for this purpose.

5.3.5 On-Site Measurements

Before well purging/pumping the static water level should be measured. Immediately after collection of the sample, on-site measurements should be conducted, if not already measured using a closed glass bulb, of temperature, pH, redox, EC, O_2, free CO_2, certain gases, and if required other parameters (e.g. NO_3, NO_2, NH_4 using a field photometer; remark: accuracy is of course less than with standard methods but storage at +4°C for up to 24 h may be difficult in some remote areas; the use of a photometer may require the availability of a generator with a power stabilizer). If it is likely that temperature measurements be influenced by certain conditions (e.g. increased by pumping or high outside temperatures), it may be best to do temperature readings in the well itself using a combined water level/temperature probe.

Electric conductivity is commonly measured together with temperature on the same instrument. EC needs to be compensated to a reference temperature of 25°C (or 20°C, depending on the local regulations).

pH-meters need to be calibrated at regular intervals (weekly or before use) and the tip of the meter should be kept in KCl solution (3 mol/l). Oxidation-reduction potential (or redox potential) which is commonly measured with a combined redox/pH instrument, must be made under non-turbulent flow-through without pressure changes and without subjecting the water to oxygen access.

Dissolved gases should be fixed and if possible determined immediately on the site. Oxygen may be analyzed by a special electrode (e.g. using the WTW TriOxmatic/CellOx sensors: www.wtw.com/). Modern instruments require only a very simple calibration, however, older instruments require a more complex calibration at weekly intervals or on demand.

A portable photometer may be used to analyze individual parameters, such as nitrate, sulfate, phosphate, metals, etc., in the field (e.g. YSI 9000 photometer: *www.ysi.com* ; Dr. Lange photometers: *www.drlange.ch*; CHEMETRICS V-2000 photometer: *www.chemetrics.com*; etc.).

5.3.6 Sample Preservation

Some parameters need to be determined in situ, others may be analyzed after some time but require pretreatment, and others again are stable for some time without treatment under certain conditions. *Annexes B-3 and B-4* lists the pretreatment methods and the chemical stability of selected parameters.

International standard methods for determination of individual parameters usually also provide details for sample conservation (compare ISO standards).

The handling of certain preservatives, such as e.g. acids or chloroform, is associated with health risks. Therefore precautions have to be taken against these risks.

Common procedures include storage of the samples at low temperatures (+4°C) or in frozen state and storage in boxes which prevent light expose. In general freezing at -20°C allow longer storage times. Plastic containers are suitable for freezing, whereas glass containers are not.

Cations and Heavy Metals

Sodium and potassium can be determined from untreated samples, whereas calcium, manganese, iron, and magnesium require that the pH be brought down to less than 1.5 by adding a mineral acid in order to prevent the precipitation of hydroxides. The acid is commonly filled into the bottles prior to sample collection.

Heavy metals may be dissolved in water either as cations, anions or as organic complexes (e.g. mercury). This makes it difficult to give general recommendations for their pretreatment. Also different analysis methods may be applied, so that it is best to consult the laboratory for their recommended conservation method for each individual parameter. If expected contents are low, the sample is often enriched, so that in total higher amounts of water are needed. However, modern analysis methods mostly provide a low detection limit and therefore mostly low amounts of water are needed. The most commonly analyzed heavy metals are: As, Cd, Cr, Cu, Hg, Pb and Zn. Sampling bottles used for heavy metals should not be used for any other purposes.

Anions

With the exception of chloride, all anions need treatment according to *Annexes B-3 and B-4*. Samples for fluoride detection should not be stored in glass bottles. 'Sulfur waters' containing anionic sulfur compounds such as sulfide, hydrogen sulfide, thiosulfate, dithionite, tri- to hexathionate, are very sensitive to oxygen exposure. The laboratory should be consulted for the best conservation method.

Cyanide is converted in presence of oxygen to cyanate. Like for all parameters sensitive to oxygen, sample bottles have to be filled to the brim and closed airtight without trapping water bubbles inside.

5.3.7 Sampling Protocol

The sampling protocol should document all relevant data which may be important for their interpretation. They should therefore encompass:

- The identification number, name and description of the location (including if possible a sketch map);
- The owner's name;
- The coordinates and elevations (land surface and reference level);
- Hydrogeological base data (e.g. aquifer, screen positions, lithology);
- The meteorological/hydrological conditions (e.g. T, air pressure, drought/wet period, snow melt, x days after rainfall event, etc.);
- A log of well drilling and design (showing the position of screens, seals, etc.);
- The general state of the monitoring site (e.g. flooding of well possible, well head damaged, etc.);
- The list of parameters to be analyzed for this site/sample;
- The sampling date and time;
- The maximum allowable time span until analysis;
- The name of person conducting the sampling;
- The sample number (and the sequential number: x of y samples at this site);
- The type of sample containment (white/brown glass bottle, plastic bottle, etc.);
- The static water level (before pumping and at end of recovery phase);
- The start and end of well purging (pumping);
- The type of purging device used;
- The position (depth) of the purging device (pump);
- The amount of water extracted before sampling or the discharge (pumping) rate;
- The on-site measurement results (pH, redox, EC, T, O_2, etc.);

- Documentation of the online measurements until parameter constancy;
- The filtration method;
- The pre-treatment method;
- The conservation method;
- The storage sites with their temperatures;
- Photo(s) of the sampling site.

A typical sample of such a sampling protocol is documented in *Annex B-2*.

After the sampling campaign a complete report should be prepared, encompassing the sampling protocols, the analysis results and a discussion of the analysis result (plausibility check, tendencies, etc.). To each sampling site a separate file should be kept containing all of the above-mentioned information.

Annual groundwater quality monitoring reports should be prepared that document the sampling campaigns conducted, the location of all monitoring wells, the analysis results, the hydrogeological interpretation and the required actions (e.g. to prevent contamination in a certain area/aquifer).

5.3.8 Sample Transport and Storage

Sample storage is commonly done by keeping the samples at a dark and cool place during transport to the laboratory. In some cases samples need to be frozen, in order to preserve their chemical composition. For details which method to apply in which case, see *Annexes B-3* and *B-4*.

5.3.9 Personal Safety

During the entire sampling procedure personal safety of the involved personnel has to be ensured. Health hazards could result from ingestion, aspiration or skin contact with substances used for treatment, such as acids, the well itself (e.g. gas), or hazardous chemical substances in the sampled water.

If it is supposed that gases (methane, hydrogen sulfide or other toxic gases) are present, such as may be the case in confined aquifers, precautionary measures against inflammation or breathing in of these gases must be made.

If toxic parameters are assumed to be present, the authority responsible for national health and safety should be consulted for assistance.

In any case it should be refrained from eating, drinking and smoking at the monitoring site.

A number of standard handbooks for personal safety regulations in environmental investigations programs have been developed. Some examples are:

- WOODWARD-CLYDE CONSULTANTS (1991);

- LfUG (1999);
- KÖHLER INGENIEURGESELLSCHAFT (1989).

5.4 Frequent Problems

In many cases preexisting wells are used for groundwater quality monitoring. Even though costs may largely be cut down by this measure, one has to be aware of the consequences. It should be closely looked at the well drilling method, the well design and the materials used. Wells which have been used for some time for groundwater abstraction may require extensive rehabilitation. Also not all required well data might be available so that additional investigations, such as geophysical logs, would have to be carried out beforehand. Only when the influence on the parameters to be analyzed is supposedly low, such wells should be considered.

When comparing long-term monitoring data of a well it is often recognized that some data do absolutely not fit in, and it must be assumed that these analyses originate from another well. It is therefore very important to put greatest care on the correct labeling. Unique and clearly readable identification tags should be prepared before each field campaign, if possible by printing them on adhesives in such a way that the ink can not be washed off by water.

UNECE list a number of recommendations for a successful monitoring :

1. The objectives must be defined first and the programme adapted to them, and not vice versa (as is often the case with multi-purpose monitoring). *Adequate financial support must then be obtained.*

2. The type and nature of the aquifer must be fully understood (most frequently *through preliminary surveys*), including the spatial and temporal variability within the aquifer. Very helpful information sources are maps of an appropriate scale (e.g. : 1:200,000) of the transboundary aquifer concerned:
   - hydrogeological and vulnerability map of the area (if it exists);
   - isoline maps of the aquifers' underlying and overlying geologic formations;
   - maps of changes in groundwater levels;
   - maps and lists of the hydrogeological boreholes (characteristic profiles and hydrogeological parameters), monitoring wells (with their basic data), significant groundwater abstractions (wells or well fields), location and abstraction data, and wells of regular water quality sampling (list of parameters);
   - all isotope data concerning the age and origin of the groundwater.

3. The appropriate well type (or spring) must be chosen (or spring).

4. The parameters, type and frequency of measurements and sampling, and the locations must be chosen with respect to the objectives.

5. The analytical field equipment and the laboratory and data analysis facilities (e.g. models) must be selected in relation to the objectives and not vice versa.

6. A complete and operational data treatment scheme (DAP) must be established.

7. Groundwater monitoring should be coupled with surface water monitoring when applicable.

8. The quality of the collected data must be regularly checked through internal and external control. The data should be given to decision makers, not merely as a list of variables and their concentrations or levels, but interpreted and assessed by experts with relevant recommendations for management action (such as indicators or indices).

9. The programme must be evaluated periodically, especially if the general situation or any particular influence on the groundwater flow system has changed, either naturally or by measures taken.

Figure 22: Recommendation for Successful Groundwater Monitoring (UNECE 2000)

6 Costs

The costs related to drilling, installation of casings and screens, well development and some field equipment are already documented in Part A, chapter 5 of this report. In addition to these costs, the costs for

- Special casing/screen materials;
- Personal safety precautions;
- Well purging;
- Sampling devices;
- Filtration;
- Sample containment;
- Sample treatment;
- Sample transport and storage; and
- Laboratory analysis

have to be considered when conducting groundwater quality monitoring. These costs may become quite substantial, so that the costs of groundwater quality monitoring are generally much higher compared to the costs for groundwater level monitoring.

These costs also depend to a large degree on the local conditions and regulations so that only limited guidance can be given here.

Table 8: Selected Costs for Groundwater Quality Monitoring (6"/150 mm)

Item	***Approx. Costs in Euro***
German Water and Energy [*www.gwe-group.com*] : Casings/screens (PVC-U) per m (7.5 mm wall thickness) Casings/screens (PVC-U) per m (9.5 mm wall thickness) Screens (PVC-H wrought wire, thick wall construction) Casings/screens (epoxy-coated steel - HAGULIT) Casings/screens (Stainless steel) per m [*www.johnsonscreens.usfilter.com*] Casings/screens (HDPE) per m (6 m lengths) Casings/screens (PTFE)	 26.4/39.5 36.8/56.4 115 86/135 prices depend on market prices for stainless steel 15.1/27.4
Grundfos [*www.grundfos.com*] : MP-1 pump SQE-NE pump SP-NE pump	prices depend on pumping lifts and pumping rates around 2,500
Bailer 1 l [*www.seba.de*] Disposable (PVC) [*www.enviroequipment.com*] Disposable (PE) [*www.hoskin.ca*; *www.enviroequipment.com*] Disposable (HDPE) [*www.solinst.com; www.enviroequipment.com*]	 650 3 4

Item	***Approx. Costs in Euro***
Disposable (Teflon) [*www.hoskin.ca; www.enviroequipment.com*] Point source bailer [*www.solinst.com*]	9-16 no price available
Sample flasks (carbonate-silicate glass) per piece 0.1/0.25/0.5 l transparent opaque Sample flasks (PVC) per piece 0.5/1.0 l Sample flasks (HDPE) per piece 0.1/0.5 l Sample flasks (Teflon PFA) per piece 0.125/0.25/0.5 l	 1.6/3.0/3.5 1.4/2.5/3.2 1.6/2.3 0.65/1.1 41/59/81
Gas detection [*www.compur.com*] Impact (detection of O_2, combustibles, H_2S, CO_2)	 1,100

7 Interpretation of Results

Since the purpose of groundwater quality monitoring is manifold and because there is a large number of publications concerning this issue, only some standard literature is referenced in this report.

In general, the purpose of quality data interpretation and monitoring reporting should be to document the natural groundwater quality (background/reference levels) and where (distribution), how (sources) and why (processes) groundwater quality differs from these levels. If a contamination by a certain source is assumed groundwater quality monitoring should be adapted to this monitoring need in order to be able to sufficiently prove the source of contamination. This concerns the selection of monitoring parameters and the installation of new monitoring sites.

Standard methods for the description of groundwater quality are documented for instance in :

- DVWK (1982);
- DVWK (1990a);
- DVWK (1999);
- APPELO & POSTMA (1993);
- FETTER (1998, 2000).

Results may be displayed in time or trend plots of concentrations (showing e.g. seasonal or long-term trends), spatial distribution maps of concentrations (for different historical time series: 5/10/20 years before present), box plots (Whisker diagrams; showing e.g. the variation of concentrations at a specific site), etc.

For the overall interpretation it is important to take into consideration the general hydrogeological conditions in the regarded groundwater systems, the groundwater flow pattern, and the behavior of the regarded contaminants.

In areas where the national water quality standards are surpassed, appropriate actions have to be taken. This is especially required when drinking water sources may be affected. For this purpose it may be important to set up contingency plans and remedial action plans. This is often done in the framework of the establishment of groundwater protection zones (MARGANE 2003b).

For the end-users, the water resources management decision-makers as well as for other landuse planners, it is important to have a reliable base for their decisions. Groundwater quality monitoring results should therefore be documented in a suitable form, such as e.g. annual monitoring reports. These technical reports should contain:

- The results of groundwater monitoring, presented in a suitable form;

- A list of sites where national water standards were exceeded and proposed counteractions;
- Recommendations for the modification of the monitoring network;
- Recommendations for groundwater resources management actions as a response to monitoring.

It may be considered to prepare a primary technical report, containing all technical details, and a summary report for decision-makers only.

8 Summary and Recommendations

Groundwater quality monitoring, if thoroughly conducted, requires much more efforts and input, concerning personnel, know-how and costs, compared to groundwater level monitoring. In order to be able to make use of the groundwater quality monitoring data, the quality of the collected data must be ensured during all steps of the monitoring procedure. Many mistakes can be made during well location determination, well installation, sample collection, and analysis. Whenever there are reasonable doubts about the quality of these data, they should be used with care, if at all.

In addition to the recommendations mentioned in *chapter 7* of *Part A* of this document, the following recommendations can be made:

- Monitoring sites should be selected with the aim to be able to fulfill the monitoring objective (e.g. prove the path and velocity of contaminant migration) and to interpret the data correctly (for which the correct understanding of the aquifer system is the major prerequisite);
- The monitoring well installation and its maintenance must be carried out thoroughly, so that no water other than from the specified depth interval reaches the well and that no chemical or biological contamination of the well may occur during the lifetime of the well;
- The material of all installations and equipments used for groundwater quality monitoring must be selected based on its suitability for monitoring of the parameters to be analyzed;
- There must be extensive cooperation and coordination with the laboratory that analyzes the water samples;
- Laboratories must operate according to standard quality assurance procedures;
- The usefulness of the monitoring information must be validated in the framework of audits. Part of this evaluation should consider the monitoring information requirement (benefit) and the measurement effort (cost) relation.

9 References and Related Literature

ANZECC & ARMCANZ (2000): Australian Guidelines for Water Quality Monitoring and Reporting - Summary. – Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand, National Water Quality Management Strategy, No. 7a, 42 p.; Canberra/Australia.

APPELO, C.A.J. & POSTMA, D. (1993): Geochemistry, Groundwater and Pollution. – 536 p.; Lisse/The Netherlands (Balkema).

ASTM (1999): Ground Water and Vadose Zone Investigations: Drilling, Sampling, Geophysical Logging, Well Installation and Decommissioning. – 2nd edition, 576 p.; West Conshohocken/PE/USA.

ASTM (2002): Standard Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers. – American Society for Testing and Materials, Standard D5092-02, 14 p.; West Conshohocken/PE/USA.

BARCZEWESKI, B., KRITZNER, W., NITSCH, C. (1996): Tiefenorientierte Grundwasserprobennahme zur Messung der Wasserbeschaffenheit. – Wasserwirtschaft, 86, 9, 446-451; Wiesbaden/Germany (Vieweg).

BAUMANN, K., BURDE, B. & GOLDBECK, J. (2003): Die gläserne Messstelle: Fortschritte bei der Bohrlochgeophysik. – BBR, 7/03, 24-32; Bonn/Germany.

CHILTON, P.J. & FOSTER, S.S.D. (1997): Monitoring of Groundwater Qaulity Assessment: Current Constraints and Future Strategies. – British Geol. Survey, Proc. Int. Workshop: Monitoring Tailor-Made II; Nunspeet/The Netherlands.

DEQ/ID (2003): Monitoring Well Construction Guidance for Wastewater Land Application Facilities. – Idaho Department of Environmental Quality, 4 p.; Boise/ID/USA. [internet download]

DNR/WI (2003): Wastewater Sampling, Preservation, and Analysis Methods. – Wisconsin Department of Natural Resources, 5 p.; Madison/WI/USA. [internet download]

DRISCOLL, F.G. (1989): Groundwater and Wells. – 2nd Edition, 1098 p.; St. Paul/USA (Johnson Filtration Syst. Inc.).

DÖRHÖFER, G. (1995): Planungskriterien für Grundwasserbeschaffenheits-meßstellen, Teil 1: Begriffsdefinitionen und Einsatzbereiche. – BBR, 11, 18-24; Bonn/Germany.

DÖRHÖFER, G. (1996): Planungskriterien für Grundwasserbeschaffenheits-meßstellen, Teil 2: Begriffsdefinitionen und Einsatzbereiche. – BBR, 1, 24-30; Bonn/Germany.

DÖRHÖFER, G., LANGE, B. & VOIGT, H. (1991): Deponieüberwachungsplan Wasser – Beweissicherung an Deponien in Niedersachsen. – Ministry of Environment Lower Saxony, 46 p; Hannover/Germany.

DÖRHÖFER, G. & HUCH, M. (1998): Methodische und hydrochemische Aspekte der zonaren Grundwasserüberwachung an Deponien und Altlasten. – Grundwasser, 3, 1, 29-40; Heidelberg/Germany (Springer).

DVGW (1997a): VP 800: Anforderungen an das Qualitätsmanagement von Wasserlaboratorien. – 17 p.; Bonn/Germany (Wirtschafts- und Verlags-gesellschaft mbH).

DVGW (1997b): Muster-Qualitätsmanagementhandbuch (QMH) für Wasserlabora-torien. – Hinweis W 260, p.; Bonn/Germany (Wirtschafts- und Verlags-gesellschaft mbH).

DVGW (1998): Technische Regel – Arbeitsblatt W135: Sanierung und Rückbau von Bohrungen, Grundwassermesstellen und Brunnen. – 76 p.; Bonn/Germany (Wirtschafts- und Verlagsgesellschaft mbH).

DVGW (2001a): Technische Mitteilung – Merkblatt W112: Entnahme von Wasserproben bei der Erschließung, Gewinnung und Überwachung von Grundwasser. – 14 p.; Bonn/Germany (Wirtschafts- und Verlags-gesellschaft mbH).

DVGW (2001b): Technische Regel – Arbeitsblatt W115: Bohrungen zur Erkundung, Gewinnung und Beobachtung von Grundwasser. – 27 p.; Bonn/Germany (Wirtschafts- und Verlagsgesellschaft mbH).

DVGW (2002): Technische Regel – Arbeitsblatt W121: Bau und Ausbau von Grundwassermessstellen. – 25 p.; Bonn/Germany (Wirtschafts- und Verlagsgesellschaft mbH).

DVGW (2003): Technische Regel – Arbeitsblatt W 108: Messnetze zur Überwachung der Grundwasserbeschaffenheit in Einzugsgebieten von Trinkwassergewinnungsanlagen. – 19 p.; Bonn/Germany (Wirtschafts- und Verlagsgesellschaft mbH).

DVWK (1982): Auswertung hydrochemischer Daten. – Schriften, 54, 193 p.; Hamburg, Berlin/Germany (Parey).

DVWK (1985): Water Sampling and Chemical Analysis for Groundwater Investigations. – Bulletin, 15, 84 p.; Hamburg, Berlin/Germany (Parey).

DVWK (1989a): Stofftransport im Grundwasser. – Schriften, 83, 296 p.; Hamburg, Berlin/Germany (Parey).

DVWK (1989b): Grundwasser – Redoxpotentialmessung und Probennahmegeräte. – Schriften, 84, 172 p.; Hamburg, Berlin/Germany (Parey).

DVWK (1990a): Methodensammlung zur Auswertung und Darstellung von Grundwasserbeschaffenheitsdaten. – Schriften, 89, 216 p.; Hamburg, Berlin/Germany (Parey).

DVWK (1990b): Manual for Water Level Gauging and Discharge Measurements. – Guidelines, 301, 274 p.; Bonn/Germany (Parey).

DVWK (1990c): Einflüsse von Messstellenausbau und Pumpenmaterialien auf die Beschaffenheit einer Wasserprobe. – Mitteilungen, 20, 141 p.; Bonn/Germany (Parey).

DVWK (1992a): Entnahme und Untersuchungsumfang von Grundwasserproben. - Merkblätter zur Wasserwirtschaft, 128, 41 p.; Hamburg, Berlin/Germany (Parey).

DVWK (1992b): Anwendung hydrochemischer Modelle. – Schriften, 100, 334 p.; Hamburg, Berlin/Germany (Parey).

DVWK (1994): Grundwassermessgeräte. – Schriften, 107, 241 p.; Hamburg, Berlin/Germany (Parey).

DVWK (1997): Tiefenorientierte Probennahme aus Grundwassermessstellen. – Merkblätter zur Wasserwirtschaft, 254, 14 p.; Bonn/Germany (Wirtschafts- und Verlagsgesellschaft mbH).

DVWK (1998a): Hydrochemische Stoffsysteme – Teil I. – Schriften, 110, 288 p.; Hamburg, Berlin/Germany (Parey).

DVWK (1998b): Hydrochemische Stoffsysteme – Teil II. – Schriften, 117, 397 p.; Hamburg, Berlin/Germany (Parey).

DVWK (1999): Methoden für die Beschreibung der Grundwasserbeschaffenheit. – Schriften, 125, 241 p.; Bonn/Germany (Wirtschafts- und Verlags-gesellschaft mbH).

EPA (1972): Handbook for Analytical Quality Control in Water and Wastewater Laboratories. – Document no. 600479019, 157 p.; Washington/USA.

EPA (1985): Practical Guide for Ground-Water Sampling. – Report No. 600/2-85/104, 94 p.; Washington/USA.

EPA (1989): Ground-Water Monitoring in Karst Terranes – Recommended Protocols and Implicit Assumptions. – Report No. 600/X-89/050, 79 p.; Las Vegas/NV/USA.

EPA (1991a): Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells. – Report No. 600/4-89/034(Rev), 221 p.; Washington/USA.

EPA (1991b): Site Characterization for Subsurface Remediation. – Report No. 625/4-91/026, 268 p.; Washington/USA. [*http://www.epa.gov/swerust1/cat/sitchasu.pdf*]

EPA (1993): Subsurface Characterization and Monitoring Techniques – A Desk Reference Guide, Vol.1: Solids and Groundwater. – Report No. 625R93003, 448 p.; Washington/USA.

EPA (1994): RCRA Ground Water Monitoring – Draft Technical Guidance. – 220 p.; Rockville/USA (Gov.Inst.Inc.).

FAO (1998): Guidelines for quality management in soil and plant laboratories. – FAO Soils Bulletin, 74, W7295/E, Rome.

FAO (2000): Water Quality Management and Control of Water Pollution. – Water Reports, 21, Proceedings of a Regional Workshop in Bangkok, Thailand, 198 p.; Bangkok/Thailand.

FAO (2003): Review of World Water Resources by Country. – Water Reports, 23, 110 p.; Rome/Italy.

FETTER, C.W. (2000): Applied Hydrogeology. – 691 p.; Upper Saddle River/NJ/USA (Prentice Hall).

FETTER, C.W. (1998): Contaminant Hydrogeology. – 500 p.; Upper Saddle River/NJ/USA (Prentice Hall).

FREEZE, R.A. & CHERRY, J.A. (1979): Groundwater. – 604 p.; (Prentice Hall).

GIBBONS, R.D. (1994): Statistical Methods for Groundwater Monitoring. – 304 p.; New York/USA (J. Wiley);

HAAS, R. (1992): Konzepte für die Untersuchung von Rüstungsaltlasten. – PhD Thesis, Univ. Marburg, 159 p.; Marburg/Germany.

HEM, J.D. (1985): Study and Interpretation of Chemical Characteristics of Natural Water. – USGS, Water Supply Paper (WSP), 2254, 263 p.; Denver/CO/USA.

IGRAC (2003): Inventory of existing guidelines and protocols for groundwater assessment and monitoring. – International Groundwater Resources Assessment Centre, 25 p.; Utrecht/The Netherlands.

ISO (1980): International Standard ISO 5667/1: Water Quality – Sampling – Part 1: Guidance on the Design of Sampling Programmes. – International Organization for Standardization, 13 p.; Switzerland.

ISO (1992): International Standard ISO 5667/10: Water Quality – Sampling – Part 10: Guidance on Sampling of Waste Waters. – International Organization for Standardization, 10 p.; Switzerland.

ISO (1993): International Standard ISO 5667/11: Water Quality – Sampling – Part 11: Guidance on Sampling of Groundwaters. – International Organization for Standardization, 10 p.; Switzerland.

ISO (1994): International Standard ISO 5667/3: Water Quality – Sampling – Part 3: Guidance on the Preservation and Handling of Samples. – International Organization for Standardization, 26 p.; Switzerland.

ISO (1997): International Standard ISO 5667/13: Water Quality – Sampling – Part 13: Guidance on Sampling of Sludges from Sewage and Water Treatment Works. – International Organization for Standardization, 21 p.; Switzerland.

ISO (1998): International Standard ISO 5667/14: Water Quality – Sampling – Part 14: Guidance on Quality Assurance of Environmental Water Sampling and Handling. – International Organization for Standardization, 18 p.; Switzerland.

ISO (1999): International Standard ISO 5667/15: Water Quality – Sampling – Part 15: Guidance on Preservation and Handling of Sludge and Sediment Samples. – International Organization for Standardization, 7 p.; Switzerland.

ISO (2001): International Standard ISO 5667/18: Water Quality – Sampling – Part 18: Guidance on Sampling of Groundwater at Contaminated Sites. – International Organization for Standardization, 23 p.; Switzerland.

ISWS (1985): Practical Guide for Ground-Water Sampling. – Illinois State Water Survey, Report No. 374, 94 p.; Champaign/IL/USA.

KEYS, W.S. (1989): Borehole Geophysics Applied to Ground Water Investigations. – USGS, Techniques of Water-Resources Investigations (TWRI), book 2, Chapter E2, 150 p.; Denver/CO/USA.

KOEHLER INGENIEURGESELLSCHAFT (1989): Arbeits- Emissions-, und Personenschutz beim Umgang mit Rüstungsaltlasten. – Unpubl. Report for Ministry of Environment of Lower Saxony, 24 p.; Peine & Munster/Germany.

KOTERBA, M.T., WILDE, F.D., and LAPHAM, W.W. (1995): Ground-water data-collection protocols and procedures for the National Water-Quality Assessment Program—Collection and documentation of water-quality samples and related data – U.S. Geological Survey, Open-File Report, 95–399, 113 p.; Denver/CO/USA.

LAWA (1993): Grundwasser – Richtlinien für Beobachtung und Auswertung, Teil 3: Grundwasserbeschaffenheit. – Landesarbeitsgemeinschaft Wasser, p.; Düsseldorf/Germany.

LAWA (1999a): Empfehlungen zu Konfiguration von Messnetzen sowie zu Bau und Betrieb von Grundwassermessstellen (qualitativ). – 32 p.; Berlin/Germany (Kulturbuchverlag).

LAWA (1999b): Empfehlungen zur Optimierung des Grundwasserdienstes (quantitativ). – 36 p.; Berlin/ Germany (Kulturbuchverlag).

LfU (1996): Grundwasserüberwachungsprogramm – Ergebnisse der Beprobung 1995. – Landesanstalt für Umweltschutz Baden-Württemberg, 57 p.; Karlsruhe/Germany.

LfUG (1999): Leitfaden zum Arbeitsschutz bei der Altlastenbehandlung. – Materialien zur Altlastenbehandlung, Landesamt für Umwelt und Geologie, Dresden/Germany. [internet download: *www.umwelt.sachsen.de/lfug/Salfaweb/ salfaweb-nt/*]

LfUG (2003): Handbuch Grundwasserbeobachtung, Teil 5: Grundwasserproben-nahme. – Sächsisches Landesamt für Umwelt und Geologie, 40 p.; Dresden/Germany. [download from SALFAWEB: *http://www.umwelt.sachsen.de/lfug/salfaweb/salfaweb-nt/*]

LUCKNER, L. & NITSCHE, C. (1999): Repräsentative Grundwassermessstellen – Eine Einführung. – in: Begleitmaterial zur Veranstaltung "Weiterbildung im DGFZ e.V.: Bewertung der Repräsentativität und des technischen Zustandes von Grundwassermessstellen" am 22./23.10.1999, Dresden/ Germany.

MANSUY, N. (1999): Water Well Rehabilitation – A Practical Guide to Understanding Well Problems and Solutions. – 174 p; Boca Raton (Lewis Publ.).

MARGANE, A. (1995): Groundwater Resources of Northern Jordan – Vol.2 Part 2: Monitoring of Groundwater Levels in Jordan. – Unpubl. Report, Technical Cooperation Project 'Advisory Services to the Water Authority of Jordan', BGR archive no. 112708, 71 p.; Amman.

MARGANE, A. & SUNNA, N. (2002): Proposal for a National Guideline for the Delineation of Groundwater Protection Zones. - Report prepared by WAJ & BGR, Technical Cooperation Project 'Groundwater Resources Management', Technical Report No. 1, 161 p.; Amman.

MARGANE, A. (2003a): Guideline for the Preparation of Groundwater Vulnerability Mapping and Risk Assessments for the Susceptibility of Groundwater Resources to Contamination. – Technical Report Vol. 4, prepared by ACSAD & BGR, Technical Cooperation Project 'Management, Protection and Sustainable Use of Groundwater and Soil Resources in the Arab Region', 177 p.; Damascus.

MARGANE, A. (2003b): Guideline for the Delineation of Groundwater Protection Zones. – Technical Report Vol. 5, prepared by ACSAD & BGR, Technical Cooperation Project 'Management, Protection and Sustainable Use of Groundwater and Soil Resources in the Arab Region', 329 p.; Damascus.

MARGANE, A. (2003c): Guideline for Sustainable Groundwater Resources Management. - Technical Report Vol. 6, prepared by ACSAD & BGR, Technical Cooperation Project 'Management, Protection and Sustainable Use of Groundwater and Soil Resources in the Arab Region', 235 p.; Damascus.

MOORE, J.E. (2002): Field Hydrogeology – A Guide for Site Investigations and Report Preparation. – 208 p.; Boca Ratton/USA (Lewis Publ.).

MORRIS, B.L., LAWRENCE, A.R.L., CHILTON, P.J.C., ADAMS, B. CALOW, R.C. & KLINCK, B.A. (2003): Groundwater and its Susceptibility to Degradation. – Report RS.03-3 prepared by BGS for UNEP, 126 p; Nottingham/UK, Nairobi/Kanya.

MUELLER, P. & MANGER, V. (1993): Modernes Grundwassermonitoring in der Wasserversorgung. – Wasserwirtschaft, 83, 1, p. 28-34; Wiesbaden/ Germany (Vieweg).

NIELSEN, D.M. (1991): Practical Handbook of Ground-Water Monitoring. – 717 p.; Boca Ratton/USA (Lewis Publ.)

NFESC (2000): Guide to Optimal Groundwater Monitoring. – Interim Final Report prepared by Radian International for the Naval Facilities Engineering Service Center, 59 p.; Port Hueneme/CA/USA. [internet download]

NLfB & NLWA (1991): Deponieüberwachungsplan Wasser – Beweissicherung an Deponien – Grundwasser, Oberirdische Gewässer. – Niedersächsisches Landesamt für Bodenforschung und Niedersächsisches Landesamt für Wasser und Abfall, 46 p.; Hannover, Hildesheim/Germany.

NLÖ & NLfB (1997): Altlastenhandbuch des Landes Niedersachsen – Geologische Erkundungsmethoden. – Niedersächsisches Landesamt für Ökologie und

Niedersächsisches Landesamt für Bodenforschung, 198 p.; Berlin/Germany (Springer).

NLWA & NLfB (1988): Altlastenprogramm des Landes Niedersachsen – Altablagerungen – Bearbeitsungshinweise zur Durchführung Gezielter Nachermittlungen. – 35 p.; Hildesheim & Hannover/Germany.

PLOETHNER, D. (1997): Advisory Services to ESCWA Member States in the Field of Water Resources - Report on Groundwater Quality Control and Conservation in the ESCWA Region. - Unpubl. Report, Techn. Cooperation BGR & ESCWA, BGR archive no. 116751, 112 p.; Amman/Jordan.

SARA, M.N. (2003): Site Assessment and Remediation Handbook. – 1150 p.; Boca Raton/FL/USA (Lewis).

SMITH, S. A. (1995): Monitoring and Remediation of Wells – Problem Prevention, Maintenance, and Rehabilitation. – 183 p.; Boca Raton/USA (Lewis Publ.).

TAYLOR, C.J. & ALLEY, W.M. (2001): Groundwater-Level Monitoring and the Importance of Long-Term Water-Level Data. – USGS, Circular 1217, 68 p.; Denver/CO/USA.

TRISCHLER & PARTNER (1987): Leitfaden für die Erkundung von Altlasten – Teil I: Grundwasser. – Unpubl. Report commissioned by Landesanstalt für Umweltschutz Baden-Wuerttemberg, 115 p.; Darmstadt.

UNECE (1999): State of the Art on Monitoring and Assessment of Groundwaters.- 83 p.; Lelystad/The Netherlands.

UNECE (2000): Guidelines on Monitoring and Assessment of Transboundary Groundwaters.- 64 p.; Lelystad/The Netherlands.

UNECE (2002): Guidance to Operation of Water Quality Laboratories.- 89 p.; Lelystad/The Netherlands.

Van BRACHT, M. J. (2001): Made to Measure – Information Requirements and Groundwater Level Monitoring Networks. – PhD thesis, Univ. Amsterdam, 210 p.; Amsterdam.

WILDE, F.D., RADTKE, D.B., GIBS, J. & IWATSUBO, R.T. (1998): National Field Manual for the Collection of Water-Quality Data. – USGS, Techniques of Water-Resources Investigations (TWRI), book 9, 765 p.; Reston/VA/USA.

WOLTER, R., ROSENBAUM, S. & HANNAPPEL, S. (2000): The German Groundwater Monitoring Network. – Proceedings MTM-III Conference, 277-282; Nunspeet/The Netherlands.

WOOD, W.W. (1976): Guidelines for Collection and field analysis of groundwater samples for selected unstable constituents. – USGS, Techniques of Water-Resources Investigations (TWRI), book 1, Chapter D2, 53 p.; Denver/CO/USA.

WOODWARD-CLYDE CONSULTANTS (1991): Leitfaden zur Sicherheitstechnik für Maßnahmen im Zuge der Gefährdungsabschätzung von Rüstungsaltlasten in Niedersachsen. - Unpubl. Report commissioned by Ministry of Environment of Lower Saxony, 24 p.; Wennigsen/Germany.

WORLD BANK, UNEP & UNIDO (1999): Pollution Prevention and Abatement Handbook – Toward Cleaner Production. – 457 p.; Washington/DC/USA.

WWA MUENCHEN (2002): Merkblatt zur Errichtung von Grundwasserbeschaffenheitsmessstellen. – 4 p.; München/Germany.

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10 Relevant Standards

In addition to the standards listed in *Part A* of this document, the International Organization for Standardization has published a number of standards which are relevant in the context of groundwater quality monitoring:

- ISO 5667-1:1980 Water quality -- Sampling -- Part 1: Guidance on the design of sampling programmes
- ISO 5667-1:1980/Cor 1:1996
- ISO 5667-2:1991 Water quality -- Sampling -- Part 2: Guidance on sampling techniques
- ISO 5667-3:1994 Water quality -- Sampling -- Part 3: Guidance on the preservation and handling of samples
- ISO 5667-4:1987 Water quality -- Sampling -- Part 4: Guidance on sampling from lakes, natural and man-made
- ISO 5667-6:1990 Water quality -- Sampling -- Part 6: Guidance on sampling of rivers and streams
- ISO 5667-9:1992 Water quality -- Sampling -- Part 9: Guidance on sampling from marine waters
- ISO 5667-10:1992 Water quality -- Sampling -- Part 10: Guidance on sampling of waste waters
- ISO 5667-11:1993 Water quality -- Sampling -- Part 11: Guidance on sampling of groundwaters
- ISO 5667-13:1997 Water quality -- Sampling -- Part 13: Guidance on sampling of sludges from sewage and water-treatment works
- ISO 5667-14:1998 Water quality -- Sampling -- Part 14: Guidance on quality assurance of environmental water sampling and handling (available in English only)
- ISO 5667-15:1999 Water quality -- Sampling -- Part 15: Guidance on preservation and handling of sludge and sediment samples (available in English only)
- ISO 5667-18:2001 Water quality -- Sampling -- Part 18: Guidance on sampling of groundwater at contaminated sites (available in English only)
- ISO 6107-1:1996 Water quality -- Vocabulary
- ISO 6107-2:1997 Water quality -- Vocabulary
- ISO 6107-3:1993 Water quality -- Vocabulary
- ISO 6107-4:1993 Water quality -- Vocabulary
- ISO 6107-5:1996 Water quality -- Vocabulary

- ISO 6107-6:1996 Water quality -- Vocabulary
- ISO 6107-7:1997 Water quality -- Vocabulary
- ISO 6107-8:1993 Water quality -- Vocabulary
- ISO 6107-9:1997 Water quality -- Vocabulary -- Part 9: Alphabetical list and subject index

Besides these there are several standards for analysis of individual parameters and analytical quality control, issued by the ISO:

- ISO xxxx:19xx: Water quality -- Determination of ... (there are presently 125 ISO standards describing analysis methods for all relevant hydrochemical parameters)
- ISO 9998:1991 Water quality -- Practices for evaluating and controlling microbiological colony count media used in water quality tests
- ISO/TR 13530:1997 Water quality -- Guide to analytical quality control for water analysis
- ISO 17025:2000 General Requirements for the Competence of Calibration and Testing Laboratories.

Standard analytical methods for most hydrochemical parameters are listed in LfU (2001), annex 6 [in German].

11 Internet Links

For further links, see *Part A*, *chapter 10* of this report.

CLARINET (Contaminated Land Rehabilitation Network for Environmental Technologies in Europe): *www.clarinet.at*

EPA – Superfund Program: *www.epa.gov/superfund/*

EPA – Water Quality Monitoring: *www.epa.gov/ebtpages/watewaterqualitymonitoring.html*

EPA – Monitoring and Assessing Water Quality: *http://www.epa.gov/OWOW/monitoring/*

EPA – RCRA (Resource Conservation and Recovery Act, 1976): *http://www.epa.gov/rcraonline/*

EPA – Source Water Protection: http://www.epa.gov/safewater/protect.html

EPA – Source Water Assessment Program: *http://www.epa.gov/safewater/ protect/swap.html*

German Ministry of Environment - *www.umweltbundesamt.de/index-e.htm*

Groundwater Monitoring and Remediation (Journal), issued by the US National Ground Water Association (NGWA): *www.ngwa.org/publication/gwmr/gwmr-menu.html*

Hanford, State of Washington/US, Environmental Restoration Project: *www.hanford.gov*, *http://www.bhi-erc.com/projects/rawd/rawd.htm*

USGS: National Water Quality Assessment Program (NAWQA): *http://water.usgs.gov/nawqa/*

USGS – Ground-Water Monitoring for Pesticides in Wyoming (USGS & Wyoming Department of Agriculture): *http://wy.water.usgs.gov/projects/pesticide/*

12 Abbreviations

ACSAD	Arab Center for the Studies of Arid Zones and Dry Lands, Damascus/Syria, www.acsad.org
ADB	Asian Development Bank, Manila/Philippines, www.adb.org/
ASR	Aquifer storage recovery (of artificially recharged water)
BCM	Billion cubic meters
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe – Federal Institute for Geosciences and Natural Resources, Hannover/Germany, www.bgr.de
BMZ	Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung – Federal Ministry for Economic Cooperation and Development, Bonn/Germany, www.bmz.de
CADSWES	Center for Advanced Decision Support for Water and Environment Systems, Boulder/Colorado/USA
DSS	Decision Support System
EEA	European Environment Agency, Copenhagen/Denmark, www.eea.eu.int/
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency, Washington/USA, www.epa.gov/
ESCWA	United Nations Economic and Social Commission for Western Asia, Beirut/Lebanon, www.escwa.org.lb/
ESCAP	United Nations Economic and Social Commission for Asia and the Pacific, Bangkok/Thailand, www.unescap.org/
FAO	Food and Agriculture Organization, Rome/Italy, www.fao.org
GEMS	Global Environmental Monitoring System, Burlington/Ontario/Canada www.gemswater.org
GIWA	UNEP' s Global International Water Assessment, Kalmar/Sweden, www.giwa.net/
GNP	Gross National Product
GRDC	Global Runoff Data Center, Koblenz/Germany www.bafg.de/grdc.htm
GTZ	Gesellschaft fuer Technische Zusammenarbeit, Corporation for Technical Cooperation, www.gtz.de
GWP	Global Water Partnership www.gwpforum.org/
HDI	Human Development Index
IADB	Inter-American Development Bank, Washington/USA, www.iadb.org/
IETC	International Environmental Technology Center, Osaka/Japan, www.unep.or.jp/ietc/
IISD	International Institute for Sustainable Development, Winnipeg/Manitoba/CDN, www.iisd.org/
IRC	International Research Center for Water Supply and Sanitation, Delft/The Netherlands, www.irc.nl/
IWRM	Integrated Water Resources Management
IWMI	International Water Management Institute, Colombo/Sri Lanka, www.iwmi.cgiar.org/
JICA	Japan International Cooperation Agency, Tokyo/Japan
MCM	Million cubic meters
SAGE	Schéma d' Aménagement et de Gestion des Eaux (France ; Water

	Management Plan)
SWSI	Social Water Scarcity Index
UFW	Unaccounted-for-water
UNCED	United Nations Conference on Environment and Development, Dublin/Ireland (1992)
UNCSD	United Nations Commission on Sustainable Development (Division for Sustainable Development, Department of Economic and Social Affairs), New York/USA, www.un.org/esa/sustdev/csd.htm
UNDP	United Nations Development Program, New York/USA, www.undp.org
UNECE	United Nations Economic Commission for Europe, Geneva/Switzerland, www.unece.org/
UNEP	United Nations Environment Program, Nairobi/Kenya, www.unep.org
UNHCR	United Nations High Commission for Refugees
UNIDO	United Nations Industrial Development Organization
USGS	United States Geological Survey, Reston/Virginia/USA, www.usgs.gov/
USBR	United States Bureau of Reclamation, Washington/DC/USA www.usbr.gov/main/
WHO	World Health Organization, Geneva/Switzerland, www.who.int
WPI	Water Poverty Index
WRSRL	Water Resource Systems Research Laboratory, Newcastle/UK
WSI	Water Stress Index
WWAP	World Water Assessment Program
WWDR	World Water Development Report

Annex B-1: Checking List for Groundwater Quality Sampling

Item	Responsibility	Date & Signature
Pump with accessories and spare parts		
Sampling device x		
Sampling device y		
Tubes, funnels, connections		
x sample bottles, glass, x ml		
x sample bottles, Teflon, y ml		
...		
...		
x filters with x syringes, RC		
x filters with x syringes, PTFE		
...		
Chemical substances for treatment		
Cooling box/freezer		
Key to open well head		
Tools box		
xxx sample protocols		
Generator and cables		
Fuel/oil/coolant		
Distilled water		
Cleaning material and substances		
Water level meter		
pH-meter		last calibrated:
O_2-meter		last calibrated:
EC-meter		
Thermometers		

Annex B-2: Sampling Protocol

Sampling Protocol	
Name of Monitoring Program	
Name of Institution	
Name of Responsible Monitoring Staff	
Sampling Ordered by	
Location Data	
Identification No.	
Name of Monitoring Site	
Name of Owner	
East Coordinate/ Latitude	
North Coordinate/Longitude	
Elevation (land surface)	
Elevation (reference point)	
Borehole Data	
Total depth	
Position of well screens	
Aquifer(s)	
Lithological description	
Inner Casing Diameter(s)	
Dates	
Well Purging	
Type of Purging/Type of Pump	
Time Well Purging started	
Duration of Purging [min]	
Discharge [l/min]	
Depth of Pump Setting	
Well Sampling	
Sampling Date	
Static Water Level (before purging)	
Static Water Level (after purging)	
Discharge during Sampling [l/min]	
Sampling Device	
Number of Samples & Sizes of Samples	
Containment Type(s) & Material(s)	
Field measurements	
EC [µS/cm]	
pH	
Redox [mV]	
O_2 [mg/l]	
T [°C]	
Color	
Turbidity	
Odor	
Sample Treatments	
Filtration Method	
Mesh Size of Filter	
Samples Filtered	
Treatment Sample 1	

Sampling Protocol	
Treatment Sample 2	
Treatment Sample 3	
Sample Conservation	
Cooling to +4°C	Samples no.
Freezing to -20°C	Samples no.
Storage	
Name and Location of Temporary Storage Site for Sample x	
Duration of Storage (from – to) for Sample x	
Storage Conditions for Sample x	
Laboratory	
Name of Laboratory	
Analysis Date	
Laboratory Identification No.	
Analytical Methods	
Noticeable Results (e.g. above xyz Standard)	
Analysis Results entered (Name/Date)	

Photos, Sketch maps, Signatures

Annex B-3: Sample Treatment and Conservation Methods

Techniques generally suitable for the preservation of samples -- Physico-chemical and chemical analysis

The information in table 1 is only a general guide to the preservation of samples. The complex nature of natural and waste waters necessitates, before analysis, a verification of the stability of each type of sample treated according to the methods proposed.

Parameter to be studied	Type of container P = Plastics (e.g. polyethylene, PTFE, PVC, PET) G =Glass BG = Borosilicate glass	Preservation technique	Place of analysis	Maximum recommended preservation time before analysis [2]	Comments	International Standard (The numbers refer to annex A.)
Acidity and alkalinity	P or G	Cooling to between 2 °C and 5 °C	Laboratory	24 h	Samples should preferably be analyzed at the spot where the sample is taken (particularly for samples high in dissolved gases)	
Aluminum dissolved [1]	P	Filtration at the place of sampling and acidification of the filtrate to pH < 2	Laboratory	1 month	The dissolved aluminum and that adhering to suspended matter can be determined from the same sample.	
total		Acidification to pH <2	Laboratory	1 month		
Ammonia, free and ionized	P or G	Acidification to pH < 2 with H_2SO_4, cooling to between 2 °C and 5 °C	Laboratory	24 h		ISO 5664 ISO 6778 ISO 7150
		Cooling to between 2 °C and 5 °C	Laboratory	6 h		

Parameter to be studied	Type of container P = Plastics (e.g. polyethylene, PTFE, PVC, PET) G =Glass BG = Borosilicate glass	Preservation technique	Place of analysis	Maximum recommended preservation time before analysis [2)]	Comments	International Standard (The numbers refer to annex A.)
AOX (absorbable organic halides)	G	Acidification to pH < 2 with nitric acid, cooling to between 2 °C and 5 °C, storage in the dark	Laboratory	3 days	Analyze as soon as possible. Refer to relevant International Standard for details for particular types of water	ISO 9562
Arsenic	P or G	Acidification to pH < 2	Laboratory	1 month	HCl should be used if the hydride technique is used for analysis	ISO 6595
Barium	P or BG	See **aluminum**			Do not use H_2SO_4	
BOD (biochemical oxygen demand)	P or G (Glass is preferable in the case of low BOD)	Cooling to between 2 °C and 5 °C and storage in the dark	Laboratory	24 h		ISO 5815
Boron and borates	P		Laboratory	1 month		ISO 9390
Bromides and bromine compounds	P or G	Cooling to between 2 °C and 5 °C	Laboratory	24 h	Samples should be kept out of direct sunlight	
Cadmium	P or BG	See **aluminum**				ISO 5961 191
Calcium	P or G	-	Laboratory	24 h	48 h may be possible but exercise caution for samples of conductivity above 70 mS/m.	ISO 60581101
		Acidification to pH < 2	Laboratory	1 month	Acidification (do not use H_2SO_4) permits determination of the calcium from the same sample as the other metals.	ISO 6059 ISO 7980

Parameter to be studied	**Type of container P = Plastics (e.g. polyethylene, PTFE, PVC, PET) G =Glass BG = Borosilicate glass**	**Preservation technique**	**Place of analysis**	**Maximum recommended preservation time before analysis [2)]**	**Comments**	**International Standard (The numbers refer to annex A.)**
Carbon dioxide	P or G	-	On site	-		
Carbon, organic	G	Acidification to pH < 2 with H_2SO_4, Cooling to between 2 °C and 5 °C and storage in the dark	Laboratory	1 week	The preservation technique will depend on the method of analysis to be used. The test should be carried out as soon as possible.	ISO 8245
	P	Freezing to - 20 °C	Laboratory	1 month	Freezing (- 20 °C) may be used in certain cases.	
Chlorides	P or G	-	Laboratory	1 month		ISO 9297
Chlorine, residual	P or G	-	On site	-	Transport in dark. The analysis should be carried out as soon as possible.	ISO 7393
Chlorophyll	P or G	Cooling to 4 °C	Laboratory	24 h	Transport in dark.	
		After filtration and freezing of the residue	Laboratory	1 month		
Chromium (VI)	P or BG	Cooling to between 2 °C and 5 °C	Laboratory	24 h		
Chromium, total	P or BG	See **aluminum**				ISO 9174
Cobalt	P or BG	See **aluminum**				ISO 8288
COD (chemical oxygen demand)	P or G (Glass is preferable in the case of low COD)	Acidification to pH < 2 with H_2SO_4, Cooling to between 2 °C and 5 °C and storage in the dark	Laboratory	5 days		ISO 6060
	P	Freezing to - 20 °C	Laboratory	1 month		
Color	P or G	-	On site			ISO 7887

Parameter to be studied	Type of container P = Plastics (e.g. polyethylene, PTFE, PVC, PET) G =Glass BG = Borosilicate glass	Preservation technique	Place of analysis	Maximum recommended preservation time before analysis [2)]	Comments	International Standard (The numbers refer to annex A.)
		Cooling to between 2 °C and 5 °C and storage in the dark	Laboratory	24 h		
Conductivity	P or G	Cooling to between 2 °C and 5 °C	Laboratory	24 h	The test should preferably be carried out on site.	ISO 7888
Copper	P or BG	See **aluminum**				ISO 8288
Cyanides, easily liberated	P	The preservation technique will depend on the method of analysis to be used.				ISO 6703-2
Cyanides, total	P	The preservation technique will depend on the method of analysis to be used.				ISO 6703-1
Detergents	See **surfactants**					
Dry residue	See **total residue**					
Fluorides	P but not PTFE	-	Laboratory	1 month		
Greases, oils, hydrocarbons	Glass washed with solvent (e.g. pentane) used for extraction	Extraction on site where practicable and Cooling to between 2 °C and 5 °C	Laboratory	24 h	It is recommended that, immediately after sampling, the extraction agent used in the method of analysis or extraction be added, or the extraction be carried out, on site (but local safety regulations should be followed).	ISO 10359-1
Heavy metals (except mercury)	P or BG	See **aluminum**				ISO 8288
Hydrazine	G	Acidification 1 mol/l (100 ml per liter of sample) and storage in the dark	Laboratory	24 h		
Hydrocarbons	See **greases**					

Parameter to be studied	Type of container P = Plastics (e.g. polyethylene, PTFE, PVC, PET) G =Glass BG = Borosilicate glass	Preservation technique	Place of analysis	Maximum recommended preservation time before analysis [2)]	Comments	International Standard (The numbers refer to annex A.)
Hydrogen carbonates	See **alkalinity**					
Iodides	Glass	Cooling to between 2 °C and 5 °C	Laboratory	24 h	Samples should be kept out of direct sunlight.	
		Alkalization to pH11	Laboratory	1 month		
Iron (II)	P or BG	Acidification to pH < 1 with HCL and exclusion of atmospheric oxygen	On site or in laboratory	24 h		
Iron, total	P or BG	See **aluminum**				ISO 6332
Kjeldahl-nitrogen	P or BG	Acidification to pH < 2 with H_2SO_4, Cooling to between 2 °C and 5 °C and storage in the dark	Laboratory	24 h	Do not acidify if free ammonia is to be measured on same sample.	ISO 5663
Lead	P or BG	See **aluminum**			Do not use H_2SO_4	ISO 8288
Lithium	P	-	Laboratory	1 month		
		Acidification to pH < 2	Laboratory	1 month	Acidification permits determination of the lithium from the same sample as the other metals.	
Magnesium	P or BG	**See calcium**				ISO 6059 ISO 7980
Manganese	P or BG	See **aluminum**				ISO 6333
Mercury, total	BG	Acidification to pH < 2 with $HN0_3$ and addition of $K_2Cr_2O_7$ (0,05 % (m/m) final concentration)	Laboratory	1 month	Particular care is needed to ensure that the samples containers are free from contamination	ISO 5666

Parameter to be studied	Type of container P = Plastics (e.g. polyethylene, PTFE, PVC, PET) G =Glass BG = Borosilicate glass	Preservation technique	Place of analysis	Maximum recommended preservation time before analysis [2)]	Comments	International Standard (The numbers refer to annex A.)
Nickel	P or BG	See **aluminum**				ISO 8288
Nitrate	P or G	Acidification to pH < 2 or cooling to between 2 °C and 5 °C	Laboratory	24 h		ISO 7890
		On-site filtration with a membrane filter of pore size 0,45 µm and cooling to between 2 °C and 5 °C	Laboratory	48 h	For ground and surface waters	
Nitrite	P or G	Cooling to between 2 °C and 5 °C	Laboratory	24 h		ISO 6777
Odour	G	Cooling to between 2 °C and 5 °C	Laboratory (for quantitative analysis)	6 h	The test can be carried out on site (qualitative analysis)	
Organic chlorine	See **AOX**					
Orthophosphate, total	B or G	Cooling to between 2 °C and 5 °C	Laboratory	24 h	The analysis should be carried out as soon as possible	ISO 6878-1
Orthophosphates, dissolved	B or G	The sample should be filtered at the time of sampling. Cooling to between 2 °C and 5 °C	Laboratory	24 h	The analysis should be carried out as soon as possible	ISO 6878-1
Oxygen	P or G	-	On site			ISO 5813 ISO 5814
	G	Fixing of the oxygen on site and storage in the dark	Laboratory	4 days at most	Fix the oxygen in accordance with the method of analysis used.	
Ozone	-	-	On site	-		

Parameter to be studied	Type of container P = Plastics (e.g. polyethylene, PTFE, PVC, PET) G =Glass BG = Borosilicate glass	Preservation technique	Place of analysis	Maximum recommended preservation time before analysis [2)]	Comments	International Standard (The numbers refer to annex A.)
Permanganate index	G	Acidification to pH < 2 with H_2SO_4, cooling to between 2 °C and 5 °C and storage in the dark	Laboratory	2 days	Analyze as soon as possible. Acidification in accordance with the start of the analytical method can be a useful preservation technique.	ISO 8467
	P	Freezing to - 20 °C	Laboratory	1 month		
Pesticides, organochlorine	G (washed with solvent)	Cooling to between 2 °C and 5 °C and storage in the dark	Laboratory	24 h	It is recommended that, immediately after sampling, the extraction agent used in the method of analysis be added, or that extraction be carried out on site.	
Pesticides, organophos-phorus	G (washed with solvent)	Cooling to between 2 °C and 5 °C and storage in the dark	Laboratory	24 h	Extraction should be commenced as soon as possible after sampling, preferably within 24 h.	
Petroleum and derivatives	See **greases, oils and hydrocarbons**					
pH	P or G	-	On site		The test should be carried as soon as possible and preferably immediately on site after sampling	
Phenol index	BG	Inhibition of biochemical oxidation by $CuSO_4$ and acidification with H_3PO_4 to pH <	Laboratory	24 h	The preservation technique will depend on the method of analysis to be used.	ISO 6439

Parameter to be studied	**Type of container P = Plastics (e.g. polyethylene, PTFE, PVC, PET) G =Glass BG = Borosilicate glass**	**Preservation technique**	**Place of analysis**	**Maximum recommended preservation time before analysis [2)]**	**Comments**	**International Standard (The numbers refer to annex A.)**
		2				
Phenols	BG	Cooling to between 2 °C and 5 °C and storage in the dark	Laboratory	24 h	Extraction should be commenced as soon as possible	
Phosphorus, dissolved	BG or G	Cooling to between 2 °C and 5 °C. Immediate on-site filtration necessary	Laboratory	24 h	The use of iodized glass containers for samples is recommended when low concentrations are being examined. (A bottle can be iodized by placing a few crystals of iodine into the sealed container, which is then heated which is then heated to 60 °C for 8 h. It should be noted that the iodine can leach back into the sample, thus becoming an interferent in the analysis. It is recommended that consultation with the analyst be carried out prior to using this technique.	ISO 6878-1
Phosphorus, total	BG or G	Cooling to between 2 °C and 5 °C and storage in the dark	Laboratory	24 h	See above	

Parameter to be studied	Type of container P = Plastics (e.g. polyethylene, PTFE, PVC, PET) G =Glass BG = Borosilicate glass	Preservation technique	Place of analysis	Maximum recommended preservation time before analysis 2)	Comments	International Standard (The numbers refer to annex A.)
		Acidification to pH < 2 with H_2SO_4	Laboratory	1 month	See above	
Potassium	See **lithium**					ISO 9964-2 ISO 9964-3
Selenium	G or BG	Acidification to pH < 1, except if selenides are present. If present, alkalize to pH > 11 with NaOH.	Laboratory	1 month		ISO 9965
Silicates, dissolved	P	Filtration at the place of sampling, acidification to pH < 2 with H_2SO_4 and cooling to between 2 °C and 5 °C	Laboratory	24 h		
Silicates, total	P	As for dissolved silicates	Laboratory	24 h		
Silver	P or BG	See **aluminum**			Do not use HCl. Some forms of silver need addition of cyanide for stabilization.	
Sodium	See **lithium**					ISO 9964-1 ISO 9964-3

Parameter to be studied	Type of container P = Plastics (e.g. polyethylene, PTFE, PVC, PET) G =Glass BG = Borosilicate glass	Preservation technique	Place of analysis	Maximum recommended preservation time before analysis [2)]	Comments	International Standard (The numbers refer to annex A.)
Sulfates	P or G	Cooling to between 2 °C and 5 °C	Laboratory	1 week	With waste water note that hydrogen sulfide may be formed; therefore hydrogen peroxide should be added to the sample. For samples with high BOD (e.g. > 200 mg/1) hydrochloric acid should be added instead, noting the possible hazard of released hydrogen sulfide.	ISO 9280
Sulfides (easily liberated)	P or G	Fix samples immediately on site by alkalization, if necessary, with sodium carbonate followed by addition of zinc acetate.	Laboratory	24 h	Stabilize according to the relevant International Standard	
Sulfides	P or G	Fix samples immediately on site by alkalization, if necessary, with sodium carbonate followed by addition of zinc acetate. Fill sample bottle to exclude air completely.	Laboratory	-	Analyze as soon as possible. Stabilize according to the relevant International Standard	
Sulfites	P or G	Fixing on site by addition of 1 ml of 2,5 % (m/m) solution of EDTA per 100 ml of sample	Laboratory	48 h		

Parameter to be studied	Type of container P = Plastics (e.g. polyethylene, PTFE, PVC, PET) G =Glass BG = Borosilicate glass	Preservation technique	Place of analysis	Maximum recommended preservation time before analysis 2)	Comments	International Standard (The numbers refer to annex A.)
Surfactants, cationic	G	Cooling to between 2 °C and 5 °C	Laboratory	48 h	Rinse glass containers as described in ISO 7875-1 and ISO 7875-2. Analyze samples as soon as possible. To prevent adsorption on the container wall, add on site 5 mg/l of a linear alkylethoxylated nonionic surfactant.	
Surfactants, anionic	G	Acidification to pH < 2 with H_2SO_4, and cooling to between 2 °C and 5 °C	Laboratory	48 h	Rinse glass containers as described in ISO 7875-1. Analyze samples as soon as possible.	ISO 7875-1 1321
Surfactants, nonionic	G	Addition of 40 % (VM formaldehyde to give a 1 % (V/V) solution; cool to between 2 °C and 5 °C and ensure sampling container is completely filled.	Laboratory	1 month	Rinse glass containers as described in ISO 7875-2. Analyze samples as soon as possible.	ISO 7875-2 1331
Suspended and sedimentary matter	P or G	-	Laboratory	24 h	The test should be carried out as soon as possible and preferably on site.	
Tin	P or BG	See **aluminum**			Do not use HN03- If organo-tin is present, use acetic acid for preservation for total tin analysis, but if speciation is required then freeze and analyze as soon as possible.	

Parameter to be studied	Type of container P = Plastics (e.g. polyethylene, PTFE, PVC, PET) G =Glass BG = Borosilicate glass	Preservation technique	Place of analysis	Maximum recommended preservation time before analysis [2)]	Comments	International Standard (The numbers refer to annex A.)
Total hardness	See **calcium**					
Total residue (dry extract)	P or G	Cooling to between 2 °C and 5 °C	Laboratory	24 h		
Turbidity	P or G	-	Laboratory	24 h	The test should preferably be carried out on site.	ISO 7027
Uranium	P or BG	See **aluminum**				
zinc	P or BG	See **aluminum**				ISO 8288

1) Dissolved: Denotes that which passes through a filter of pore size 0,45 µm.

2) If a preservation period is not specified, it is generally unimportant. The indication "1 month" represents preservations without particular difficulty.

Annex B-4: Required containers, preservation techniques, and holding times

adopted from Wisconsin Department of Natural Resources (internet download)

Parameter	Container[b]	Preservative	Maximum Holding Time
Bacterial Test			
Coliform, fecal and total	P,G	Cool, 4°C 0.008% $Na_2S_2O_3$	6 hours
Fecal streptococci	P,G	Cool, 4°C 0.008% $Na_2S_2O_3$	6 hours
Inorganic Tests			
Acidity	P,G	Cool, 4°C	14 days
Alkalinity	P,G	Cool, 4°C	14 days
Ammonia	P,G	Cool, 4°C H_2SO_4 to pH < 2	28 days
Biochemical oxygen demand	P,G	Cool, 4°C	48 hours
Biochemical oxygen demand, carbonaceous	P,G	Cool, 4°C	48 hours
Bromide	P,G	None required	28 days
Chemical oxygen demand	P,G	Cool, 4°C H_2SO_4 to pH < 2	28 days
Chloride	P,G	None required	28 days
Chlorine, total residual	P,G	None required	Analyze immediately
Color	P,G	Cool, 4°C	48 hours
Cyanide, total and amenable to chlorination	P,G	Cool, 4°C NaOH to pH > 12	14 days
Fluoride	P	None required	28 days
Hardness	P,G	HNO_3 to pH < 2	6 months
Hydrogen ion (pH)	P,G	None required	Analyze immediately
Kjeldahl and organic nitrogen	P,G	Cool, 4°C H_2SO_4 to pH < 2	28 day
Metals			
Chromium (VI)	P,G	Cool, 4°C	24 hours
Mercury	P,G	HNO_3 to pH < 2	28 days
Metals, except above	P,G	HNO_3 to pH < 2	6 months

Parameter	Container[b]	Preservative	Maximum Holding Time
Nitrate	P,G	Cool, 4°C	48 hours
Nitrate-nitrite	P,G	Cool, 4°C H_2SO_4 to pH < 2	28 days
Nitrite	P,G	Cool, 4°C	48 hours
Oil and grease	G	Cool, 4°C H_2SO_4 to pH < 2	28 days
Organic carbon	P,G	Cool, 4°C HCl or H_2SO_4 to pH < 2	28 days
Orthophosphate	P,G	Filter immediately Cool, 4°C	48 hours
Oxygen, dissolved probe	G	None required	Analyze immediately
Phenols	G	Cool, 4°C H_2SO_4 to pH < 2	28 days
Phosphorus (elemental)	G	Cool, 4°C	48 hours
Phosphorus, total	P,G	Cool, 4°C H_2SO_4 to pH < 2	28 days
Residue, total	P,G	Cool, 4°C	7 days
Residue, filterable	P,G	Cool, 4°C	7 days
Residue, non-filterable (TSS)	P,G	Cool, 4°C	7 days
Residue, settleable	P,G	Cool, 4°C	48 hours
Residue, volatile	P,G	Cool, 4°C	7 days

[a] Adopted from Environmental Protection Agency Guidelines for handling and preserving samples.

[b] P = plastic, G = glass.

Annex B-5: Types of Preservation and Parameters

Allocating the corresponding parameters to one of the non-specific types of preservation given in this table is intended to help the user to select a type of preservation which is effective for several parameters simultaneously, if necessary. However, limited applicability should be checked in each individual case on the basis of the data for individual materials. Parameters not listed should not normally be preserved using these methods.

Preservation by	Suitable for	Not suitable for
Acidification to pH < 2	Alkaline metals Aluminum Ammonia (but not if separate free and total ammonia analyses are required) Arsenic Alkaline earth metals Nitrate Total hardness Phosphorus, total Heavy rnetals	Cyanides Sulfides Carbonates, bicarbonates, carbon dioxide Sulfites, sulfur dioxide Thiosulfates Nitrites Phosphonates (if speciation is required) Soaps and esters Hexamethylenetetramine Do not use sulfuric acid for calcium, strontium, barium, radium, lead. Do not use hydrochloric acid for silver, thallium, lead, bismuth, mercury(1) and antimony. Do not use nitric acid for tin.
Alkalization to pH > 11	Iodides	Most organic compounds, heavy metals, especially in lower valence states. Some metals form soluble anions at higher valence states. (Depending on the anion present consult solubility tables.) Ammoniac ammonium Amines and amides Phosphorus, total Hydrazine Hydroxylamine
Cooling to 2 °C to 5 °C	Acidity, alkalinity Ammonium Bromide and bromine compounds	

Preservation by	Suitable for	Not suitable for
	Chlorophyll Iodides Kjeldahl-nitrogen Conductivity Nitrate Nitrite Odor Orthophosphates Phosphorus Sulfates Surfactants, cationic Dry residue Total residue Biological tests	
Deep freezing (- 20°C)	Chlorophyll	Not suitable for biota if a distinction is to be made between liquid content and biota cell content
	COD	Dissolved gases
	Biological tests, toxicity tests	Microorganisms for identification
	Organic carbon	Changes can also occur in many solutes requiring homogenization after thawing.
		Precipitation (and polymerization) can occur making resolution difficult.
		Conversely some polyacids depolymerize. Suitability should be evaluated before routine use.

Annex B-6: Suitability of Materials for Sampling of Individual Parameters

Source: DVWK (1990)

Parameter	**PTFE**	**Stainless Steel**	**PVC**
Inorganic			
Heavy metals	+	(+)	+ [2)]
Corrosive conditions	+	(+)	+
Organic			
Tensides	+	+ [1)]	(+)
Phenols	(+)	(+)	(+)
Chloronitrogen complexes	+	(+) [1)]	(+)
Aliphatic and aromatic hydrocarbons	+ [1)]	+ [1)]	-
Chlorinated hydrocarbons	+ [2)]		(+)
Pesticides	(+) [1)]	+ [1)]	-
Ketones, esters, aldehydes	(+) [1)]	+ [1)]	-
Bacteria, microorganisms	+	+	(+)

+ suitable

(+) partially suitable

- unsuitable

[1)] based on analogue results

[2)] under unfavorable conditions increased likelihood of poor results

Annex B-7: Index of Potential Sources of Drinking Water Contamination

(Potential Source and Possibly Associated Contaminant)

Source: US Environmental Protection Agency (*http://www.epa.gov/safewater/swp/sources1.html*)

POTENTIAL SOURCE	CONTAMINANT
Commercial / Industrial	
Above-ground storage tanks	Arsenic, Barium, Benzene, Cadmium, 1,4-Dichlorobenzene or P-Dichlorobenzene, cis 1,2-Dichloroethylene, trans 1,2-Dichloroethylene, Dichloromethane or Methylene Chloride, Lead, Trichloroethylene (TCE), Tetrachloroethylene or Perchlorethylene (Perc)
Automobile, Body Shops/Repair Shops	Arsenic, Barium, Benzene, Cadmium, Chlorobenzene, Copper, cis 1,2-Dichloroethylene, trans 1,2-Dichloroethylene, 1,4-Dichlorobenzene or P-Dichlorobenzene, Lead, Fluoride, 1,1,1-Trichloroethane or Methyl Chloroform, Dichloromethane or Methylene Chloride, Tetrachloroethylene or Perchlorethylene (Perc), Trichloroethylene (TCE), Xylene (Mixed Isomers)
Boat Repair/Refinishing/Marinas	Benzene, Cadmium, cis 1,2-Dichloroethylene, Coliform, Cryptosporidium, Dichloromethane or Methylene Chloride, *Giardia Lambia*, Lead, Mercury, Nitrate, Nitrite, trans 1,2-Dichloroethylene, Tetrachloroethylene or Perchlorethylene (Perc), Trichloroethylene (TCE), Vinyl Chloride, Viruses
Cement/Concrete Plants	Barium, Benzene, Dichloromethane or Methylene Chloride, Ethylbenzene, Lead, Styrene, Tetrachloroethylene or Perchlorethylene (Perc), Toluene, Xylene (Mixed Isomers)
Chemical/Petroleum Processing	Acrylamide, Arsenic, Atrazine, Alachlor, Aluminum (Fume or Dust), Barium, Benzene, Cadmium, Carbofuran, Carbon Tetrachloride, Chlorobenzene, Copper, Cyanide, 2,4-D, 1,2-Dibromoethane or Ethylene Dibromide (EDB), 1,2-Dichlorobenzene or O-Dichlorobenzene, 1,4-Dichlorobenzene or P-Dichlorobenzene, 1,1-Dichloroethylene or Vinylidene Chloride, cis 1,2 Dichloroethylene, Dichloromethane or Methylene Chloride, Di(2-ethylhexyl) adipate, Di(2-ethylhexyl) phthlate, 1,2-Dichloroethane or Ethylene Dichloride, Dioxin, Endrin, Epichlorohydrin, Ethylbenzene, Hexachlorobenzene, Hexachlorocyclopentadiene, Lead, Mercury, Methoxychlor,Polychlorinated Biphenyls, Selenium, Styrene, Sulfate, Tetrachloroethylene or Perchlorethylene (Perc), Toluene, 1,2,4-Trichlorobenzene, 1,1,1-Trichloroethane or Methyl Chloroform, Trichloroethylene (TCE), Vinyl Chloride, Xylene (Mixed Isomers), Zinc (Fume or Dust)
Construction/Demolition	Arsenic, Asbestos, Benzene, Cadmium, Chloride, Copper,Cyanide, cis 1,2-Dichloroethylene, trans 1,2-Dichloroethylene, Dichloromethane or Methylene Chloride, Fluorides, Lead, Selenium, Tetrachloroethylene or Perchlorethylene (Perc), 1,1,1-Trichloroethane or Methyl Chloroform, Trichloroethylene (TCE), Turbidity, Xylene (Mixed Isomers), Zinc (Fume or Dust)
Dry Cleaners/Dry Cleaning	Tetrachloroethylene or Perchlorethylene (Perc), 1,1,1-Trichloroethane or Methyl Chloroform, 1,1,2-Trichloroethane
Dry Goods Manufacturing	Barium, Benzene, Cadmium, Copper, Dichloromethane or Methylene Chloride, Di(2-ethylhexyl) phthlate, Lead, 1,1,1-Trichloroethane or Methyl Chloroform, Polychlorinated Biphenyls, Tetrachloroethylene or Perchlorethylene (Perc), Toluene, Trichloroethylene (TCE), Xylene (Mixed Isomers)

POTENTIAL SOURCE	**CONTAMINANT**
Electrical/Electronic Manufacturing	Aluminum (Fume or Dust), Antimony, Arsenic, Barium, Benzene, Cadmium, Chlorobenzene, Copper, Cyanide, Carbon Tetrachloride, 1,2-Dichlorobenzene or O-Dichlorobenzene, 1,2-Dichloroethane or Ethylene Dichloride, cis 1,2-Dichloroethylene, trans 1,2-Dichloroethylene, Dichloromethane or Methylene Chloride, Di(2-ethylhexyl) phthlate, Ethylbenzene, Lead, Mercury, Polychlorinated Biphenyls, Selenium, Styrene, Sulfate, Tetrachloroethylene or Perchlorethylene (Perc), 1,1,1-Trichloroethane or Methyl Chloroform, 1,1,2-Trichloroethane, Trichloroethylene (TCE), Thallium, Toluene, Vinyl Chloride, Xylene (Mixed Isomers), Zinc (Fume or Dust)
Fleet/Trucking/ Bus Terminals	Arsenic, Acrylamide, Barium, Benzene, Benzo(a)pyrene, Cadmium, Chlorobenzene, Cyanide, Carbon Tetrachloride, 2,4-D, 1,2-Dichlorobenzene or O-Dichlorobenzene, 1,4-Dichlorobenzene or P-Dichlorobenzene, 1,2-Dichloroethane or Ethylene Dichloride, cis 1,2-Dichloroethylene, trans 1,2-Dichloroethylene, Dichloromethane or Methylene Chloride, Di(2-ethylhexyl) phthlate, Epichlorohydrin, Heptachlor (and Epoxide), Lead, Mercury, Methoxychlor, Pentachlorophenol, Propylene Dichloride or 1,2-Dichloropropane, Selenium, Styrene, Toxaphene, Tetrachloroethylene or Perchlorethylene (Perc), Toluene, 1,1,1-Trichloroethane or Methyl Chloroform, Trichloroethylene (TCE), Vinyl Chloride, Xylene (Mixed Isomers)
Food Processing	Arsenic, Benzene, Cadmium, Copper, Carbon Tetrachloride, Dichloromethane or Methylene Chloride, Lead, Mercury, Picloram, Tetrachloroethylene or Perchlorethylene (Perc), Toluene, 1,1,1-Trichloroethane or Methyl Chloroform, Trichloroethylene (TCE), Xylene (Mixed Isomers)
Funeral Services/Taxidermy	Glyphosate, Dichloromethane or Methylene Chloride, Nitrate, Nitrite, Total Coliforms, Viruses
Furniture Repair/Manufacturing	Barium, 1,2-Dichloroethane or Ethylene Dichloride, Dichloromethane or Methylene Chloride, Ethylbenzene, Lead, Mercury, Selenium, Trichloroethylene (TCE)
Gas Stations (see also above ground/underground storage tanks, motor-vehicle drainage wells)	cis 1,2-Dichloroethylene, trans 1,2-Dichloroethylene, Dichloromethane or Methylene Chloride, Tetrachloroethylene or Perchlorethylene (Perc), Trichloroethylene (TCE)
Graveyards/Cemetaries	Dalapon, Lindane, Nitrate, Nitrite, Total Coliforms, Viruses.
Hardware/Lumber/Parts Stores	Aluminum (Fume or Dust), Barium, Benzene, Cadmium, Chlorobenzene, Copper, Dichloromethane or Methylene Chloride, Di(2-ethylhexyl)adipate, Di(2-ethylhexyl) phthlate, 1,4-Dichlorobenzene or P-Dichlorobenzene, Ethylbenzene, Lead, Mercury, Tetrachloroethylene or Perchlorethylene (Perc), 1,1,1-Trichloroethane or Methyl Chloroform, Trichloroethylene (TCE), Toluene, Xylene (Mixed Isomers)
Historic Waste Dumps/Landfills	Atrazine, Alachlor, Carbofuran, cis 1,2-Dichloroethylene, trans 1,2-Dichloroethylene, Diquat, Dalapon, Glyphosate, Dichloromethane or Methylene Chloride, Nitrate, Nitrite, Oxamyl (Vydate), Sulfate, Simazine, Tetrachloroethylene or Perchlorethylene (Perc), Trichloroethylene(TCE)
Home Manufacturing	Arsenic, Barium, Benzene, Cadmium, Chlorobenzene, Copper, Carbon Tetrachloride, 1,2-Dichlorobenzene or O-Dichlorobenzene, cis 1,2-Dichloroethylene, trans 1,2-Dichloroethylene, Dichloromethane or Methylene Chloride, Di(2-ethylhexyl) phthlate, Ethylbenzene, Lead, Mercury, Selenium, Styrene, Tetrachloroethylene or Perchlorethylene (Perc), 1,1,1-Trichloroethane or Methyl Chloroform, Trichloroethylene (TCE), Toluene, Turbidity, Xylene (Mixed Isomers)

POTENTIAL SOURCE	**CONTAMINANT**
Industrial Waste Disposal Wells (see UIC for more information on concerns, and locations)	Acrylamide, Arsenic, Atrazine, Alachlor, Aluminum (Fume or Dust), Ammonia, Barium, Benzene, Cadmium, Carbofuran, Carbon Tetrachloride, Chlorobenzene, Copper, Cyanide, 2,4-D, 1,2-Dibromoethane or Ethylene Dibromide (EDB), 1,2-Dichlorobenzene or O-Dichlorobenzene, 1,4-Dichlorobenzene or p-Dichlorobenzene, 1,1-Dichloroethylene or Vinylidene Chloride, cis 1,2 Dichloroethylene, Dichloromethane or Methylene Chloride, Di(2-ethylhexyl) adipate, Di(2-ethylhexyl) phthlate, 1,2-Dichloroethane or Ethylene Dichloride, Dioxin, Endrin, Epichlorohydrin, Hexachlorobenzene, Hexachlorocyclopentadiene, Lead, Mercury, Methoxychlor, Oxamyl (Vydate), Polychlorinated Biphenyls, Selenium, Styrene, Sulfate, Tetrachloroethylene or Perchlorethylene (Perc), Toluene, 1,2,4-Trichlorobenzene, 1,1,1-Trichloroethane or Methyl Chloroform, Trichloroethylene (TCE), Vinyl Chloride, Xylene (Mixed Isomers), Zinc (Fume or Dust)
Junk/Scrap/Salvage Yards	Barium, Benzene, Copper, Dalapon, cis 1,2-Dichloroethylene, Diquat, Glyphosate, Lead, Polychlorinated Biphenyls, Sulfate, Simazine, Trichloroethylene (TCE), Tetrachloroethylene or Perchlorethylene (Perc)
Machine Shops	Arsenic, Aluminum (Fume or Dust), Barium, Benzene, Boric Acid, Cadmium, Chlorobenzene, Copper, Cyanide, Carbon Tetrachloride 2,4-D, 1,4-Dichlorobenzene or P-Dichlorobenzene, 1,2-Dichloroethane or Ethylene Dichloride, 1,1-Dichloroethylene or Vinylidene Chloride, cis 1,2-Dichloroethylene, trans 1,2-Dichloroethylene, Dichloromethane or Methylene Chloride, Di(2-ethylhexyl) phthlate, Ethylbenzene, Fluoride, Hexachlorobenzene, Lead, Mercury, Polychlorinated Biphenyls, Pentachlorophenol, Selenium, Styrene, Tetrachloroethylene or Perchlorethylene (Perc), Toluene, 1,1,1-Trichloroethane or Methyl Chloroform, 1,1,2-Trichloroethane, Trichloroethylene (TCE), Xylene (Mixed Isomers), Zinc (Fume or Dust)
Medical/Vet Offices	Arsenic, Acrylamide, Barium, Benzene, Cadmium, Copper, Cyanide, Carbon Tetrachloride, Dichloromethane or Methylene Chloride, 1,2-Dichloroethane or Ethylene Dichloride, Lead, Mercury, Methoxychlor, 1,1,1-Trichloroethane or Methyl Chloroform, Radionuclides, Selenium, Silver, Tetrachloroethylene or Perchlorethylene (Perc), 2,4,5-TP (Silvex), Thallium, Xylene (Mixed Isomers)
Metal Plating/Finishing/Fabricating	Antimony, Aluminum (Fume or Dust), Arsenic, Barium, Benzene, Cadmium, Carbon Tetrachloride, Chlorobenzene, Chromium, Copper, Cyanide, 1,4-Dichlorobenzene or P-Dichlorobenzene, cis 1,2-Dichloroethylene, trans 1,2-Dichloroethylene, Dichloromethane or Methylene Chloride, Di(2-ethylhexyl) adipate, Ethylbenzene,Lead, Mercury, Polychlorinated Biphenyls, Pentachlorophenol, Selenium, Styrene, Sulfate, Tetrachloroethylene or Perchlorethylene (Perc), , Thallium, Toluene, 1,1,1-Trichloroethane or Methyl Chloroform, 1,1,2-Trichloroethane, Trichloroethylene(TCE), Vinyl Chloride, Xylene (Mixed Isomers), Zinc (Fume or Dust)
Military Installations	Arsenic, Barium, Benzene, Cadmium, Chlorobenzene, 1,2-Dichlorobenzene or O-Dichlorobenzene, 1,2-Dichloroethane or Ethylene Dichloride, cis 1,2-Dichloroethylene, trans 1,2-Dichloroethylene, Dichloromethane or Methylene Chloride, Hexachlorobenzene, Lead, Mercury, Methoxychlor, 1,1,1-Trichloroethane or Methyl Chloroform, Radionuclides, Selenium, Tetrachloroethylene or Perchlorethylene (Perc), , Toluene, Trichloroethylene (TCE)
Mines/Gravel Pits	Lead, Selenium, Sulfate, Tetrachloroethylene or Perchlorethylene (Perc), 1,1,1-Trichloroethane or Methyl Chloroform, Turbidity
Motor Pools	cis 1,2-Dichloroethylene, trans 1,2-Dichloroethylene, Dichloromethane or Methylene Chloride,
Motor Vehicle Waste Disposal Wells (gas stations, repair shops) See UIC for more on concerns for these sources http://www.epa.gov/safewater/uic/cv-fs.html	Arsenic, Barium, Benzene, Cadmium, Chlorobenzene, Copper, cis 1,2-Dichloroethylene, trans 1,2-Dichloroethylene, 1,4-Dichlorobenzene or P-Dichlorobenzene, Lead, Fluoride, 1,1,1-Trichloroethane or Methyl Chloroform, Dichloromethane or Methylene Chloride, Tetrachloroethylene or Perchlorethylene (Perc), Trichloroethylene (TCE), Xylene (Mixed Isomers)

POTENTIAL SOURCE	CONTAMINANT
Office Building/Complex	Barium, Benzene, Cadmium, Copper, 2,4-D, Diazinon, 1,2-Dichlorobenzene or O-Dichlorobenzene, Dichloromethane or Methylene Chloride, Diquat, 1,2-Dichloroethane or Ethylene Dichloride, Ethylbenzene, Glyphosate, Lead, Mercury, Selenium, Simazine, Tetrachloroethylene or Perchlorethylene (Perc), 1,1,1-Trichloroethane or Methyl Chloroform, Trichloroethylene (TCE), Vinyl Chloride, Xylene (Mixed Isomers)
Photo Processing/Printing	Acrylamide, Aluminum (Fume or Dust), Arsenic, Barium, Benzene, Cadmium, Carbon Tetrachloride, Chlorobenzene, Copper, Cyanide, 1,1-Dichloroethylene or Vinylidene Chloride, cis 1,2-Dichloroethylene, trans 1,2-Dichloroethylene, Dichloromethane or Methylene Chloride, Di(2-ethylhexyl) phthlate, 1,2-Dichlorobenzene or O-Dichlorobenzene, 1,4-Dichlorobenzene or P-Dichlorobenzene, 1,2-Dichloroethane or Ethylene Dichloride, 1,2-Dibromoethane or Ethylene Dibromide (EDB), Heptachlor epoxide, Hexachlorobenzene, Lead, Lindane, Mercury, Methoxychlor, Propylene Dichloride or 1,2-Dichloropropane, Selenium, Styrene, Tetrachloroethylene or Perchlorethylene (Perc), 1,1,1-Trichloroethane or Methyl Chloroform, Toluene, 1,1,2-Trichloroethane, Trichloroethylene(TCE), Vinyl Chloride, Xylene (Mixed Isomers), Zinc (Fume or Dust)
Synthetic / Plastics Production	Antimony, Arsenic, Barium, Benzene, Cadmium, Carbon Tetrachloride, Chlorobenzene, Copper, Cyanide, 1,2-Dichlorobenzene or O-Dichlorobenzene, 1,4-Dichlorobenzene or P-Dichlorobenzene, 1,2-Dichloroethane or Ethylene Dichloride, cis 1,2-Dichloroethylene, trans 1,2-Dichloroethylene, Dichloromethane or Methylene Chloride, Di(2-ethylhexyl) adipate, Di(2-ethylhexyl) phthlate, Ethylbenzene, Hexachlorobenzene, Lead, Mercury, Methyl Chloroform or 1,1,1-Trichloroethane, Pentachlorophenol, Selenium, Styrene, Tetrachloroethylene or Perchlorethylene (Perk), Toluene,, Trichloroethylene (TCE), Vinyl Chloride, Xylene (Mixed Isomers), Zinc (Fume or Dust)
RV/Mini Storage	Arsenic, Barium, Cyanide, 2,4-D, Endrin, Lead, Methoxychlor
Railroad Yards/Maintenance/Fueling Areas	Atrazine, Barium, Benzene, Cadmium, Dalapon, 1,4-Dichlorobenzene or P-Dichlorobenzene, cis 1,2-Dichloroethylene, trans 1,2-Dichloroethylene, Dichloromethane or Methylene Chloride, Lead, Mercury, Tetrachloroethylene or Perchlorethylene (Perc), Trichloroethylene (TCE).
Research Laboratories	Arsenic, Barium, Benzene, Beryllium Powder, Cadmium, Carbon Tetrachloride, Chlorobenzene, Cyanide, 1,2-Dichloroethane or Ethylene Dichloride, 1,1-Dichloroethylene or Vinylidene Chloride, cis 1,2-Dichloroethylene, trans 1,2-Dichloroethylene, Dichloromethane or Methylene Chloride, Endrin, Lead, Mercury, Polychlorinated Biphenyls, Selenium, Tetrachloroethylene or Perchlorethylene (Perc), Thallium, Thiosulfates, Toluene, 1,1,1-Trichloroethane or Methyl Chloroform, Trichloroethylene (TCE), Vinyl Chloride, Xylene (Mixed Isomers)
Retail Operations	Arsenic, Barium, Benzene, Cadmium, 2,4-D, 1,2-Dichloroethane or Ethylene Dichloride, Lead, Mercury, Styrene, Tetrachloroethylene or Perchlorethylene (Perc), Toluene, 1,1,1-Trichloroethane, Vinyl Chloride
Underground Storage Tanks	Arsenic, Barium, Benzene, Cadmium, 1,4-Dichlorobenzene or P-Dichlorobenzene, cis 1,2-Dichloroethylene, trans 1,2-Dichloroethylene, Dichloromethane or Methylene Chloride, Lead, Tetrachloroethylene or Perchlorethylene (Perc), Trichloroethylene (TCE).
Wood Preserving/Treating	cis 1,2-Dichloroethylene, trans 1,2-Dichloroethylene, Lead, Sulfate
Wood/Pulp/Paper Processing	Arsenic, Barium, Benzene, Cadmium, Carbon Tetrachloride, Copper, Dichloromethane or Methylene Chloride, Dioxin, 1,2-Dichloroethane or Ethylene Dichloride, Ethylbenzene, Lead, Mercury, Polychlorinated Biphenyls, Selenium, Styrene, Tetrachloroethylene or Perchlorethylene (Perc), Trichloroethylene (TCE), Toluene, 1,1,1-Trichloroethane or Methyl Chloroform, Xylene (Mixed Isomers)

POTENTIAL SOURCE	CONTAMINANT
Residential / Municipal	
Airports (Maintenance/Fueling Areas)	Arsenic, Barium, Benzene, Cadmium, Carbon Tetrachloride, cis 1,2- Dichloroethylene, Dichloromethane or Methylene Chloride, Ethylbenzene, Lead, Mercury, Selenium, Tetrachloroethylene or Perchlorethylene (Perc), 1,1,1-Trichloroethane or Methyl Chloroform, Trichloroethylene (TCE), Xylene (Mixed Isomers)
Apartments and Condominiums	Atrazine, Alachlor, Coliform, Cryptosporidium, Dalapon, Diquat, *Giardia Lambia*, Glyphosate, Nitrate, Nitrite, Picloram,Sulfate,Simazine, Vinyl Chloride, Viruses
Camp Grounds/RV Parks	Benomyl, Coliform, Cryptosporidium, Diquat, Dalapon, *Giardia Lambia*, Glyphosate, Isopropanol, Nitrate, Nitrite, Picloram,Sulfate,Simazine, Turbidity, Vinyl Chloride, Viruses
Cesspools - Large Capacity (see UIC for more information)	Atrazine, Alachlor, Carbofuran, Coliform, Cryptosporidium, Diquat, Dalapon, *Giardia Lambia*, Glyphosate, Nitrate, Nitrite, Oxamyl (Vydate), Picloram,Sulfate,Simazine, Vinyl Chloride, Viruses
Drinking Water Treatment Facilities	Atrazine, Benzene, Cadmium, Cyanide, Fluoride, Lead, Polychlorinated Biphenyls, Toluene, Total Trihalomethanes, 1,1,1-Trichloroethane or Methyl Chloroform
Gas Pipelines	cis 1,2-Dichloroethylene, trans 1,2-Dichloroethylene, Dichloromethane or Methylene Chloride, Tetrachloroethylene or Perchlorethylene (Perc), Trichloroethylene or TCE
Golf Courses and Urban Parks	Arsenic, Atrazine, Benzene, Chlorobenzene, Carbofuran, 2,4-D, Diquat, Dalapon, Glyphosate, Lead, Methoxychlor, Nitrate, Nitrite, Picloram, Simazine, Turbidity
Housing developments	Atrazine, Alachlor, Coliform, Cryptosporidium, Carbofuran, Diquat, Dalapon, *Giardia Lambia*, Glyphosate, Dichloromethane or Methylene Chloride, Nitrate, Nitrite, Picloram, Simazine, Trichloroethylene (TCE), Turbidity, Vinyl Chloride, Viruses
Landfills/Dumps	Arsenic, Atrazine, Alachlor, Barium, Benzene, Cadmium, Carbofuran, cis 1,2 Dichloroethylene, Diquat, Glyphosate, Lead, Lindane, Mercury, 1,1,1-Trichloroethane or Methyl Chloroform, Dichloromethane or Methylene Chloride, Nitrate, Nitrite, Picloram, Selenium, Simazine, Trichloroethylene (TCE)
Public Buildings (e.g., schools, town halls, fire stations, police stations) and Civic Organizations	Arsenic, Acrylamide, Barium, Benzene, Beryllium Powder, Cadmium, Carbon Tetrachloride, Chlorobenzene, Cyanide, 2,4-D, 1,2-Dichlorobenzene or O-Dichlorobenzene, 1,4-Dichlorobenzene or P-Dichlorobenzene, Dichloromethane or Methylene Chloride, Di(2-ethylhexyl) phthlate, 1,2-Dichloroethane or Ethylene Dichloride, Endothall, Endrin, 1,2-Dibromoethane or Ethylene Dibromide (EDB), Lead, Lindane, Mercury, Methoxychlor, Selenium, Toluene, 1,1,1-Trichloroethane or Methyl Chloroform, Trichloroethylene (TCE), Vinyl Chloride, Xylene (Mixed Isomers)
Septic Systems	Atrazine, Alachlor, Carbofuran, Coliform, Cryptosporidium, Diquat, Dalapon, *Giardia Lambia*, Glyphosate, Nitrate, Nitrite, Oxamyl (Vydate), Picloram, Sulfate, Simazine, Vinyl Chloride, Viruses
Sewer Lines	Coliform, Cryptosporidium, Diquat, Dalapon, *Giardia Lambia*, Glyphosate, Nitrate, Nitrite, Oxamyl (Vydate), Picloram,Sulfate,Simazine, Vinyl Chloride, Viruses
Stormwater infiltration basins/injection into wells (UIC Class V), runoff zones	Atrazine, Alachlor, Coliform, Cryptosporidium, Carbofuran, Chlorine, Diquat, Dalapon, *Giardia Lambia*, Glyphosate, Dichloromethane or Methylene Chloride, Nitrate, Nitrite, Nitrosamine, Oxamyl (Vydate), Phosphates, Picloram, Simazine, Trichloroethylene(TCE), Turbidity, Vinyl Chloride, Viruses
Transportation Corridors (e.g.,	Dalapon, Picloram, Simazine, Sodium, Sodium Chloride, Turbidity

POTENTIAL SOURCE	**CONTAMINANT**
Roads, railroads)	
Utility Stations	Arsenic, Barium, Benzene, Cadmium, Chlorobenzene, Cyanide, 2,4-D, 1,4-Dichlorobenzene or P-Dichlorobenzene, 1,2-Dichloroethane or Ethylene Dichloride, cis 1,2-Dichloroethylene, trans 1,2-Dichloroethylene, Dichloromethane or Methylene Chloride, Lead, Mercury, Picloram, Toluene, 1,1,2,2- Tetrachloroethane, Tetrachloroethylene or Perchlorethylene (Perc), Trichloroethylene (TCE), Xylene (Mixed Isomers)
Waste Transfer /Recycling	Coliform, Cryptosporidium, *Giardia Lambia*, Nitrate, Nitrite, Vinyl Chloride, Viruses
Wastewater Treatment Facilities/Discharge locations (incl. land disposal and underground injection of sludge)	Cadmium, Coliform, Cryptosporidium, cis 1,2-Dichloroethylene, trans 1,2-Dichloroethylene, Dichloromethane or Methylene Chloride, Fluoride, *Giardia Lambia*, Lead, Mercury, Nitrate, Nitrite, Tetrachloroethylene or Perchlorethylene (Perc) Selenium, sulfate,Trichloroethylene (TCE), Vinyl Chloride, Viruses
Agricultural / Rural	
Auction Lots/Boarding Stables	Coliform, Cryptosporidium, *Giardia Lambia*, Nitrate, Nitrite,Sulfate,Viruses
Animal Feeding Operations/ Confined Animal Feeding Operations	Coliform, Cryptosporidium, *Giardia Lambia*, Nitrate, Nitrite, Sulfate, Turbidity, Viruses
Bird Rookeries/Wildlife feeding /migration zones	Coliform, Cryptosporidium, *Giardia Lambia*, Nitrate , Nitrite , Sulfate, Turbidity, Viruses
Crops - Irrigated + Non-irrigated	Benzene, 2,4-D, Dalapon, Dinoseb, Diquat, Glyphosate, Lindane, Lead, Nitrate, Nitrite , Picloram, Simazine, Turbidity
Dairy operations	Coliform, Cryptosporidium, *Giardia Lambia*, Nitrate , Nitrite,Sulfate,Turbidity, Viruses
Drainage Wells, Lagoons and Liquid Waste Disposal - Agricultural	Atrazine, Alachlor, Coliform, Cryptosporidium, Carbofuran, Diquat, Dalapon, *Giardia Lambia*, Glyphosate, Nitrate, Nitrite, Oxamyl (Vydate), Picloram,Sulfate,Simazine, Vinyl Chloride, Viruses
Managed Forests/Grass Lands	Atrazine, Diquat, Glyphosate, Picloram, Simazine, Turbidity
Pesticide/Fertilizer Storage Facilities	Atrazine, Alachlor, Carbofuran, Chlordane, 2,4-D, Diquat, Dalapon, 1,2-Dibromo-3-Chloropropane or DBCP, Glyphosate, Nitrate, Nitrite, Oxamyl (Vydate), Picloram, Simazine, 2,4,5-TP (Silvex)
Rangeland/Grazing lands	Coliform, Cryptosporidium, *Giardia Lambia*, Nitrate, Nitrite, Sulfate, Turbidity, Viruses
Residential Wastewater lagoons	Atrazine, Alachlor, Carbofuran, Coliform, Cryptosporidium, Diquat, Dalapon, *Giardia Lambia*, Glyphosate, Nitrate, Nitrite, Oxamyl (Vydate), Picloram,Sulfate,Simazine, Vinyl Chloride, Viruses
Rural Homesteads	Atrazine, Alachlor, Carbofuran, Coliform, Cryptosporidium, cis 1,2-Dichloroethylene, trans 1,2-Dichloroethylene, Diquat, Dalapon, *Giardia Lambia*, Glyphosate, Nitrate, Nitrite,Oxamyl (Vydate), Picloram, Sulfate, Simazine, Vinyl Chloride, Viruses
MISCELLANEOUS SOURCES	
Abandoned drinking water wells (conduits for contamination)	Atrazine, Alachlor, Coliform, Cryptosporidium, Carbofuran, Diquat, Dalapon, *Giardia Lambia*, Glyphosate, Dichloromethane or Methylene Chloride, Nitrate, Nitrite, Oxamyl (Vydate), Picloram, Simazine, Trichloroethylene (TCE), Turbidity, Vinyl Chloride, Viruses

POTENTIAL SOURCE	CONTAMINANT
Naturally Occurring	Arsenic, Asbestos, Barium, Cadmium, Chromium, Coliform, Copper, Cryptosporidium, Fluoride, *Giardia Lambia,* Iron, Lead, Manganese, Mercury, Nitrate, Nitrite, Radionuclides, Selenium, Silver, Sulfate, Viruses, Zinc (Fume or Dust)
Underground Injection Control (UIC) Wells CLASS I - deep injection of hazardous and non-hazardous wastes into aquifers separated from underground sources of drinking water	see UIC (link: http://www.epa.gov/safewater/types)
UIC Wells CLASS II deep injection wells of fluids associated with oil/gas production (for more detailed list of sites click here)	see UIC
UIC Wells CLASS III re-injection of water/steam into mineral formations for mineral extraction	see UIC
UIC Wells CLASS IV - officially banned. Inject hazardous or radioactive waste into or above underground sources of drinking water	see UIC
UIC Wells Class V (SHALLOW INJECTION WELLS). Click here for more information on sources of UIC Class V wells	see UIC

Parameter lists for groups of potential contaminants are available in LfU (2001), annex 7 [in German].

Annex B-8: Potential Drinking Water Contaminant Index

(Contaminants, Maximum Allowable Contents and Potential Sources)

Source: US Environmental Protection Agency (*http://www.epa.gov/safewater/swp/sources1.html*)

Contaminant Name	MCL 1 (mg/L)	MCLG2 (if applicable) (mg/L)	**Potential Source(s)**	
PRIMARY DRINKING WATER CONTAMINANTS*				
Inorganic Contaminants				
Antimony	0.006	0.006	**Commercial / Industrial**	Electrical / Electronic Manufacturing, Fire Retardents, Metal Plating / Finishing / Fabricating, Petroleum Processing, Synthetics / Plastics Production
Arsenic	0.05	None	**Commercial / Industrial**	Automobile Body Shops / Repair Shops, Chemical / Petroleum Processing, Construction / Demolition, Electrical / Electronic Manufacturing, Fleet / Trucking / Bus Terminals, Food Processing, Home Manufacturing, Machine Shops, Medical / Vet Offices, Metal Plating / Finishing / Fabricating, Military Installations, Photo Processing / Printing, Research Laboratories, Retail Operations, Wood / Pulp / Paper Processing
			Residential / Municipal	Airports (Maintenance / Fueling Areas), Golf Courses and Parks, Landfills / Dumps, Public Buildings and Civic Organizations, Schools, Utility Stations
			Agricultural/Rural	Orchards, Hebicides, Erosion of Natural Deposits
Asbestos	7 million fibers per Liter	7 million fibers per Liter	**Commercial / Industrial**	Construction / Demolition, Erosion of natural deposits

Contaminant Name	MCL 1 (mg/L)	MCLG2 (if applicable) (mg/L)	**Potential Source(s)**	
Barium	2	2	**Commercial / Industrial**	Automobile Body Shops / Repair Shops, Cement / Concrete Plants, Chemical / Petroleum Processing, Dry Goods Manufacturing, Electrical / Electronic Manufacturing, Fleet / Trucking / Bus Terminals, Furniture Repair / Manufacturing, Hardware / Lumber / Parts Stores, Home Manufacturing, Junk / Scrap / Salvage Yards, Machine Shops, Office Building / Complex, Medical / Vet Offices, Metal Plating / Finishing / Fabricating, Military Installations, Photo Processing / Printing, Railroad Yards / Maintenance / Fueling Areas, Research Laboratories, Retail Operations, Synthetics / Plastics Production, Underground Storage Tanks, Wood / Pulp / Paper Processing
			Residential / Municipal	Airports (Maintenance / Fueling Areas), Landfills / Dumps, Public Buildings and Civic Organizations, RV / Mini Storage, Utility Stations, Erosion of natural deposits
Beryllium Powder	0.004	0.004	**Commercial / Industrial**	Research Laboratories, Metal Plating/Finishing/Fabricating, Coal-Burning Factories, Electrical/Electronic Manufacturing, Aerospace and Defense Industries
			Residential / Municipal	Public Buildings and Civic Organizations, Schools
Cadmium	0.005	0.005	**Commercial / Industrial**	Automobile Body Shops / Repair Shops, Boat Repair / Refinishing, Chemical / Petroleum Processing, Construction / Demolition, Drinking Water Treatment, Dry Goods Manufacturing, Electrical / Electronic Manufacturing, Fleet / Trucking / Bus Terminals, Food Processing, Hardware / Lumber / Parts Stores, Home Manufacturing, Machine Shops, Metal Plating / Finishing / Fabricating, Military Installations, Office Building / Complex, Photo Processing / Printing, Medical / Vet Offices, Railroad Yards / Maintenance / Fueling Areas, Research Laboratories, Retail Operations, Synthetics / Plastics Producers, Underground Storage Tanks Wood / Pulp / Paper Processing
			Residential / Municipal	Airports (Maintenance / Fueling Areas), Landfills / Dumps, Public Buildings and Civic Organizations, Schools, Utility Stations, Wastewater
Chromium	0.1	0.1	**Commercial / Industrial**	Metal Plating / Finishing / Fabricating, Erosion of natural deposits
Copper	TT[3]	1.3	**Commercial / Industrial**	Automobile Body Shops / Repair Shops, Chemical / Petroleum Processing, Construction / Demolition, Dry Goods Manufacturing, Electrical / Electronic Manufacturing, Food Processing, Hardware / Lumber / Parts Stores, Home Manufacturing, Junk / Scrap / Salvage Yards, Machine Shops, Medical / Vet Offices, Metal Plating / Finishing / Fabricating, Office Building / Complex, Photo Processing / Printing, Synthetics / Plastics Producers, Transportation Corridors, Wood / Pulp / Paper Processing , Erosion of natural deposits
Cyanide	0.2	0.2	**Commercial / Industrial**	Chemical / Petroleum Processing, Construction / Demolition, Electrical / Electronic Manufacturing, Fertilizer Factories, Fleet / Trucking / Bus Terminals, Machine Shops, Medical / Vet Offices, Metal Plating / Finishing / Fabricating, Photo Processing / Printing, Research Laboratories, Synthetics / Plastics Producers

Contaminant Name	MCL 1 (mg/L)	MCLG2 (if applicable) (mg/L)	**Potential Source(s)**	
			Residential / Municipal	Waste Water Treatment, Public Buildings and Civic Organizations, Schools, RV / Mini Storage, Utility Stations
Fluoride	4	4	**Commercial / Industrial**	Construction / Demolition, Fertilizer Factories, Aluminum Factories
			Residential/Municipal	Drinking Water Treatment additive, Erosion natural deposits
Lead	TT	0.015	**Commercial / Industrial**	Automobile Body Shops / Repair Shops, Boat Repair / Refinishing, Cement / Concrete Plants, Chemical / Petroleum Processing, Construction / Demolition, Dry Goods Manufacturing, Electrical / Electronic Manufacturing, Fleet / Trucking / Bus Terminals, Food Processing, Furniture Repair / Manufacturing, Hardware / Lumber / Parts Stores, Home Manufacturing, Junk / Scrap / Salvage Yards, Machine Shops, Medical / Vet Offices, Metal Plating / Finishing / Fabricating, Military Installations, Mines / Gravel Pits, Office Building / Complex, Photo Processing / Printing, Railroad Yards / Maintenance / Fueling Areas, Research Laboratories, Retail Operations, Synthetics / Plastics Producers, Underground Storage Tanks, Wholesale Distribution Activities, Wood Preserving / Treating, Wood / Pulp / Paper Processing
			Residential / Municipal	Airports (Maintenance / Fueling Areas), Drinking Water Pipe Corrosion, Golf Courses and Parks, Landfills / Dumps, Public Buildings and Civic Organizations, Schools, Utility Stations, Wastewater, Erosion of natural deposits
Inorganic Mercury	0.002	0.002	**Commercial / Industrial**	Automobile Body Shops / Repair Shops, Boat Repair / Refinishing, Chemical / Petroleum Processing, Electrical / Electronic Manufacturing, Fleet / Trucking / Bus Terminals, Food Processing, Furniture Repair / Manufacturing, Hardware / Lumber / Parts Stores, Home Manufacturing, Machine Shops, Office Building / Complex, Photo Processing / Printing, Medical / Vet Offices, Metal Plating / Finishing / Fabricating, Military Installations, Railroad Yards / Maintenance / Fueling Areas, Research Laboratories, Retail Operations, Synthetics / Plastics Producers, Wood / Pulp / Paper Processing
			Residential / Municipal	Airports (Maintenance / Fueling Areas), Landfills / Dumps, Public Buildings and Civic Organizations, RV / Mini Storage, Schools, Utility Stations, Wastewater
			Agricultural / Rural	Crops - Irrigated + Non irrigated, Erosion of Natural Deposits
Nitrate	10	10	**Commercial / Industrial**	Boat Repair / Refinishing, Historic Waste Dumps / Landfills
			Residential / Municipal	Apartments and Condominiums, Camp Grounds / RV Parks, Golf Courses and Parks, Housing, Landfills / Dumps, Septic Systems Waste Transfer / Recycling, Wastewater
			Agricultural / Rural	Auction Lots / Boarding Stables, Confined Animal Feeding Operations, Crops - Irrigated + Non irrigated, Lagoons and Liquid Waste, Pesticide / Fertilizer / Petroleum Storage Sites, Rural Homesteads , Erosion of Natural Deposits
Nitrite	1	1	**Commercial / Industrial**	Boat Repair / Refinishing, Historic Waste Dumps / Landfills

Contaminant Name	MCL 1 (mg/L)	MCLG2 (if applicable) (mg/L)	**Potential Source(s)**	
			Residential / Municipal	Apartments and Condominiums, Camp Grounds / RV Parks, Golf Courses and Parks, Housing, Landfills / Dumps, Septic Systems, Waste Transfer / Recycling, Wastewater
			Agricultural / Rural	Auction Lots / Boarding Stables, Confined Animal Feeding Operations, Lagoons and Liquid Waste, Pesticide / Fertilizer / Petroleum Storage Sites, Rural Homesteads, Crops - Irrigated + Non irrigated, Erosion of Natural Deposits
Selenium			**Commercial / Industrial**	Chemical / Petroleum Processing, Construction / Demolition, Electrical / Electronic Manufacturing, Fleet / Trucking / Bus Terminals, Furniture Repair / Manufacturing, Home Manufacturing, Machine Shops, Medical / Vet Offices, Metal Plating / Finishing / Fabricating, Military Installations, Mines / Gravel Pits, Office Building / Complex, Photo Processing / Printing, Research Laboratories, Synthetics / Plastics Producers, Wood / Pulp / Paper Processing, Erosion of Natural Deposits
			Residential / Municipal	Airports (Maintenance / Fueling Areas), Landfills / Dumps, Public Buildings and Civic Organizations, Schools, Wastewater
Thallium	0.002	0.0005	**Commercial / Industrial**	Electrical / Electronic Manufacturing, Medical / Vet Offices, Metal Plating / Finishing / Fabricating, Research Laboratories
Organic Contaminants				
Acrylamide	TT	zero	**Residential/Municipal**	Drinking Water and Waste Water Treatment
Alachlor	0.002	zero	**Commercial / Industrial**	Chemical / Petroleum Processing, Historic Waste Dumps / Landfills, Injection Wells
			Residential / Municipal	Apartments and Condominiums, Housing, Injection Wells, Landfills / Dumps, Septic Systems Wells
			Agricultural / Rural	Injection Wells, Lagoons and Liquid Waste, Pesticide / Fertilizer / Petroleum Storage Sites, Rural Homesteads
Atrazine	0.003	0.003	**Commercial / Industrial**	Chemical / Petroleum Processing, Funeral Services / Graveyards, Historic Waste Dumps / Landfills, Injection Wells, Office Building / Complex, Railroad Yards
			Residential / Municipal	Apartments and Condominiums, Some Surface Water Drinking Water Treatment, Golf Courses and Parks, Housing, Injection Wells, Landfills / Dumps, Schools, Septic Systems, Utility Stations, Wells
			Agricultural / Rural	Injection Wells, Lagoons and Liquid Waste, Managed Forests, Pesticide / Fertilizer / Petroleum Storage Sites, Rural Homesteads

Contaminant Name	MCL 1 (mg/L)	MCLG2 (if applicable) (mg/L)	**Potential Source(s)**	
Benzene	0.005	zero	**Commercial / Industrial**	Automobile Body Shops / Repair Shops, Boat Repair / Refinishing, Cement / Concrete Plants, Chemical / Petroleum Processing, Construction / Demolition, Dry Goods Manufacturing, Electrical / Electronic Manufacturing, Fleet / Trucking / Bus Terminals, Food Processing, Hardware / Lumber / Parts Stores, Home Manufacturing, Junk / Scrap / Salvage Yards, Machine Shops, Medical / Vet Offices, Metal Plating / Finishing / Fabricating, Military Installations, Office Building / Complex, Photo Processing / Printing, Railroad Yards / Maintenance / Fueling Areas, Research Laboratories, Retail Operations, Synthetic / Plastics Production, Synethetics / Plastics Producers, Underground Storage Tanks, Wholesale Distribution Activities, Wood / Pulp / Paper Processing
			Residential / Municipal	Airports (Maintenance / Fueling Areas), Drinking Water Treatment, Golf Courses and Parks, Landfills / Dumps, Public Buildings and Civic Organizations, Utility Stations, Schools
			Agricultural / Rural	Crops - Irrigated + Non irrigated
Benzo(a)pyrene	0.0002	zero	**Commercial / Industrial**	Fleet / Trucking / Bus Terminals
Carbofuran	0.04	0.04	**Commercial / Industrial**	Chemical / Petroleum Processing, Historic Waste Dumps / Landfills, Injection Wells
			Residential / Municipal	Golf Courses and Parks, Housing, Injection Wells, Landfills / Dumps, Septic Systems, Wells
			Agricultural / Rural	Injection Wells, Lagoons and Liquid Waste, Pesticide / Fertilizer / Petroleum Storage Sites, Rural Homesteads, Rice and Alfalfa Fields
Carbon Tetrachloride	0.005	zero	**Commercial / Industrial**	Chemical / Petroleum Processing, Electrical / Electronic Manufacturing, Fleet / Trucking / Bus Terminals, Food Processing, Home Manufacturing, Machine Shops, Medical / Vet Offices, Metal Plating / Finishing / Fabricating, Photo Processing / Printing, Research Laboratories, Synthetics / Plastics Producers, Wood / Pulp / Paper Processing
			Residential / Municipal	Airports (Maintenance / Fueling Areas), Public Buildings and Civic Organizations, Schools
Chlordane	0.002	zero	**Agricultural / Rural**	Pesticide / Fertilizer / Petroleum Storage Sites
Chlorobenzene	0.1	0.1	**Commercial / Industrial**	Automobile Body Shops / Repair Shops, Chemical / Petroleum Processing, Electrical / Electronic Manufacturing, Fleet / Trucking / Bus Terminals, Hardware / Lumber / Parts Stores, Home Manufacturing, Machine Shops, Metal Plating / Finishing / Fabricating, Military Installations, Photo Processing / Printing, Research Laboratories, Synthetics / Plastics Producers
			Residential / Municipal	Golf Courses and Parks, Public Buildings and Civic Organizations, Schools, Utility Stations
2,4-D	0.07	0.07	**Commercial / Industrial**	Chemical / Petroleum Processing, Fleet / Trucking / Bus Terminals, Machine Shops, Retail Operations, Office Building / Complex
			Agricultural / Rural	Crops - Irrigated + Non irrigated, Pesticide / Fertilizer / Petroleum Storage Sites

Contaminant Name	MCL 1 (mg/L)	MCLG2 (if applicable) (mg/L)	**Potential Source(s)**	
			Residential / Municipal	Golf Courses and Parks, Public Buildings and Civic Organizations, RV / Mini Storage, Schools, Utility Stations
Dalapon	0.2	0.2	**Commercial / Industrial**	Historic Waste Dumps / Landfills, Injection Wells, Junk / Scrap / Salvage Yards, Railroad Yards
			Residential / Municipal	Apartments and Condominiums, Camp Grounds / RV Parks, Housing, Injection Wells, Septic Systems, Transportation Corridors, Utility Stations, Wells, Golf Courses and Parks
			Agricultural / Rural	Crops - Irrigated + Non irrigated, Injection Wells, Lagoons and Liquid Waste, Pesticide / Fertilizer / Petroleum Storage Sites, Rural Homesteads
Di(2-ethylhexyl) adipate	0.4	0.4	**Commercial / Industrial**	Chemical / Petroleum Processing, Hardware / Lumber / Parts Stores, Metal Plating / Finishing / Fabricating, Synthetics / Plastics Producers
Di(2-ethylhexyl) phthalate	0.006	zero	**Commercial / Industrial**	Chemical / Petroleum Processing, Dry Goods Manufacturing, Electrical / Electronic Manufacturing, Fleet / Trucking / Bus Terminals, Hardware / Lumber / Parts Stores, Home Manufacturing, Machine Shops, Photo Processing / Printing, Synthetics / Plastics Producers
			Residential / Municipal	Public Buildings and Civic Organizations
Dibromochloropropane	0.0002	zero	**Agricultural / Rural**	Pesticide / Fertilizer / Petroleum Storage Sites; Soybeans, Cotton, Pineapples and Orchards
1,2-Dibromoethane or Ethylene Dibromide (EDB)	0.00005	zero	**Commercial / Industrial**	Chemical / Petroleum Processing, Photo Processing / Printing
			Residential / Municipal	Public Buildings and Civic Organizations
1,4-Dichlorobenzene or P-Dichlorobenzene	0.075	0.075	**Commercial / Industrial**	Automobile Body Shops / Repair Shops, Chemical / Petroleum Processing, Fleet / Trucking / Bus Terminals, Hardware / Lumber / Parts Stores, Machine Shops, Metal Plating / Finishing / Fabricating, Photo Processing / Printing, Railroad Yards / Maintenance / Fueling Areas, Synthetics / Plastics Producers, Underground Storage Tanks
			Residential / Municipal	Public Buildings and Civic Organizations, Schools Utility Stations
1,2-Dichlorobenzene or O-Dichlorobenzene	0.6	0.6	**Commercial / Industrial**	Chemical / Petroleum Processing, Electrical / Electronic Manufacturing, Fleet / Trucking / Bus Terminals, Home Manufacturing, Military Installations, Photo Processing / Printing, Synthetic / Plastics Production, Office Building / Complex

Contaminant Name	MCL 1 (mg/L)	MCLG2 (if applicable) (mg/L)	**Potential Source(s)**	
1,2-Dichloroethane or Ethylene Dichloride	0.005	zero	**Commercial / Industrial**	Chemical / Petroleum Processing, Electrical / Electronic Manufacturing, Fleet / Trucking / Bus Terminals, Furniture Repair / Manufacturing, Machine Shops, Medical / Vet Offices, Military Installations, Office Building / Complex, Photo Processing / Printing, Synthetic / Plastics Production, Research Laboratories, Retail Operations
			Residential / Municipal	Public Buildings and Civic Organizations, Schools, Wood / Pulp / Paper Processing, Utility Stations
			Residential / Municipal	Public Buildings and Civic Organizations, Schools
1,1-Dichloroethylene or Vinylidene Chloride	0.007	0.007	**Commercial / Industrial**	Chemical / Petroleum Processing, Machine Shops, Photo Processing / Printing, Research Laboratories
cis 1,2 - Dichloroethylene	0.07	0.07	**Commercial / Industrial**	Automobile Body Shops / Repair Shops, Chemical / Petroleum Processing, Construction / Demolition, Electrical / Electronic Manufacturing, Fleet / Trucking / Bus Terminals, Gas Stations, Historic Waste Dumps / Landfills, Home Manufacturing, Injection Wells, Junk / Scrap / Salvage Yards, Machine Shops, Metal Plating / Finishing / Fabricating, Military Installations, Motor Pools, Photo Processing / Printing, Synthetic / Plastics Production, Railroad Yards, Research Laboratories, Wood Preserving / Treating
			Residential / Municipal	Airports (Maintenance / Fueling Areas), Injection Wells, Landfills / Dumps, Utility Stations, Wastewater
			Agricultural / Rural	Injection Wells, Rural Homesteads
trans 1,2 - Dichloroethylene			**Commercial / Industrial**	Automobile Body Shops / Repair Shops, Chemical / Petroleum Processing, Construction / Demolition, Electrical / Electronic Manufacturing, Fleet / Trucking / Bus Terminals, Gas Stations, Historic Waste Dumps / Landfills, Home Manufacturing, Injection Wells, Junk / Scrap / Salvage Yards, Machine Shops, Metal Plating / Finishing / Fabricating, Military Installations, Motor Pools, Photo Processing / Printing, Synthetic / Plastics Production, Railroad Yards, Research Laboratories, Wood Preserving / Treating
			Residential / Municipal	Airports (Maintenance / Fueling Areas), Injection Wells, Landfills / Dumps, Utility Stations, Wastewater
			Agricultural / Rural	Injection Wells

Contaminant Name	MCL 1 (mg/L)	MCLG2 (if applicable) (mg/L)	Potential Source(s)	
Dichloromethane or Methylene Chloride	0.005	zero	**Commercial / Industrial**	Automobile Body Shops / Repair Shops, Cement / Concrete Plants, Chemical / Petroleum Processing, Construction / Demolition, Dry Goods Manufacturing, Electrical / Electronic Manufacturing, Funeral Services / Graveyards, Fleet / Trucking / Bus Terminals, Food Processing, Gas Stations, Hardware / Lumber / Parts Stores, Home Manufacturing, Machine Shops, Medical / Vet Offices, Metal Plating / Finishing / Fabricating, Military Installations, Motor Pools, Office Building / Complex, Photo Processing / Printing, Railroad Yard / Maintenance / Fueling Areas, Research Laboratories, Synthetics / Plastics Producers, Wood / Pulp / Paper Processing
			Residential / Municipal	Airports (Maintenance / Fueling Areas), Public Buildings and Civic Organizations, Schools
Dinoseb	0.007	0.007	**Agricultural / Rural**	Crops - Irrigated + Non irrigated, Soybeans and vegetables
Dioxin	3E-08	zero	**Commercial / Industrial**	Chemical / Petroleum Processing, Wood / Pulp / Paper Processing
Diquat	0.02	0.02	**Commercial / Industrial**	Funeral Services / Graveyards, Historic Waste Dumps / Landfills, Junk / Scrap / Salvage Yards, Injection Wells, Office Building / Complex
			Residential / Municipal	Apartments and Condominiums, Housing, Injection Wells, Landfills / Dumps, Schools, Septic Systems, Wells, Camp Grounds / RV Parks, Golf Courses and Parks
			Agricultural / Rural	Crops - Irrigated + Non irrigated, Injection Wells, Lagoons and Liquid Waste, Managed Forests, Pesticide / Fertilizer / Petroleum Storage Sites, Rural Homesteads
Endothall	0.1	0.1	**Residential / Municipal**	Injection Wells, Public Buildings and Civic Organizations, Schools
Endrin	0.002	0.002	**Commercial / Industrial**	Chemical / Petroleum Processing, Research Laboratories
			Residential / Municipal	Public Buildings and Civic Organizations, RV / Mini Storage, Schools
Ethylbenzene	0.7	0.7	**Commercial / Industrial**	Cement / Concrete Plants, Chemical / Petroleum Processing, Electrical / Electronic Manufacturing, Furniture Repair / Manufacturing, Hardware / Lumber / Parts Stores, Home Manufacturing, Machine Shops, Metal Plating / Finishing / Fabricating, Office Building / Complex, Synthetics / Plastics Producers, Wood / Pulp / Paper Processing
			Residential / Municipal	Airports (Maintenance / Fueling Areas)
Glyphosate	0.7	0.7	**Commercial / Industrial**	Funeral Services / Graveyards, Historic Waste Dumps / Landfills, Injection Wells, Junk / Scrap / Salvage Yards, Office Building / Complex
			Residential / Municipal	Apartments and Condominiums, Camp Grounds / RV Parks, Golf Courses and Parks, Housing, Injection Wells, Landfills / Dumps, Schools, Septic Systems, Wells
			Agricultural / Rural	Crops - Irrigated + Non irrigated, Injection Wells, Lagoons and Liquid Waste, Managed Forests, Pesticide / Fertilizer / Petroleum Storage Sites, Rural Homesteads

Contaminant Name	MCL 1 (mg/L)	MCLG2 (if applicable) (mg/L)	**Potential Source(s)**	
Heptachlor (and Epoxide)	0.0004 -0.0002	zero	**Commercial / Industrial**	Fleet / Trucking / Bus Terminals, Photo Processing / Printing
			Residential / Municipal	Wells
Hexachlorobenzene	0.001	zero	**Commercial / Industrial**	Chemical / Petroleum Processing, Machine Shops, Military Installations, Photo Processing / Printing, Synthetics / Plastics Producers
Hexachlorocyclopentadiene	0.05	0.05	**Commercial / Industrial**	Chemical / Petroleum Processing
Lindane	0.0002	0.0002	**Commercial / Industrial**	Construction / Demolition, Fleet / Trucking / Bus Terminals, Photo Processing / Printing
			Residential / Municipal	Landfills / Dumps, Public Buildings and Civic Organizations
			Agricultural / Rural	Crops - Irrigated + Non irrigated
Methoxychlor	0.04	0.04	**Commercial / Industrial**	Chemical / Petroleum Processing, Fleet / Trucking / Bus Terminals, Medical / Vet Offices, Military Installations, Photo Processing / Printing
			Residential / Municipal	Golf Courses and Parks, Public Buildings and Civic Organizations, RV / Mini Storage
Oxamyl (Vydate)	0.2	0.2	**Commercial / Industrial**	Chemical / Petroleum Processing, Historic Waste Dumps / Landfills, Injection Wells
			Residential / Municipal	Apartments and Condominiums, Housing, Injection Wells, Landfills / Dumps, Septic Systems, Wells
			Agricultural / Rural	Injection Wells, Lagoons and Liquid Waste, Pesticide / Fertilizer / Petroleum Storage Sites, Rural Homesteads , apple, potato, and tomato farming
Pentachlorophenol	0.001	zero	**Commercial / Industrial**	Fleet / Trucking / Bus Terminals, Food Processing, Machine Shops, Metal Plating / Finishing / Fabricating, Synthetics / Plastics Producers
Picloram	0.5	0.5	**Commercial / Industrial**	Historic Waste Dumps / Landfills, Injection Wells
			Residential / Municipal	Apartments and Condominiums, Camp Grounds / RV Parks, Golf Courses and Parks, Housing, Injection Wells, Landfills / Dumps, Septic Systems, Transportation Corridors, Utility Stations, Wells

Contaminant Name	MCL 1 (mg/L)	MCLG2 (if applicable) (mg/L)	**Potential Source(s)**	
			Agricultural / Rural	Crops - Irrigated + Non irrigated, Injection Wells, Lagoons and Liquid Waste, Managed Forests, Pesticide / Fertilizer / Petroleum Storage Sites, Rural Homesteads
Polychlorinated Biphenyls	0.0005	zero	**Commercial / Industrial**	Chemical / Petroleum Processing, Dry Goods Manufacturing, Electrical / Electronic Manufacturing, Junk / Scrap / Salvage Yards, Machine Shops, Metal Plating / Finishing / Fabricating, Research Laboratories, Wood / Pulp / Paper Processing
			Residential / Municipal	Drinking Water Treatment
Propylene Dichloride or 1,2-Dichloropropane	0.005	zero	**Commercial / Industrial**	Fleet / Trucking / Bus Terminals, Photo Processing / Printing
Simazine	0.004	0.004	**Commercial / Industrial**	Historic Waste Dumps / Landfills, Injection Wells, Junk / Scrap / Salvage Yards, Office Building / Complex
			Residential / Municipal	Apartments and Condominiums, Camp Grounds / RV Parks, Golf Courses and Parks, Housing, Injection Wells, Landfills / Dumps, Septic Systems, Transportation Corridors, Utility Stations Wells
			Agricultural / Rural	Crops - Irrigated + Non irrigated, Lagoons and Liquid Waste, Managed Forests, Pesticide / Fertilizer / Petroleum Storage Sites, Rural Homesteads
Styrene	0.1	0.1	**Commercial / Industrial**	Cement / Concrete Plants, Chemical / Petroleum Processing, Electrical / Electronic Manufacturing, Fleet / Trucking / Bus Terminals, Home Manufacturing, Machine Shops, Metal Plating / Finishing / Fabricating, Photo Processing / Printing, Retail Operations, Synthetics / Plastics Producers, Wholesale Distribution Activities, Wood / Pulp / Paper Processing
Tetrachloroethylene or Perchlorethylene (Perc)	0.005	zero	**Commercial / Industrial**	Automobile Body Shops / Repair Shops, Cement / Concrete Plants, Chemical / Petroleum Processing, Construction / Demolition, Drinking Water Treatment, Dry Cleaners / Dry Cleaning, Dry Goods Manufacturing, Electrical / Electronic Manufacturing, Fleet / Trucking / Bus Terminals Food Processing, Gas Stations, Hardware / Lumber / Parts Stores, Historic Waste Dumps / Landfills, Home Manufacturing, Injection Wells, Junk / Scrap / Salvage Yards, Machine Shops, Medical / Vet Offices, Metal Plating / Finishing / Fabricating, Military Installations, Mines / Gravel Pits, Motor Pools, Office Building / Complex, Photo Processing / Printing, Railroad Yards / Maintenance / Fueling Areas, Research Laboratories, Retail Operations, Synthetics / Plastics Producers, Wood / Pulp / Paper Processing
			Residential / Municipal	Airports (Maintenance / Fueling Areas), Injection Wells, Public Buildings and Civic Organizations, Schools, Utility Stations, Wastewater

Contaminant Name	MCL 1 (mg/L)	MCLG2 (if applicable) (mg/L)	**Potential Source(s)**	
Toluene	1	1	**Commercial / Industrial**	Cement / Concrete Plants, Chemical / Petroleum Processing, Drinking Water Treatment, Dry Goods Manufacturing, Electrical / Electronic Manufacturing, Fleet / Trucking / Bus Terminals, Food Processing, Hardware / Lumber / Parts Stores, Home Manufacturing, Machine Shops, Medical / Vet Offices, Metal Plating / Finishing / Fabricating, Military Installations, Research Laboratories, Synthetics / Plastics Producers, Retail Operations, Office Building / Complex, Photo Processing / Printing, Wood / Pulp / Paper Processing
			Residential / Municipal	Public Buildings and Civic Organizations, Schools, Utility Stations
Total Trihalomethanes	0.1	None	**Residential / Municipal**	Drinking Water Treatment
Toxaphene	0.003	zero	**Commercial / Industrial**	Fleet / Trucking / Bus Terminals
2,4,5-TP (Silvex)	0.05	0.05	**Commercial / Industrial**	Medical / Vet Offices
			Agricultural / Rural	Pesticide / Fertilizer / Petroleum Storage Sites
1,2,4-Trichlorobenzene	0.07	0.07	**Commercial / Industrial**	Chemical / Petroleum Processing
1,1,2-Trichloroethane	0.005	0.003	**Commercial / Industrial**	Dry Cleaners / Dry Cleaning, Electrical / Electronic Manufacturing, Machine Shops, Metal Plating / Finishing / Fabricating, Photo Processing / Printing
1,1,1-Trichloroethane or Methyl Chloroform	0.2	0.2	**Commercial / Industrial**	Body Shops/Repair Shops, Chemical / Petroleum Processing, Dry Cleaners / Dry Cleaning, Dry Goods Manufacturing, Electrical / Electronic Manufacturing, Fleet / Trucking / Bus Terminals, Food Processing, Hardware / Lumber / Parts Stores, Home Manufacturing, Machine Shops, Medical / Vet Offices, Metal Plating / Finishing / Fabricating, Military Installations, Mines / Gravel Pits, Office Building / Complex, Photo Processing / Printing, Research Laboratories, Retail Operations, Wholesale Distribution Activities, Wood / Pulp / Paper Processing
			Residential / Municipal	Airports (Maintenance / Fueling Areas), Construction / Demolition Areas, Drinking Water Treatment, Landfills / Dumps, Naturally Occurring, Public Buildings and Civic Organizations, Schools

Contaminant Name	MCL 1 (mg/L)	MCLG2 (if applicable) (mg/L)	**Potential Source(s)**	
Trichloroethylene or TCE	0.005	zero	**Commercial / Industrial**	Automobile Body Shops / Repair Shops, Chemical / Petroleum Processing, Dry Goods Manufacturing, Electrical / Electronic Manufacturing, Fleet / Trucking / Bus Terminals, Food Processing, Furniture Repair / Manufacturing, Hardware / Lumber / Parts Stores, Historic Waste Dumps / Landfills, Home Manufacturing, Injection Wells, Junk / Scrap / Salvage Yards, Machine Shops, Metal Plating / Finishing / Fabricating, Military Installations, Motor Pools, Office Building / Complex, Photo Processing / Printing, Railroad Yards / Maintenance / Fueling Areas, Research Laboratories, Synthetics / Plastics Producers, Underground Storage Tanks, Wood / Pulp / Paper Processing
			Residential / Municipal	Airports (Maintenance / Fueling Areas), Injection Wells, Public Buildings and Civic Organizations, Schools, Utility Stations
Vinyl Chloride	0.002	zero	**Commercial / Industrial**	Boat Repair / Refinishing, Chemical / Petroleum Processing, Electrical / Electronic Manufacturing, Metal Plating / Finishing / Fabricating, Office Building / Complex, Photo Processing / Printing, Fleet / Trucking / Bus Terminals, Research Laboratories, Retail Operations, Synthetic / Plastics Production
			Residential / Municipal	Apartments and Condominiums, Camp Grounds / RV Parks Housing, Public Buildings and Civic Organizations, Septic Systems, Waste Transfer / Recycling Wastewater
			Agricultural / Rural	Confined Animal Feeding Operations Lagoons and Liquid Waste, Rural Homesteads
Xylene (Mixed Isomers)	10	10	**Commercial / Industrial**	Automobile Body Shops / Repair Shops, Cement / Concrete Plants, Chemical / Petroleum Processing, Construction / Demolition, Dry Goods Manufacturing, Electrical / Electronic Manufacturing, Fleet / Trucking / Bus Terminals, Food Processing, Hardware / Lumber / Parts Stores, Home Manufacturing, Machine Shops, Medical / Vet Offices, Metal Plating / Finishing / Fabricating, Office Building / Complex, Photo Processing / Printing, Research Laboratories, Synthetics / Plastics Production, Wood / Pulp / Paper Processing
			Residential / Municipal	Airports (Maintenance / Fueling Areas), Public Buildings and Civic Organizations, Schools, Utility Stations,
Micro-Organisms				
Coliform	5.0%[4]	Zero	**Commercial / Industrial**	Boat Repair / Refinishing
			Residential / Municipal	Apartments and Condominiums, Camp Grounds / RV Parks, Housing, Septic Systems, Waste Transfer / Recycling, Wastewater
			Agricultural / Rural	Auction Lots / Boarding Stables, Confined Animal Feeding Operations, Lagoons and Liquid Waste, Rural Homesteads

Contaminant Name	MCL 1 (mg/L)	MCLG2 (if applicable) (mg/L)	**Potential Source(s)**	
Cryptosporidium			**Commercial / Industrial**	Boat Repair / Refinishing
			Residential / Municipal	Apartments and Condominiums, Camp Grounds / RV Parks, Housing, Septic Systems, Waste Transfer / Recycling, Wastewater
			Agricultural / Rural	Auction Lots / Boarding Stables, Confined Animal Feeding Operations, Dairies, Lagoons and Liquid Waste Dsiposal Sites, Rural Homesteads, Wildlife feeding/migration zones
Giardia Lambia			**Commercial / Industrial**	Boat Repair / Refinishing
			Residential / Municipal	Apartments and Condominiums, Camp Grounds / RV Parks, Housing, Septic Systems, Waste Transfer / Recycling, Wastewater
			Agricultural / Rural	Auction Lots / Boarding Stables, Confined Animal Feeding Operations, Lagoons and Liquid Waste, Rural Homesteads,
Legionella	zero	TT	**All**	Surface Water
Viruses	TT	N/A	**Commercial / Industrial**	Waste Water
			Residential / Municipal	Apartments and Condominiums, Camp Grounds / RV Parks, Housing, Septic Systems, Waste Transfer / Recycling, Wastewater
			Agricultural / Rural	Auction Lots / Boarding Stables, Confined Animal Feeding Operations, Dairies, Grazing lands, Lagoons and Liquid Waste, Rural Homesteads, Wildlife migration/feeding zones
Turbidity	TT	N/A	**Commercial / Industrial**	Construction / Demolition, Home Manufacturing, Mines / Gravel Pits
			Residential / Municipal	Camp Grounds / RV Parks, Golf Courses and Parks, Housing Developments, Industrial Parks, Stormwater discharge sites, Transportation Corridors
			Agricultural / Rural	Crops - Irrigated + Non irrigated, Managed Forests, Animal grazing lands, Animal feedlots, Dairies
Radionuclides				
Beta particles and photon emitters*	Beta: 4 millirems per year;	none	**Commercial / Industrial**	Medical / Vet Offices, Military Installations, Naturally Occurring
Gross Alpha particle activity	15 pCi/L per year;	none	same as above	same as above
Radium 226 & Radium 228 (combined)	5 pCi/L per year	none	same as above	same as above

Contaminant Name	MCL 1 (mg/L)	MCLG2 (if applicable) (mg/L)	Potential Source(s)	
SECONDARY DRINKING WATER CONTAMINANTS				
Contaminant Name	**MCL (mg/L)**	**MCLG[2] (if applicable) (mg/L)**	**Potential Source(s)**	
Aluminum (Fume or Dust)		0.05 to 0.2	**Commercial / Industrial**	Chemical / Petroleum Processing, Electrical / Electronic Manufacturing, Hardware / Lumber / Parts Stores, Machine Shops, Metal Plating / Finishing / Fabricating, Photo Processing / Printing
Chloride		250	**Commercial / Industrial**	Construction / Demolition
Iron		0.3	**Commercial / Industrial**	Historic Waste Dumps / Landfills, Junk / Scrap / Salvage Yards, Naturally Occurring
			Residential / Municipal	Naturally Occurring
			Agricultural / Rural	Naturally Occurring
Manganese		0.05	**Commercial / Industrial**	Historic Waste Dumps / Landfills, Junk / Scrap / Salvage Yards, Naturally Occurring
			Residential / Municipal	Naturally Occurring
Silver		0.1	**Commercial / Industrial**	Medical / Vet Offices, Naturally Occurring
			Residential / Municipal	Naturally Occurring
			Agricultural / Rural	Naturally Occurring
Sulfate		250	**Commercial / Industrial**	Chemical / Petroleum Processing, Electrical / Electronic Manufacturing, Historic Waste Dumps / Landfills, Metal Plating / Finishing / Fabricating, Mines / Gravel Pits, Wood Preserving / Treating, Injection Wells, Junk / Scrap / Salvage Yards
			Residential / Municipal	Apartments and Condominiums, Camp Grounds / RV Parks, Injection Wells, Septic Systems, Wastewater, Wells, Naturally Occuring
			Agricultural / Rural	Auction Lots / Boarding Stables, Confined Animal Feeding Operations, Injection Wells, Lagoons and Liquid Waste, Rural Homesteads, Naturally Occuring
Total Dissolved Solids		500		
Zinc (Fume or Dust)		5	**Commercial / Industrial**	Chemical / Petroleum Processing, Construction / Demolition, Electrical / Electronic Manufacturing, Machine Shops, Metal Plating / Finishing / Fabricating, Photo Processing / Printing, Synthetic / Plastics Production

Notes:

[1]MCL - Maximum Contaminant Level; the maximum permissible level of a contaminant in water which is delivered to any user of a public water system. MCLs are enforceable standards. Listed in Milligrams per Liter (mg/L) unless otherwise noted.

[2]MCLG – Maximum Contaminant Level Goal; the maximum level of a contaminant in drinking water at which no known or anticipated adverse effect on the health of persons would occur, and which allows for an adequate margin of safety. MCLGs are non-enforceable public health goals. Listed in Milligrams per Liter (mg/L) unless otherwise noted.

[3]TT- Treatment Technique

[4] No more than 5.0% of samples should detect total coliforms in one month. Every system that detects total coliform must be analyzed for fecal coliforms.

Part C - Present Situation of Groundwater Resources Management in Selected ACSAD Member Countries

A questionnaire (*Annex B-1*) was sent to competent and reliable persons in selected ACSAD member countries in order document the present situation and the Government's policy on the issue of groundwater protection. This documentation is by no means complete and only reflects the knowledge and opinion of the respective authors. Wherever possible and necessary, additions to the author's texts were made. For many countries in the Arab region it is extremely difficult to obtain sufficient and reliable information on laws, regulations, Government policy and the practice.

1 General Aspects

In many countries of the Arab region water resources are very scarce, even though they are distributed fairly uneven. In some countries of the Maghreb region rainfall is relatively high in the northern part so that surface water resources are sufficient through the rainy season. However, it is difficult to store adequate amounts throughout the year. Also the climate is extremely variable so that these areas are often threatened both by flooding and droughts.

Syria and Iraq depend to a large extent on the transboundary water resources of the Euphrates and Tigris Rivers. Transboundary groundwater forms also the source for many countries depending on groundwater, such as most countries of the Maghreb, which receive inflows from the Saharan aquifer systems.

Table C-1: Water Resources Availability, Consumption and Sustainability in the Arab Region

Country	Renewable Water Resources : Groundwater (km^3/yr)	Renewable Water Resources : Surface Water (km^3/yr)	Total Renewable Water Resources (km^3/yr)	Land Area (km^2)	Population in 2000 (1000)	Water Resources Availability per Capita in 1997 ($m^3/ca/yr$)	Groundwater Use (km^3/yr)	Desalination (km^3/yr)	Wastewater & Drainage reuse (km^3/yr)	Water Consumption (km^3/yr)	Sustainability Index/ Utilization (%)	Water Resources Consumption per Capita ($m^3/ca/yr$)
Lebanon	0.60	2.50	3.10	10,230	3,281	995	0.24	0.0017	0.002	1.225	40	373
Syria	5.10	16.375	21.475	183,780	16,125	1438	3.5	0.002	1.447	9.81	46	608
Iraq	2.00	70.37	72.37	437,370	23,280	2963	0.513	0.0074	1.5	49.1	78	2109
Egypt	4.10	55.50	59.60	995,450	68,523	925	4.85	0.0066	4.92	65.76	**102**	960
Oman	0.55	0.918	1.468	212,460	2,518	613	1.644	0.051	>0.04[1]	1.721	**117**	683
Jordan	0.277	0.475	0.752	88,930	5,003	168	0.486	0.0025	0.061	0.76	**121**	152
West Bank & Gaza	0.185	0.03	0.215	5,800	*2,859*	*262*	0.2	0.0005	0.002	0.44	***205***	154
Saudi Arabia	3.85	2.23	6.08	2,149,690	21,930	311	14.43	1.983[1]	0.131	16.3	**268**	743
Bahrain	0.10	0.0002	0.1002	690	613	173	0.258	0.286[1]	0.0175	0.31	**309**	506
Qatar	0.085	0.0014	0.0864	11,000	579	98	0.185	0.300[1]	>0.04[1]	0.298	**345**	515
UAE	0.13	0.185	0.315	83,600	2,441	137	0.9	1.874[1]	0.108	1.223	**388**	501
Kuwait	0.16	0.0001	0.1601	17,820	2,165	89	0.405	0.603[1]	0.025[1]	0.701	**439**	324
Yemen	1.40	2.25	3.65	527,970	18,654	303	2.2	0.009	0.052	2.9	**779**	155
Mauritania	*5.80*	*1.50*	*7.30*	1,025,220	*2,327*	*3137*	*1.03*	*0.0017*	*0.0676*	*1.10*	*15*	*471*
Somalia	*3.30*	*8.16*	*11.46*	627,340	*10,916*	*1050*	*1.95*	*0.0001*		*1.95*	*17*	*178*
Morocco	*22.50*	*7.50*	*30.00*	446,300	*28,781*	*1042*	*12.85*	*0.0012*	*0.35*	*13.20*	*44*	*459*
Algeria	*13.00*	*2.00*	*15.00*	2,381,740	*32,362*	*464*	*7.18*	*0.0746*	*0.4*	*7.65*	*51*	*236*
Tunisia	*2.70*	*1.94*	*4.64*	155,360	*9,480*	*489*	*2.91*	*0.0087*	*0.006*	*2.92*	*63*	*308*
Sudan	*1.00*	*26.00*	*27.00*	2,376,000	*33,064*	*817*	*22.95*	*0.0006*		*22.95*	*85*	*694*
Djibouti	*0.20*	*0.05*	*0.25*	23,180	*991*	*252*	*0.52*	*0.00015*		*0.52*	***207***	*522*
Libya	*0.40*	*0.65*	*1.047*	1,759,540	*6,562*	*160*	*7.18*	*0.21*	*0.11*	*7.50*	***716***	*1142*
Eritrea			6.30	101,000	3,659	1722						

source: ASCAD (1997); ESCWA (1999); *KHOURI (2000)*; [1] ALSHARHAN et al. (2001)

Table C-2: Water Resources Availability in the Arab Region

Country	Total Internal Renewable Water Resources (km^3/yr)	Groundwater: Produced Internally (km^3/yr)	Surface Water: Produced Internally (km^3/yr)	Overlap: Surface – Groundwater (km^3/yr)	Total Renewable Water Resources (km^3/yr)	Land Area (km^2)	Population in 2000 (1000)	Water Resources Availability per Capita ($m^3/ca/yr$)
Mauritania	0.40	0.30	0.10	0.00	11.40	1,025,220	2,665	4,278
Iraq	35.20	1.20	34.00	0.00	75.42	437,370	22,946	3,287
Sudan	30.00	7.00	28.00	5.00	64.50	2,376,000	31,095	2,074
Iran	128.50	49.30	97.30	18.10	137.51	1,622,000	70,330	1,955
Eritrea	2.80					101,000	3,659	1,722
Syria	7.00	4.20	4.80	2.00	26.26	183,780	16,189	1,622
Somalia	6.00	3.30	5.70	3.00	13.50	627,340	8,778	1,538
Lebanon	4.80	3.20	4.10	2.50	4.41	10,230	3,496	1,261
Morocco	29.00	10.00	22.00	3.00	29.00	446,300	29,878	971
Egypt	1.80	1.30	0.50	0.00	58.30	995,450	67,884	859
Tunisia	4.15	1.45	3.10	0.40	4.56	155,360	9,459	482
Algeria	13.90	1.70	13.20	1.00	14.49	2,381,740	30,291	478
Djibouti	0.30	0.02	0.30	0.02	0.30	23,180	632	475
Oman	0.99	0.96	0.93	0.90	0.99	212,460	2,538	388
Yemen	4.10	1.50	4.00	1.40	4.10	527,970	18,349	223
Bahrain	0.004	0.00	0.004	0.00	0.12	690	640	181
Jordan	0.68	0.50	0.40	0.22	0.88	88,930	4,913	179
Saudi Arabia	2.40	2.20	2.20	2.00	2.40	2,149,690	20,346	118
Libya	0.60	0.50	0.20	0.10	0.60	1,759,540	5,290	113
Qatar	0.05	0.05	0.001	0.00	0.05	11,000	565	94
UAE	0.15	0.12	0.15	0.12	0.15	83,600	2,606	58
Kuwait	0.00	0.00	0.00	0.00	0.02	17,820	1,914	10
West Bank & Gaza	0.75	0.68	0.07	0.00	0.75	5,800	2,859	-

source: UNESCO (2003)

Table C-3: Water Consumption and Efficiency in the Agricultural Sector of the Arab Region

	Total renewable water resources (km³)	*Irrigation water requirements (km³)*	*Water use efficiency in percentages*	*Water consumption for agriculture (km³)*	*Water withdrawal as percentage of renewable water resources*
Eritrea	6.3	0.09	32%	0.29	5%
Mauritania	11.4	0.44	29%	1.5	13%
Lebanon	4.407	0.37	40%	0.92	21%
Algeria	14.32	1.45	37%	3.94	27%
Morocco	29	4.28	37%	11.48	40%
Tunisia	4.56	1.21	54%	2.23	49%
Iraq	75.42	11.2	28%	39.38	52%
Sudan	64.5	14.43	40%	36.07	56%
Syria	26.26	8.52	45%	18.93	**72%**
Jordan	0.88	0.29	39%	0.76	**86%**
Egypt	58.3	28.43	53%	53.85	**92%**
Yemen	4.1	2.53	40%	6.32	**154%**
Saudi Arabia	2.4	6.68	43%	15.42	**643%**
Libya	0.6	2.56	60%	4.27	**712%**
Bahrain	n.a.; table C-2	n.a.	n.a.	*0.139*	n.a.
Djibouti	n.a.; table C-2	n.a.	n.a.	*0.001*	n.a.
Kuwait	n.a.; table C-2	n.a.	n.a.	*0.216*	n.a.
Oman	n.a.; table C-2	n.a.	n.a.	*1.15*	n.a.
Qatar	n.a.; table C-2	n.a.	n.a.	*0.185*	n.a.
Somalia	n.a.; table C-2	n.a.	n.a.	*3.954*	n.a.
UAE	n.a.; table C-2	n.a.	n.a.	*1.408*	n.a.
West Bank & Gaza	n.a.; table C-2	n.a.	n.a.	*0.343*	n.a.

n.a. – not available

source: FAO Aquastat; *UNESCO & ESCWA (1999)*

2 Groundwater Monitoring in Morocco

(compiled from: FAO Aquastat and various World Bank reports and scattered internet resources)

<u>General Aspects</u>

Morocco covers a total area of 446,500 km². The total population is 29.2 million (2001), of which 52% is rural. Annual population growth is estimated at 2.1% (1995). The increase in urban population is around 5%.

The country can be divided into four physiographic units:

- The Coastal Plains, that extend along the entire Moroccan coastline. They are narrow on the Mediterranean Coast and wide on the Atlantic Coast. These plains are crossed by the majority of the rivers and valleys of the country;
- The Northern Hills, that run parallel to the Mediterranean Sea and are called the El-Reef Mountains with their peak reaching 2,456 meters above sea level;
- The Central Hills, that run along the middle of the country and extend from north-east to southwest. They consist of the mountain ranges of the Central, Upper and Lower Atlas, which run almost parallel to one another. The peak is in the Upper Atlas at 4,165 meters above sea level;
- The Desert Hills, that are extensions of the southern slopes of the Upper and Lower Atlas Mountains.

The cultivable area has been estimated at 8 million hectares, which is 18% of the total area. In 1993, the total cultivated area was 7.23 million ha.

<u>Water Resources</u>

The water resources have been evaluated at 29 km³/year, out of which 16 km³ of surface water and 4 km³ of groundwater are considered to represent water development potential. The most important rivers are equipped with dams, allowing surface water to be stored for use during the dry seasons. In 1997, 88 dams were operational, with a total dam capacity of 14 km³. Of these dams, 13 were used (1990) in the schemes operated by the regional agricultural development offices (ORMVA or Office Regional de Mise en Valeur Agricole).

The renewable groundwater resources are estimated at 9,000 MCM, spread over 32 deep aquifers and 46 shallow aquifers, of which 4,000 MCM can be mobilized. Groundwater abstraction reached 3,600 MCM in 1997. Groundwater is generally over-exploited leading to lowering of water tables and the deterioration of water quality. Around 50% of the groundwater resources are located in the North and the Center of the country.

Non-conventional water resources, such as the re-use of treated wastewater and desalinated water, are not yet commonly used. In 1995, the use of untreated wastewater for irrigation was about 60 MCM/year.

In 1992, water withdrawal was estimated at about 11 km³, of which 92.2 % for agricultural purposes (4.9% is withdrawn for domestic use and 2.9% for industrial use). Of this total of 11 km³, 7.5 km³ was surface water and 3.5 km³ groundwater. In 1990, 236,000 water points were counted in the rural areas (91 % wells, 8% springs, 1% surface water points). A health survey showed that 84% of water points delivered non-potable water.

Irrigation is a strategic sector in Morocco. The water managed areas, in total about 1.26 million ha, represent only 17% of the cultivated area, but 76% of the irrigation potential area estimated at 1.65 million ha.

Since the 1960s emphasis has been put on the construction of dams and on the development of large schemes (referred to as 'grande hydraulique'). The schemes (with areas > 30,000 ha) are managed in a decentralized manner by the ORMVA. In total there were nine schemes over a total area of 496,000 ha in 1993.

The estimated volume of wastewater generated from the urban areas is around 546 MCM per year and is expected to reach 670 and 900 MCM in 2010 and 2020, respectively. Generated wastewater is mostly discharged without any treatment into natural water bodies. Around 43% are directly discharged into the ocean, and the rest are either discharged into the water resources (30%) or are spread on the soil (27%). Out of the 69 wastewater treatment facilities only 42% were functioning properly (2001).

With respect to industrial effluents, there are no laws forcing or requesting industries to treat their effluents prior to discharge. All industries discharge their untreated effluents into various natural water bodies. The report on the state of the environment that was completed in 1999 indicates that around 1,000 MCM of untreated industrial effluent are discharged per year. It is estimated that the majority of these effluents (98%) are discharged into the ocean and the sea, however, the remaining (2%) that are discharged into the inland water resources and the soil contain considerable pollution loads.

Municipal, industrial and hospital solid wastes (495 Million m³ in 2000) generated in the country are mainly discharged to uncontrolled sites, thus contributing to the degradation of the water quality and specially the groundwater resources. Survey studies conducted by the Direction Générale de l’Hydraulique in 1996 confirm the pollution of the groundwater resources in the vicinity of the solid wastes discharge sites.

Leaching practices and agricultural drainage are also a pollution source of water resources. Pollution is mainly due to the over-use of pesticides and fertilizers. Although agriculture pollution is not well controlled nor properly monitored, the available data on the utilization of pesticides and fertilizers give an idea about the expected pollution. On the average 720,000 tons of fertilizers are applied annually at the rate of 45 kg/ha. With respect to pesticides, around 7,500 tones are locally produced and used annually. In addition, around 1,000 tons of pesticides are imported annually. The available data on surface water quality reveal that important levels of fertilizers mainly nitrates and phosphorus are present. Pesticides residues were also detected in some surface waters and in some wells.

Since 1992, a water quality monitoring program has been established for surface water and groundwater resources. Around 1000 stations have been established at important points.

Data collected by the DGH indicate that:

- An important percentage (above 30% !) of underground water sources is of poor quality due to high salinity and nitrate concentrations;
- Several water streams have important concentrations of phosphorus, ammonia, organic matters and high Coliforms counts mainly at the monitoring stations which are located downstream of the industrial and municipal wastewater discharges;
- Sebou basin that constitutes 29% of Morocco water resources is heavily polluted by untreated industrial and municipal discharges and by agricultural drainage.

Institutional Aspects

The Superior Council of Water and Climate (Conseil supérieur de l'eau et du climat) is the principal institution involved in the water resources management sub-sector. It has the mandate to coordinate the development of the water resources by examining the development policies of the sector, approving the regional master plans related to the development of the water resources (prepared by the Directorate of Rural Equipment), resolving conflicts over the allocation of the water resources and establishing policies for water quality conservation. The General Directorate for Hydraulics (DGH or Direction générale de l'hydraulique) of the Ministry for Infrastructure (Ministère de l'Equipement) is in charge of the secretariat of the Council and brings together the main services concerned in this sector, elected representatives, socio-professional organizations, local authorities and representatives of the different types of water users.

The main organizations involved in the drinking water supply sub-sector are:

- The Ministry of Infrastructure (Ministère de l'Equipement, MEq) with its regional Directorates for Water Resources Management;
- The DGH, which is part of the Ministry of Public Works. It is in charge of water supply at basin level and is responsible for research and the exploitation of the water resources;
- The National Office for Drinking Water (ONEP or Office national de l'eau potable), which is placed under the Ministry of Public Works. It is in charge of water distribution control in urban areas and in some rural municipalities. It plans, builds and operates the installations for treatment and transport from the primary sources, i.e. reservoirs and primary canals;
- 16 autonomous, inter-communal state-owned water companies (Agence de Bassin Hydraulique, ABH), which are placed under the Ministry of Interior and supervised by the Directorate for state-owned companies and services conceded by this Ministry. They are in charge of water distribution in the municipalities;
- The Ministry of Public Health (MSP or Ministère de la santé publique) which, together with ONEP, is in charge of quality control for water resources for

drinking water supply networks in the towns and villages to which it provides water;
- The Ministry of Environment (Ministère de l'Aménagement du Territoire, de l'Habitat, de l'Urbanisme et de l'Environnement, MATHUE);
- The Ministry of Agriculture, Rural Development and Waters and Forests: It is mainly in charge of elaborating and implementing the policy concerning the reuse of treated wastewaters in agriculture via the regional service (ORMVA and DPA) in addition to the management of these waters, the awareness and technical framing of Associations of Agricultural Waters Users (AUEA).

The main organizations involved in the irrigated agriculture sector are:

- The Ministry of Agriculture and Agricultural Development (MAMVA or Ministère de l'agriculture et de la mise en valeur agricole), which is in charge of the supervision of new investments, in particular the extension, rehabilitation and maintenance of all the large and medium irrigation schemes;
- The DGH, which is in charge of providing irrigation water for the large schemes. It constructs and maintains the large hydraulic structures like dams, river diversion structures and projects for the exploitation of groundwater;
- The Agricultural Engineering Service (AGR or Administration du génie rural), which is responsible for the management of the irrigation schemes:
- The ORMVA, which are public but financially autonomous entities placed under the MAMVA, and which are responsible for the planning and management of the water resources for agriculture and the design, construction and management of the large schemes. They are also responsible for the small and medium schemes within their geographical jurisdiction;
- Outside the areas controlled by the ORMVA, the provincial Directorates for Agriculture are in charge of the promotion and management of the small and medium irrigation schemes, in reality mainly limited to extension activities.

On the 20 September 1995, a new Water Law became effective. In order to provide drinking water and to protect the water resources more effectively so-called Water Basin Agencies were created (Agences de Bassin Hydraulique – ABH). These agencies aim to establish a long-term balance for the water resources using an integrated approach in cooperation with the local authorities.

The law 10/95 of 16th August 1995 forms the legal basis for water policy in Morocco. It aims to establish the legal instruments necessary for controlling the use of water resources and for their conservation.

It provided the legal basis for the creation of basin agencies, for which the missions are extensive. These bodies, which have financial autonomy and a legal status, are in charge of:

- royal type missions concerned with water law enforcement which are currently taken care of by State directorates (Directorate General for Water):
  - the inventory of water rights and concessions;
  - the monitoring of quality and quantity, both for ground and surface water;
  - the issue of new permits and concessions for water withdrawals;

  - the control of the use of resources;
- new missions within the river basin context:
  - the formulation and implementation of the water development plan which is to be integrated into the national water plan;
  - the levying of pollution and withdrawal fees which will be reinvested in pollution control;
  - providing contracting authorities with financial assistance and services for pollution control, improvement in water resources and flood management.

In 1995, Morocco developed the ‘Code des Eaux’ under law No. 10-95. This code includes several articles related to the protection and preservation of surface and groundwater, the disposal of wastewater, as well as water re-use for agriculture purposes.

The ‘Code des Eaux’ calls for the integration of water quality and quantity, the elaboration of national water plan and river basin plans, recovery of costs through charges for water abstraction, and a water pollution tax based on the polluter-pays principle. The law also provides for the establishment of basin agencies, the participation of water user’s association in decision-making as well as for sanctions, penalties and fines for water law violation.

According to the new water law water has become a public property. The newly established water basin agencies have to prepare water basin master plans. Also a mechanism for cost recovery is provided through the collection of an abstraction charge and a pollution charge, which is to be based on the polluter-pays-principle.

The available quality standards are those prepared by ONEP, Ministry of Health and Ministry of Interior for water, including:

- NM 03-7-001: Standards for Potable Water;

- Decree 2-97-875: Standard the Use of Treated Water in Irrigation;

- NM 03-7-002: Standards for the Monitoring of Water Supply Systems.

Trends in water resources management

The surface water resources are limited and must be saved in order to be able to satisfy the water needs for drinking, industrial and agricultural purposes in the 21st century. While in general the water demand is satisfied, certain regions already suffer from water scarcity, especially during dry years.

Since the 1960s Morocco’s water policy was dominated by the effort to construct large water reservoirs, for which about 15 % of the annual investment budget was spent. At present around 100 dams are in operation, managing about 70% of the renewable water resources. Agriculture consumes approximately 92% of the water resources. Water protection measures were neglected for a long time.

The multiplication of the number of dams is one way chosen to increase water availability. Siltation of dams, however, is a major problem. The capacity already lost in 1990 was estimated at 800 MCM, which is 7% of the total capacity. A program for the protection of dams against siltation has been set up. Another way chosen to increase water availability is increasing groundwater extraction. However the cost of groundwater extraction is very high and a number of aquifers are already over-exploited. Government policies are moving from supply towards demand management.

A new strategy for integrated water management is being developed under the ongoing National Water Plan. This new strategy is based on management of supply, valorization, decentralization and integration. It will also address the need to use non-conventional water sources including the re-use of treated wastewater and desalinization. Action plans that are being prepared include:

- National action plan for water;
- National action plan for water quality;
- National action plan for the abatement of flooding.

In the wastewater sector, the Government is moving towards the privatization of wastewater treatment. The management of the wastewater of Casablanca, Rabat-Sale, Tangier and Tetouan has been lately given to private firms. A National Wastewater Master Plan was elaborated and enabled the Government to draw the guidelines for the development of the sector.

In the agriculture sector, the Ministry has developed a strategy and an action plan for the rationalization and the utilization of water for irrigation purposes. The identified actions will contribute to the protection of the environment through rationalizing the use of fertilizer and mastering irrigation practices.

A National Irrigation Program for the year 2000 (PNI 2000 or Programme National d'Irrigation en 2000) was adopted in 1992, with the following objectives:

- to equip by the year 2000 the whole area controlled by existing dams and dams under construction with the appropriate water distribution infrastructure;
- to improve the performances of the old irrigation schemes through modernization and/or rehabilitation of equipment.

Land ownership, which is characterized by very small properties (< 5 ha), land fragmentation, the absence of land ownership deeds and security, is being reviewed together with its implications for schemes and resources management.

The Moroccan water sector is facing serious problems, the reasons of which are complex. The Moroccan economy saw a rapid industrial and an increasingly export-oriented agricultural development over the past 2 decades. At the same time the population growth was very high. Due to these facts, water demand increased enormously. The water tariffs are not covering the costs, which has led to a wasting of resources. The investment budget has not kept pace with the increasing water demands, so that investments into maintenance were neglected, leading to a decay of the water infrastructure. Moreover, no sufficient investments were made in the wastewater sector.

The following 5 policies for water sector development have recently been adopted:

- Preparation of a National Water Master Plan, based on the principle of integrated water resources management;

- Development of a new institutional and legal framework promoting decentralized water resources management with increased stakeholder participation;
- Introduction of economic incentives in water allocation decisions through rational water tariffs, based on the principle of cost recovery;
- Enhancement of institutional capacities;
- Establishment of an effective system of monitoring and control of water quality to reduce environmental degradation.

>>>>>>>>>>>>>>><<<<<<<<<<<<<<<

A. *Groundwater Level Monitoring* and
B. *Groundwater Quality Monitoring*

1. Has a monitoring network been established already (since when) ?

No information available.

2. How many observation wells are monitored by which facilities (water level: automatic recorders, pressure transducers, manually) and how often (weekly, monthly, annually) ?

No information available.

3. Is groundwater monitoring being conducted for specific purposes (such as monitoring programs for: water level decline in certain well field areas, pollution control for sewage treatment plants, waste disposals, etc.) ? List examples.

No information available.

4. Are the data being stored in a data bank (where and what for) ?

No information available.

5. Are monitoring reports being prepared on a regular basis ?

No information available.

6. Are the monitoring data being used for management decisions ? If so, please list examples.

No information available.

3 Groundwater Monitoring in Tunisia

(sources: El BATTI, 2003; various World Bank reports; FAO Aquastat; various internet sources)

General Aspects

Tunisia has a total area of 193,610 km², of which 11,160 km², almost 7%, consist of lakes and shats (salty depressions).

The country can be divided into four physiographic regions:

- The North-western Mountains, which are located at the eastern end of the two mountain ranges, the Atlas El-Talli and the Desert Atlas, which extend from Morocco through Algeria and reach a peak at 1,500 metres in Tunisia. This area is crossed by permanent rivers;
- The Southern Mountains, which slope towards the east to the Coastal Plains and towards the west to the Desert Plains and are covered by sand dunes;
- The Coastal Plains which run close to the Mediterranean Sea as wide plains;
- Desert Plain. This plain forms the northern boundary of the Sahara Desert. A number of shats exist in this plain, the largest one being the Shat El-Jarid with an area of 5,000 km² at a minimum elevation of 15 meters below sea level.

The cultivable area is estimated at 8.7 million ha, which is about half the total area of the country. In 1993, the cultivated area was estimated at 4.25 million ha.

The total population is 8.9 million (1995) with an annual growth rate of less than 2%. The importance of the agricultural sector in the economy decreased from 1960 to 1994: in 1960 it accounted for 24% of the country's GDP, while in 1994 this figure had fallen to 16%.

Water Resources

The hydrographic system is dense in the north where the Medjerda wadi is the most important water course. This is also the zone where the principal irrigation development and flood protection works have been carried out.

Surface water resources have been estimated at 2.91 km³/year, of which 2.31 km³ are produced internally. About 1.5 km³/year are exploitable at present through reservoirs. It will be possible in the future to exploit another 0.6 km³/year, but the remaining part could only be used by means of large water conservation works and groundwater recharge systems. At present, there are 18 large dams and 22 hillside dams. Presently 81% of the surface water resources are mobilized.

Internal renewable groundwater resources have been estimated at 1.21 km³/year. At present, there are 83,000 open wells and 1,830 tubewells. Two categories of groundwater resources can be distinguished in function of the depth:

- when the water table is above 50 meters, groundwater is defined as phreatic and can be used for private exploitation (with some restrictions). The potential has been estimated at 669 million m³/year;
- below 50 meters of depth, the groundwater has been reserved for public exploitation. Potential has been estimated at 1,170 MCM/year, of which 630 MCM is fossil water.

Presently 88.5% of the renewable groundwater resources are exploited.

For the past 20 years, reuse of treated wastewater has taken place. In 1993, 96 MCM was treated, of which 20 MCM was reused. It is planned to increase the treatment to 200 MCM/year by the year 2000.

In 1990, water withdrawal was estimated at about 3.1 km³/year, of which 88.7% for agricultural purposes (8.5% is withdrawn for domestic use and 2.8% for industrial use). However, the amount of water withdrawn depends to a large extent on the quantity and the distribution of the precipitation. In particular, irrigation water withdrawal varies in function of the rainfall and of the area actually irrigated within the public irrigation network. Of the total of 3.1 km³ of water used annually, only 1.9 km³ are estimated to be actually used.

In 1992, the rural population with access to good drinking water within a distance of 3 km was estimated at 65 %, while 91 % of the urban population was connected to the drinking water supply network.

The irrigation potential has been estimated at 563,000 ha, based on land and water resources. In 1991, the water managed area was estimated at 385,000 ha. The average annual growth of irrigation development is about 2 %, which means that at this rate full potential will have been achieved by the year 2010.

Large-scale public irrigation schemes are managed by the state while medium-scale public irrigation schemes are managed by users associations (AIC or Associations d'intérêt collectif). The services of the state or AIC are in charge of the operation and maintenance of the irrigation network as well as of the distribution of water to the farmers, applying a water charge according to volume. However irrigation water is still subsidized by the state for up to 20-30% of its real exploitation cost.

Irrigation water is quite saline (1.5-4.0 g/l), but the degree of salinization of the irrigated soils is not yet a serious problem due to the low intensification. A monitoring system has been set up for all the schemes with a high risk of salinization. Subsurface drainage is not very developed (162,000 ha) and is limited to soils with a high water table (schemes in the north).

Institutional Aspects

The Ministry of Agriculture, Environment and Water Resources (Ministère de l'Agriculture, de l'Environnement et des Ressources Hydrauliques; MAERH), founded in September 2002, is the main institution involved in the water sector. The main General Directorates in charge of water are:

- The General Directorate of Water Resources (DGRE or Direction Générale des Ressources en Eau), which is in charge of the monitoring, evaluation and research of water resources in regarding their exploitation and protection;
- The General Directorate of Rural Engineering (DGGREE or Direction Générale du Génie Rural et de l'Exploitation des Eaux), which is responsible for irrigation, rural equipment and for drinking water supply to the rural population;
- The General Directorate of Dams an Large Hydraulic Works (DGBGTH or Direction Générale des Barrages et des Grands Travaux Hydrauliques), the main activity of which is conducting general hydraulics studies and studies concerning the use of surface water, the construction of dams, the development of large-scale water schemes and management of the dams;
- The Regional Commissions for Agricultural Development (Commissariats Régionaux de Développement Agricole ; CRDA);
- The National Society for Exploitation and Distribution of Water (Société Nationale d'Exploitation et de Distribution des Eaux; SONEDE) a semi-private agency for urban water supply, under the supervision of the MAERH. It also operates water desalination plants;
- The Society for Canal Water Use in the North (Société d'Exploitation du Canal et des Adductions des Eaux du Nord; SECADENORD) which is another semi-private water agency operating the canals in the north;
- The Water User Associations (Groupements de Développement d'Intérêt Collectif; GDIC) which are under the supervision of the regional authorities (Governor) and the MAERH;
- The National Office of Sanitation (Office National de l'Assainissement; ONAS) which is in charge of waste water management;
- The National Agency for Environmental Protection (Agence Nationale de Protection de l'Environnement; ANPE), created in 1988 and under the authority of the MAERH, is responsible for drafting the government policy related to all environmental issues, for proposing action plans for environmental protection, for preparing and conducting contingency plans in case of accidental pollution, for promoting environmental protection, for coordinating all national and international activities in the field of environmental protection and for the management of hazardous wastes.

Other ministries involved in water management and protection are:

- The Ministry of Equipment, Housing and Utilities (Ministère de l'Equipement, de l'Habitat et de l'Aménagement du Territoire ; Direction de l'Hydraulique Urbaine : D.H.M., et l'Agence de Protection et de l'Aménagement du Littoral : APAL) ;
- The Ministry of Public Health (Ministère de la Santé Publique ; Direction de l'Hygiène du Milieu et Protection de l'Environnement : DHMPE) ;
- The Ministry of Interior and Development (Ministère de l'Intérieur et du Développement);
- The Minstry of Tourism, Commerce and Handicraft (Ministère du Tourisme, du Commerce et de l'Artisanat; Office du Thermalisme) watches over the safety of bottled mineral waters and the protection of touristic zones.

- The Ministry of Justice and Human Rights (Ministère de la Justice et des Droits de l'Homme) watch over the proper execution of legal matters by the water police.

The regional agricultural development offices (CDRA or Commissariat regional de développement agricole), linked to the Ministry of Agriculture, are the institutions responsible at regional level for the development of public irrigation schemes. The management of these schemes is shared between CDRA and AIC.

The water code (Code des Eaux; loi n° 75-16), promulgated in 1975, determines all interventions in the water sector.

<u>Trends in Water Resources Management</u>

The strategy for the future use of water, adopted in 1990, aims at the development of 90% of surface water resources and 100% of groundwater resources by the year 2010, by means of the construction of 21 dams, 235 hillside dams and 610 deep tube-wells.

This improvement in the control of water resources is associated with the agricultural development of the irrigation schemes. The objectives of the country are at present to encourage the adoption of water saving techniques, to favour the reuse of treated wastewater for irrigation, to expand the irrigated areas and to set up the related activities necessary for agricultural development and a better use of irrigation schemes.

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A. *Groundwater Level Monitoring* and
B. *Groundwater Quality Monitoring*

1. Has a monitoring network been established already (since when) ?

No dates known.

2. How many observation wells are monitored by which facilities (water level: automatic recorders, pressure transducers, manually) and how often (weekly, monthly, annually) ?

Altogether there are around 3,274 wells in the piezometric network, of which 2,252 are shallow wells (less than 50 m deep), 920 piezometers, and 102 deep wells. The first and the last category of monitoring facilities are monitored by manual measurements that are conducted twice a year (1* high water season: April-May, 1* low water season: September-October). The piezometers are equipped with mechanical or electronic recorders.

The groundwater quality monitoring network consists of 729 shallow wells (dug wells) and 471 drilled (deep) wells. TDS and nitrate contents are measured in these wells commonly twice a year (see above).

3. Is groundwater monitoring being conducted for specific purposes (such as monitoring programs for: water level decline in certain well field areas, pollution control for sewage treatment plants, waste disposals, etc.) ? List examples.

Water level monitoring focuses on the

- Overexploited aquifers;
- Coastal aquifers;
- Non-renewable resources; and

Protected aquifers.

4. Are the data being stored in a data bank (where and what for) ?

No information available.

5. Are monitoring reports being prepared on a regular basis ?

The DGRE publishes annual yearbooks for the piezometric network (since 1992) as well as for the groundwater quality monitoring network (since 1997).

6. Are the monitoring data being used for management decisions ? If so, please list examples.

The information is used for appropriate resources management decisions (e.g. allocation of surface waters; artificial groundwater recharge; drought prevention; etc.).

4 Groundwater Monitoring in Egypt

(sources: KHATER, 2003; NWRC homepage; FAO Aquastat; various internet sources)

General Aspects

Egypt covers a total area of about 1 million km². Total population is about 64 million (1999), of which 55% is rural, with annual demographic growth estimated at 2.1 %.

In 1993, the total cultivated land was estimated to be 3.24 million ha, or 3.2% of the total area.

Water Resources

The Nile River is the main source of water for Egypt. Under the 1959 Nile Waters Agreement between Egypt and Sudan, Egypt's share is 55.5 km³/year. The 1959 Agreement was based on the average flow of the Nile during the 1900-1959 period, which was 84 km³/year at Aswan.

The total groundwater volume in storage in the Nubian sandstone aquifer is estimated at 60,000 km³ (1 km³ = 1 BCM). The current total extraction amounts to about 0.5 km³/year. The volume of groundwater entering the country from Libya is estimated at 1 km³/year. Internal renewable groundwater resources are estimated at 1.3 km³/year. This brings the total renewable groundwater resources to 2.3 km³/year. The main source of internal recharge is percolation from irrigation water, and its quality depends mainly on the quality of the irrigation water. In the northern part of the Delta, groundwater becomes brackish to saline due to sea water intrusion. About half of the Delta contains brackish to saline groundwater. The Nubian Sandstone aquifer, located under the Western Desert and extending to Libya, Sudan and Chad, contains important non-renewable fresh groundwater resources, already developed in the oasis of the New Valley. Large irrigation schemes pumping water from the Nubian aquifer are under development in the southwestern part of the country (Al Aweinat).

In 1994, the quantity of agricultural drainage water flowing back into the Nile River and becoming available again for withdrawal downstream was estimated at 4 km³/year.

In 1994, the treatment of domestic wastewater was estimated at 650 MCM/year and in 1993 about 200 MCM/year of treated wastewater was estimated to have been reused. The quantity of desalinated water was estimated at only 25 MCM in 1990.

The Table below shows the actual water availability and water use by the different sectors. Agricultural water withdrawal includes an annual estimated loss of 2 km³/year due to evaporation from 31,000 km of canals (1.000 km of main canals and 30,000 km of secondary canals).

Table C-4: Water availability and water use in Egypt in 1993

Water Resources	km³/year	**Water Use**	km³/year
Surface water resources	56.0	Agriculture (incl. evaporation)	47.4
Renewable groundwater resources	2.3	Domestic	3.1
Agricultural drainage water	4.0	Industry	4.6
Reused treated wastewater	0.2	Navigation/regulation	1.8
Total available water resources	62.5	Total water use	56.9

It is estimated that by the year 2000 the total water use will approach 70 km³/year, which is more than the actual water availability.

Almost all agriculture in Egypt is irrigated. The total water managed area is 3,246,000 ha, of which more than 90% is in the Nile Valley and Delta.

An extensive National Drainage Program has been carried out over the past 30 years to control water logging and salinity. The drainage system consists of open drains, subsurface drains and pumping stations. Of the total irrigated area, 2,931,000 ha (90%) are drained, of which 1,681,000 ha with subsurface drainage. The subsurface drained area represents nearly 52% of the total cultivated area and more than 74% of the cultivated land in the Valley and the Delta.

Institutional Aspects

With the establishment of the Water Research Center (WRC) in 1975 (Presidential Decree No. 83), the Groundwater Research Institute (GRI) became the Research Institute for Groundwater (RIGW), one of the eleven Research Institutes under the WRC. In 1994 the WRC was promoted to University status and renamed the National Water Research Center (NWRC; www.nwrc.gov.eg/nwrc/). The mission of the RIGW is to carry out research to support groundwater development and management plans, in the framework of the overall integrated water resources development/management, aiming at increasing the contribution of groundwater in the water and food security programs for growing population of Egypt:

1. Study, outline and propose long-term policies for managing water resources in Egypt.
2. Solve the technical and applied problems associated with general policies for irrigation, drainage and water resources.
3. Carry out investigations and research work connected with the extension of agricultural lands.
4. Find the means for utilizing the water resources of the country in the most efficient and cost-effective way.
5. Propose measures for environmentally sound development of the irrigation and drainage systems.

Table C-5: Responsibilities in the Groundwater Sector in Egypt

Activities	Institutions Involved
1. Research on National and Regional Levels	1.1 The Research Institute for Groundwater (MWRI) 1.2 The Water Resources Research Institute (MWRI) 1.3 The Desert Research Center (MOA)
2. Local Studies and Investigations	2.1 The Research Institute for Groundwater 2.2 The Water Resources Research Institute 2.3 The Desert Research Center 2.4 Universities and individual consultants
3. Assessment of Groundwater Potential	3.1 The Research Institute for Groundwater 3.2 The Water Resources Research Institute
4. Policy development and Planning	4.1 The Groundwater Sector in cooperation with other sectors in the MWRI
5. Licensing of wells	5.1 The Groundwater Sector
6. Design and implementation (or supervision)	[depends on the ownership]
7. Monitoring, including sampling and analysis	7.1 The Research Institute for Groundwater 7.2 Ministry of Health (adhoc) 7.3 Individuals (owners)
8. Operation and maintenance	[depends on ownership]
9. Awareness	MWRI (GS)
10. Regulation and enforcement of law	The Groundwater Sector

The Ministry of Public Works and Water Resources (MPWWR) is in charge of water resources research, development and distribution, and undertakes the construction, operation and maintenance of the irrigation and drainage networks. "The Groundwater Sector" of this Ministry is responsible for policy development, regulations and enforcement of laws. At central level, the Planning Sector is responsible for data collection, processing and analysis for planning and monitoring investment projects. Water resources development works are coordinated by the Sector of Public Works and Water Resources. The Nile Water Sector is in charge of cooperation with Sudan and other Nilotic countries. The Irrigation Department provides technical guidance and monitoring of irrigation development, including dams. The Mechanical and Electrical Department is in charge of the construction and maintenance of pumping stations for irrigation and drainage.

Further to these institutions, other public authorities operate in direct relation to the MPWWR. They are the High Aswan Dam Authority, responsible for dam operation; the Drainage Authority, responsible for the construction and maintenance of tile and open drains; and the Water Research Centre. The Water Research Centre comprises 12 institutes and is the scientific body of MPWWR for all aspects related to water resources management.

The Ministry of Agriculture and Land Reclamation (MALR) is in charge of agricultural research and extension, land reclamation and agricultural, fisheries and animal wealth development.

Trends in water resources management

Water demand is increasing due to the increase in population and economic activities. At present all available fresh water is consumed, except groundwater in the deserts. This dictates quick responses from professionals to augment available fresh water and the use of non-conventional water (treated and desalinated water).

Table C-6: Main Problems Pertaining to the Water Sector in Egypt

Issue	Causes
1. Partial utilization of Egypt's territories.	1.1 Nile valley morphology and type of boundaries. 1.2 Aridity and poor distribution of water resources over the country area.
2. Unbalanced population distribution and continuous immigration from rural to urban areas.	2.1 Lack of regional plans and facilities/services to the rural community. 2.2 Continuous decrease of job opportunities in the rural areas, especially in the farming sector.
3. Lack of suitable potable water and sanitation in some regions, especially the rural ones.	3.1 The economic conditions of the country. 3.2 Concentration of activities in the urban regions/governorates
4. Decrease of per capita agricultural land area and share in main food.	4.1 Heritage and distribution of land among the family. 4.2 Poor return from agriculture and transfer to cash crops. 4.3 Encroachment of urban areas.
5. Biased distribution of opportunities among men and women.	5.1 Cultural, especially in the rural regions.
6. Continuous decrease of per capita water resources.	6.1 Deterioration of water quality. 6.2 Poor enforcement of water protection legislation. 6.3 Increase of water-intensive cropping. 6.4 Inefficient use of water on the farm level. 6.5 Inefficient water distribution. 6.6 Low efficiency of urban drinking water supply.

The objectives of Egypt's water policy are to:

1) Protect surface water and groundwater from pollution, and prevent deterioration of water quantity.
2) Control the demand for water.
3) Secure the future water supply from the Nile River by adopting a holistic approach to water management based on the river basin, integrating all water resources and use sectors.
4) Locate, identify, and develop new water resources (e.g. rainfall and flash floods).
5) Raise water use efficiency by: (i) promoting conjunctive use of surface water and groundwater; (ii) controlling use and depletion of groundwater; and (iii) promoting water use.
6) Increase water use effectiveness by: (i) establishing planning capacity, including appropriate planning approaches and tools; (ii) public and stakeholder participation in all steps of water management, including policy, planning, design, and implementation; (iii) establishing drought management plans, with

implementation mechanisms; (iv) reviewing and adjusting water use legislation and regulations for proper implementation of water policy; and (v) engaging and mobilizing women and building public awareness about water management by better communications, in particular, in rural areas.

One important characteristic of Egyptian agriculture is land distribution. More than 95% of the landowners hold less than 2 ha each. Only 3 % own 20 ha or more.

It was planned to develop an additional 920,000 ha for agriculture by 2000. This was to be achieved through further developing the country's surface water and groundwater resources, increasing drainage water and treated wastewater reuse, and improving irrigation efficiency.

Al Salam canal was planned for the reuse of drainage water from two main drains in the Eastern Delta. This water, added to water extracted from the Damietta branch of the Nile, will be used for the irrigation of a new area of 252,000 ha in the Eastern Delta and North Sinai. The total area planned to be developed for irrigation by different projects in the Sinai is estimated at 630,000 ha.

At present, Egypt and Sudan base their water development plans on the shares stipulated in the 1959 Nile water agreement between the two countries and on future conservation projects in the Sudd area in southern Sudan to increase the yield of the river. However, future developments in upstream countries will have to be taken into account from the point of view of present shares and any future increments that can become available from the conservation projects. In any case, the expansion of irrigation in the Nile basin in the years ahead will require basin-wide cooperation in the management of water resources to meet increasing demands and to face the associated environmental consequences.

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A. *Groundwater Level Monitoring* and
B. *Groundwater Quality Monitoring*

1. Has a monitoring network been established already (since when) ?

The National Groundwater Level Network and the National Groundwater Quality Monitoring Network were established in 1953 and 1998, respectively.

2. How many observation wells are monitored by which facilities (water level: automatic recorders, pressure transducers, manually) and how often (weekly, monthly, annually) ?

The groundwater level monitoring network consists of around 1,200 wells. Most wells monitor the Quaternary aquifers in the Nile Delta and along the Nile River and are commonly screened between 20 m and 50 m below land surface. The quality monitoring network comprises around 200 wells, of which 60% are located in the Nile basin.

3. Is groundwater monitoring being conducted for specific purposes (such as monitoring programs for: water level decline in certain well field areas, pollution control for sewage treatment plants, waste disposals, etc.) ? List examples.

During the four annual sampling rounds 1998 to 2001 all quality monitoring wells were sampled for around 50 parameters. Monitoring was conducted with the aim to show the general status of groundwater quality in the country.

4. Are the data being stored in a data bank (where and what for) ?

A database for monitoring data was established in 1984 at RIGW.

5. Are monitoring reports being prepared on a regular basis ?

No information available.

6. Are the monitoring data being used for management decisions ? If so, please list examples.

No information available.

5 Groundwater Monitoring in Jordan

(sources: MARGANE et al. 2002; MARGANE & ALMOMANI 2002 ; MARGANE & SUNNA 2002 ; MARGANE 1995 ; FAO Aquastat ; various internet sources)

General Aspects

Jordan covers a total area of about 89,210 km² and is divided into eight governorates: Amman, Zarqa, Irbid, Mafraq, Balqa, Karak, Tafileh and Ma'an.

The country can be divided into four physiographic regions:

- the Ghors (lowlands) in the western part of the country, which consist of 3 zones: the Jordan Valley, the lowlands along the Dead Sea and the Wadi Araba which extends in a southerly direction to the northern shores of the Red Sea;
- the highlands, which run from north to south at an altitude of between 600 and 1,600 m above sea level;
- the plains, which extend from north to south along the western borders of the desert (Badiah);
- the desert region (Badiah) in the east, which is an extension of the Arabian desert.

The total population is around 5.47 million (2003), of which 22% (1994) is rural (Department of Statistics (www.dos.gov.jo/sdb_pop/growth_2005_e.htm). The population growth is estimated at 2.7% (2003). The cultivable land was estimated at 381,740 ha in 1992, or 4.3% of the total area of the country. In 1991, the total cultivated area was estimated at 214,767 ha. Agriculture accounted for 6% of Jordan's GDP in 1992 and for 12% of its exports earnings.

Water Resources

Surface water resources are unevenly distributed among 15 basins. The largest source of external surface water is the Yarmouk River, at the border with Syria. Originally, the annual flow of the Yarmouk river was estimated at about 400 MCM (of which about 100 MCM are withdrawn by Israel). Total flow is now much lower than 400 MCM as a result of the upstream Syrian development works which took place in the 1980's. The Yarmouk River accounts for 40% of the surface water resources of Jordan, including water contributed from the Syrian part of the Yarmouk basin. It is the main source of water for the King Abdullah Canal (KAC) and is thus considered to be the backbone of development in the Jordan Valley. Other major basins include Zarqa River, Jordan River side wadis, Wadi Mujib, the Dead Sea side wadis, Wadi Hasa and Wadi Araba. Internally generated surface water resources are estimated at 400 MCM/year.

Jordan's groundwater is distributed among 12 major so-called groundwater basins. Total internally produced renewable groundwater resources, the so-called safe yield, is estimated by the Ministry of Water and Irrigation (MWI) at 277 MCM/year. The baseflow of the rivers constitutes around 335 MCM, a large portion of which, however, is of fossil origin, recharged during more humid climatic periods, and thus does not reflect present day recharge. Groundwater resources are concentrated mainly in the Yarmouk, Amman-Zarqa and Dead Sea basins.

Most of the 'safe yield' is at present exploited at maximum capacity, in some cases well beyond. The annual deficit in the water balance is estimated at around 230 MCM/yr (MARGANE et al., 2002). Over-extraction of groundwater resources has degraded water quality and reduced exploitable quantities, resulting in the abandonment of municipal and irrigation water well fields, such as e.g. in the area of Wadi Dhuleil. High nitrate contents are observed in the area east of Mafraq (NE-desert) and south of Amman. Several large springs (e.g. in the Salt area and around Irbid) are affected by bacteriological contamination, due to insufficient sewage water collection and treatment.

Table C-7: Groundwater Abstraction in Jordan in 1998

Catchment Area	**Groundwater Abstraction (MCM)**
Yarmouk and Wadi al Arab	55.6
Jordan River side Wadis	5.5
Jordan Valley	41.5
Amman-Zarqa	145.7
Azraq	55.7
Dead Sea	100.8
Northern Wadi Araba	3.8
Southern Wadi Araba & Disi-Mudawara	70.0
Jafr	21.8
Sirhan	1.5
Hamad	1.3
Total	**503.1**

The main non-renewable aquifer presently exploited is the Disi aquifer (sandstone; fossil groundwater resource), in southern Jordan with a 'safe yield' (remark: principally fossil groundwater resources should not be considered as amounts of safe yield because this implies that there would be present day recharge) estimated at 125 MCM/year for 50 years. Other non-renewable water resources are found in the Jafr basin, for which the annual safe yield is around 18 MCM. In total it is estimated by the Water Authority of Jordan (WAJ) that the safe yield of fossil groundwater is 143 MCM/year.

Total dam capacity in Jordan is estimated at 143 MCM, including desert dams. The largest dam, the King Talal dam on the Zarqa River, has a total capacity of 80 MCM. The other main dams are located on the Wadi Araba (20 MCM), Wadi Ziglab (4.3 MCM), Wadi Kafrein (3.8 MCM) and Wadi Shuayb (2.3 MCM). The proposed design of the Al Wahda (Unity) dam on the Yarmouk River, following a treaty between Jordan and Syria, allows for a dam of 100 m in height with a gross storage capacity of about 230 MCM. Another proposed dam is the Karameh dam with a gross storage capacity of 55 MCM. Following the signature of the Peace Treaty with Israel (1994), investigations have been initiated to assess the need for future storage facilities on the Jordan and Yarmouk Rivers.

The produced wastewater was estimated at 232 MCM/year in 1993 and the quantity of reused treated wastewater reached 50 MCM, of which 48 MCM are used for irrigation and 2 MCM for industrial purposes. The reuse of treated wastewater in Jordan reaches one of the highest levels in the world. The treated wastewater flow in the country is returned to the Zarqa River and the King Tall dam, where it is mixed with surface water flow and used in the pressurized irrigation distribution system in the Jordan Valley. The importance of reused wastewater is an essential element of Jordan's water strategy.

In 1993, total annual water withdrawal was estimated at 984 MCM, up from 619 MCM in 1986. Agricultural water withdrawal accounted for 74.9 % of the total water withdrawal (73.9% for agriculture and 1% for lifestock, industrial and domestic use accounted for 3.4% and 21.7%, respectively) including the use of treated wastewater. Due to limited and widely scattered sources of water, the construction of important water conveyance facilities was undertaken between 1962 and 1987 in order to meet the demand of the population which is concentrated in some areas. Some shortages have been observed during recent years, but they are generally limited to less than 10% of the demand. However, during the dry year of 1990, the water shortage affected 17% of the water demand.

The level of the Dead Sea falls each year by 85 centimeters due to extensive water use in the Jordan basin. Irrigated soils along the Jordan Valley are showing signs of salinization since natural floods are no longer available to flush the irrigated land and leach salts.

The potential for irrigated cultivation is estimated at around 840,000 ha. However, taking into consideration potentially available water resources, the irrigation potential is only about 85,000 ha, including the area currently irrigated.

Although irrigation has been practiced in Jordan for a very long time, particularly in the Jordan Valley, intensive irrigation projects have been implemented since 1958 when the Government decided to divert part of the Yarmouk River water and constructed the East Ghor Canal (later named King Abdullah Canal). The canal reaches a total length of 110.5 km. Apart from in the Jordan Valley, irrigation is also practiced in the highlands, mainly dependent on groundwater resources.

In 1995, the total area equipped for irrigation was estimated at 72,850 ha. One of the main sources of water is the King Talal dam on the Zarqa River from which water is diverted into the King Abdullah Canal.

In 1992, it was estimated that about 55% of the area was irrigated from groundwater, 39% from surface water and 6 % from treated wastewater. The Disi irrigation project, one of the largest schemes in Jordan covering a total area of 3,000 ha, is supplied with fossil groundwater.

Institutional Aspects

The following ministries/institutions are involved in the water sector in Jordan:

- The Ministry of Water and Irrigation (MWI), with the Ministry of Water and Irrigation (as a separate entity), the Water Authority of Jordan (WAJ) and the Jordan Valley Authority (JVA) as its operational entities;
- The Ministry of Agriculture;

- The Ministry of Municipal and Rural Affairs and the Environment (MMRAE).

The Ministry of Water and Irrigation is the body responsible in Jordan for the formulation and implementation of water and wastewater development programs. Water policies, covering all aspects of the water sector, were issued in 1998 (file *Jordan Water Strategy & Policies.doc* on CD.

Municipal water use was made more systematic with the creation of the Water Authority in 1985. Prior to that, many agencies and municipalities were responsible for the production and distribution of municipal water.

Trends in water resources management

Jordan's past economic development plans reveal that surface water resources have been extensively developed by the Government, with priority given to the construction of dams and irrigation projects in the Jordan Valley in order to maximize the utilization of this resource before its drainage to the Dead Sea. Limited additional untapped surface water resources could be developed in the Jordan Valley side wadis and in the Mujib, Zarqa, Ma'an and Zara basins, subject to specific conditions.

Jordan, Israel and the West Bank are presently over-exploiting their water resources by between 10 and 20%. Water levels are dropping, groundwater resources are being mined, salinization and salt water intrusion are observed and the domestic water supply does not reach adequate standards. The following actions are envisaged to remedy this crisis:

- reduction of water demand for irrigation;
- importation of water from water-rich countries like Turkey;
- desalinization of brackish water (in the southern Jordan Valley) and sea water (Aqaba).

As part of the efforts towards joint management of water resources, the Jordanian-Israeli Peace Treaty includes the following arrangements:

- 20 MCM of Yarmouk water will be stored by Israel in the winter and released to Jordan in the summer;
- 10 MCM will be released from the Tiberias Lake outside the summer season for Jordan until the construction of a desalinization plant;
- construction of storage facilities on the Yarmouk and Jordan Rivers and groundwater potential in Wadi Araba are under investigation;
- 50 MCM of drinking water should be further allocated to Jordan through cooperation between both parties.

Although the potential for irrigation development in the highlands is great, a very small increase in irrigated agriculture is anticipated due to the unavailability of water resources. The average water consumption for irrigation in the Jordan Valley and southern Ghor is less than 10,000 m^3/ha per year, which is much less than in the highlands where it reaches on average 16,000 m^3/ha per year.

Some of the water resources which would be made available for irrigation purposes are recycled water from municipal wastewater treatment plants. The total quantity of reused treated wastewater is expected to grow from 50 MCM in 1993 to about 89 MCM in 2000 and 237 MCM in 2020.

Future projects include the construction of storage facilities on major rivers and side wadis (the Al Wahdah, Karameh, Walah, Tannur, Mujib and Yabis dams) to alleviate part of the water shortages for agricultural activities. The total yield of these dams for agricultural purposes will be about 200 MCM/year.

Water harvesting techniques are not yet widely practiced in Jordan. However, small research pilot projects are trying to see whether this technique would suit the country's characteristics.

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A. *Groundwater Level Monitoring* and
B. *Groundwater Quality Monitoring*

1. Has a monitoring network been established already (since when) ?

Until the foundation of the Water Authority of Jordan (WAJ) in 1984, monitoring was performed by the Amman Water and Sewage Authority (AWSA), the Water Supply Corporation (WSC) and the Natural Resources Authority (NRA). Until 1989 groundwater level monitoring of wells in Jordan Valley and Wadi Araba was carried out by Jordan Valley Authority (JVA).

Presently monitoring is mainly being carried out by the Groundwater Monitoring Division in the Water Resources Planning Directorate of MWI. In addition, some wells are monitored (in most cases for relatively short time periods) by projects implemented in the MWI, WAJ, JVA, and Royal Scientific Society (RSS), Higher Council of Science and Technology (HCST) or other.

2. How many observation wells are monitored by which facilities (water level: automatic recorders, pressure transducers, manually) and how often (weekly, monthly, annually) ?

About 198 groundwater level monitoring wells are presently monitored throughout the country. One hundred and seventeen of wells are equipped with automatic recorders. At 81 well sites manual measurements are taken at irregular time intervals. Most of wells serve for water level monitoring of the A7/B2 aquifer. Most monitoring wells are located in the northern and central parts of Jordan.

Table C-8: Groundwater Monitoring Wells in Jordan in 2002

No.	Basin Name	GW Level Monitoring		GW Quality Monitoring	
		Recorder	Manual	Chemical	Bacteriological
1	Yarmouk	6	3	10	5
2	Rift Side Wadis	3	2	8	-
3	Jordan Valley	11	7	15	5
4	Amman - Zarqa	35	25	86	20
5	Dead Sea	21	12	37	9
6	Disi (Southern Desert)	10	5	5	-
7	North Wadi Araba	6	4	3	-
8	South Wadi Araba	7	3	4	-
9	Jafer	7	7	9	-
10	Azraq	10	10	29	-
11	Wadi Sirhan	-	-	-	-
12	Hammad	1	3	6	-
	Total	117	81	212	39

Groundwater quality monitoring has been conducted routinely since 1970s and historical data are available in the Water Information System (WIS) database. There are totally 1148 wells and 742 springs with water quality records. In 1995 the number of wells with water quality records was 653 and that of springs 646.

The water quality items in the WIS data base include water salinity (as EC), pH, main cations (Na, K, Ca, and Mg) and anions (Cl, CO_3, HCO_3, NO_3, and SO_4). There are few records of coliforms or fecal coliforms.

3. Is groundwater monitoring being conducted for specific purposes (such as monitoring programs for: water level decline in certain well field areas, pollution control for sewage treatment plants, waste disposals, etc.) ? List examples.

Groundwater level monitoring: Groundwater resources management decisions (allocation and distribution of water resources).

Groundwater quality monitoring: Observation of nitrate contents in intensively cultivated areas; monitoring of TDS in intensively exploited aquifers (e.g. from irrigation return flow).

4. Are the data being stored in a data bank (where and what for) ?

All monitoring data are stored in the Water Information System (WIS).

5. Are monitoring reports being prepared on a regular basis ?

Annual monitoring reports are being not prepared. An evaluation of all groundwater level monitoring data was conducted within the framework of the Jordanian-German Technical Cooperation Project 'Groundwater Resources of Northern Jordan' (MARGANE 1995).

6. Are the monitoring data being used for management decisions ? If so, please list examples.

Yes, to a limited extend.

6 Groundwater Monitoring in Syria

(sources: MISKI & SHAWAF 2003; KHOURI 2000; FAO Aquastat; UNDP & WORLD BANK 2000; WORLD BANK 2001a; various internet sources)

General Aspects

Syria covers a total area of 185,180 km². The Syrian Arab Republic is divided into 14 administrative units (Governorates or Mohafazat): City of Damascus, Suburban Damascus, Homs, Hama, Aleppo, Latakia, Tartous, Idlib, Raqqa, Dair Es Zhor, Hasaqeh, Dera'a, Suwaida, Quanaitra.

The country can be divided into 4 physiographic regions:

- the coastal region between the mountains and the sea;
- the mountains and the highlands extending from north to south parallel to the Mediterranean coast;
- the plains, or interior, located east of the highlands and including the plains of Damascus, Homs, Hama, Aleppo, Al-Hassakeh and Dara'a;
- the Badiah and the desert plains in the south-eastern part of the country, bordering Jordan and Iraq.

In 1993, the cultivable land was estimated at 5.94 million ha, or 32 % of the total area of the country. The cultivated land was estimated at 4.94 million ha (FAO Aquastat; WORLD BANK, 2001a: 5.5 million ha), which is 83% of the cultivable area.

The total population is 14.6 million (1995), of which 48% is rural. Actual population growth is 3.3%.

Syria is divided into 7 hydrological basins: Barada and Awaj, Yarmouk, Assi, Coastal, Tigris and Khabour, Euphrates, Badia.

The natural average surface runoff to Syria from international rivers is estimated at 28,730 MCM/year. The water resources generated inside the country are estimated at around 9,700 MCM per year as the long-term average. Groundwater recharge is about 4,200 MCM/year, of which about 2,000 MCM/year discharges into rivers as spring water. Total groundwater transboundary inflow has been estimated at 1,350 MCM/year, of which 1,200 MCM from Turkey and 150 MCM from Lebanon.

There are 160 dams in Syria with a total storage capacity of 18 BCM. The largest dam is the Al-Tabka dam on the Euphrates with a storage capacity of 14,160 MCM (WORLD BANK, 2001a).

Total annual water withdrawal in Syria in 1993 was estimated at 14.41 km³/year, of which agricultural use accounted for 94.4% (3.7% is withdrawn for domestic use and 1.9% for industrial use). The treatment of domestic wastewater is carried out mainly in the towns of Damascus, Aleppo, Homs and Salamieh. The total amount of treated wastewater was estimated at 0.37 km³/year in 1993, which represents 60% of the total produced volume of 0.61 km³/year. All treated wastewater is reused.

In 1998, the total area equipped for irrigation was estimated at 1.2 million ha (WORLD BANK, 2001a). Irrigation is mainly developed in the north-eastern part of the country and more than one-third of the irrigated areas are located in the Al-Hassakeh governorate. In 1993 it was estimated that 60.2% of the area was irrigated from groundwater and 39.8 % from surface water. The use of groundwater for irrigation has been expanding rapidly in the past five years because irrigation from groundwater is cheaper than irrigation by gravity. Irrigation efficiency is still rather low, with sprinkler irrigation applied on around 80,000 ha and drip irrigation on 8,500 ha, only.

The cost of operation and maintenance of irrigation schemes by surface water is recovered from the farmers. Presently (1999) this charge is set to 3,500 SP/ha. Farmers irrigating with groundwater do not pay any charges. The absence of appropriate irrigation tariffs on a volumetric basis and subsidized energy costs do not support modernizing irrigation systems. Subsidizing certain agricultural products has also contributed to substantial irrigation water use in low-value crops like wheat and maize.

Institutional Aspects

Water is considered as a public property, owned by the Government. The major player in the water sector is the Ministry of Irrigation (MI) that was established in 1982. In 1986 General Directorates of Irrigation were established for each of the seven hydrologic basins.

There are 4 other organizations involved in the water sector in Syria:

- the Ministry of Agriculture and Agrarian Reform, Directorate of Irrigation and Water Uses;
- the Ministry of Housing and Public Services, Directorate of Water Supply and Waste Water being responsible for water supply and sanitation;
- the State Planning Commission, Section: Irrigation and Agriculture Sector;
- the Ministry of Environment;
- the State Environmental Affairs Commission, Section: Water Environment Safety Sector.

The Ministry of Irrigation is in charge of the study of water resources, their protection from depletion and pollution, of irrigation, dams, planning, research, operation and maintenance and pollution control. Allocation of water to agriculture is one of the main tasks of the ministry and it is thus responsible for the study and implementation of irrigation water structures and irrigation schemes. The Directorate of Irrigation is involved in water resources studies and surveys, water legislation and sharing international waters. There are three other departments under the responsibility of the Ministry of Irrigation: the Euphrates Basin Development Authority, the Euphrates Basin Land Reclamation Authority and the General Company of Major Water Resources Studies. Under the Ministry of Irrigation there are seven General Directorates, one for each of the seven hydrological basins.

The Ministry of Irrigation also is in charge of groundwater monitoring and the issuing of licenses for groundwater well drilling. In some areas with a high concentration of wells, such as parts of the Aleppo and Salamieh areas, the water table is dropping. The Ministry is exploring means of increasing the recharge of the shallow aquifers.

The Ministry of Housing and Utilities (MHU) is responsible for setting the master plans for all cities, town and villages as well as for providing drinking water and sewerage facilities to them. Even though the MHU is principally responsible for water supply and sanitation, its power is limited due to the fact that planning, design, implementation and operation of water supply and sanitation schemes is in the hand of the relatively independent Governorate’s Water Supply and Sewerage Authorities (WSSA). The water resources are allocated to the MHU’s WSSAs by the MI’s General Directorates. There is some duplication of tasks between the MI and the MHU, e.g. in the field of groundwater monitoring.

The Ministry of Agriculture and Agrarian Reform, through its Directorate of Irrigation and Water Uses deals with issues of irrigation efficiency and the allocation of land to be irrigated/cultivated.

The role of the Ministry of Environment is defined by law no. 50 of the year 2002 (28.07.2002). It is concerned with the monitoring, control and protection of the air, water and soil quality.

At the local level, the city and town councils have competence over all works within its administrative responsibility under the supervision of the governorate council. They establish water supply services and are involved in the planning and implementation of agricultural and water project in cooperation with the agricultural cooperative associations.

<u>Water Resources</u>

The following numbers on water resources and uses are adopted from MARTIN (1999). According to this report, the renewable water resources are distributed as follows:

Table C-9: Renewable Water Resources of Syria

Basin	**Renewable Water Resources (MCM/yr)**	
Euphrates	Surface Water	>5262
	Groundwater	1424
	Total	6686
Khabour	Surface Water	?
	Groundwater	?
	Total	>1800
Tigris	Surface Water	2500
	Groundwater	0
	Total	2500
Steppe	Surface Water	209
	Groundwater	182
	Total	391
Yarmouk	Surface Water	195
	Groundwater	265
	Total	460

Basin	**Renewable Water Resources (MCM/yr)**	
Barada & Awaj	Surface Water Groundwater Total	719 272 991
Orontes	Surface Water Groundwater Total	650 1607 2257
Aleppo	Surface Water Groundwater Total	273 222 495
Coastal	Surface Water Groundwater Total	1557 741 2298
Total		**>17878**

The non-conventional water resources are assumed to be:

Table C-10: Non-Conventional Water Resources of Syria in 1997

Basin	**Wastewater Reuse**	**Irrigation Return Flow**	**Total Non-Conventional Water**
Euphrates	?	1040	>1040
Khabour	?	806	>806
Tigris	?	37	>37
Steppe	?	42	>42
Yarmouk	?	64	>64
Barada & Awaj	>177	135	>312
Orontes	>40	400	>440
Aleppo	>95	140	>235
Coastal	?	243	>243
Total	**>317**	**2905**	**>3219**

The estimate for domestic water use in 1997 is not based on metered flow but on population statistics, assumed average consumption values and assumed unaccounted-for water percentage values per capita for each governorate, and is therefore only a very rough estimate (JICA, 1997: 1,390 MCM):

Table C-11: Domestic Water Consumption in Syria in 1997

Basin	**Domestic Water Use (MCM/yr)**
Euphrates	132
Khabour	36
Tigris	2
Steppe	57
Yarmouk	50
Barada & Awaj	294
Orontes	151
Aleppo	160
Coastal	75
Total	**957**

Even more difficult is the estimation of water use in agriculture. In 1997 about 60% of the irrigated area depended on groundwater. The number of licensed wells was 72,375, whereas more than 65,983 (official number) unlicensed wells existed in Syria. Since no records of water abstraction from these wells exist, agricultural uses can only be estimated using irrigated land area, crop distribution/production, cropping patterns, conveyance losses (10%), on-farm losses, and crop water requirements. The total irrigated land area is estimated to be 1,380,594. The total agricultural abstraction estimate also is only a very rough estimate (JICA, 1997: 12,750 MCM):

Table C-12: Agricultural Water Consumption in Syria in 1997

Basin	**Agricultural Water Use (MCM/yr)**
Euphrates	4258
Khabour	3226
Tigris	148
Steppe	168
Yarmouk	256
Barada & Awaj	554
Orontes	1601
Aleppo	558
Coastal	887
Total	**11656**

Water use for livestock breeding is estimated to be around 46.3 MCM/yr. Industrial water abstractions are also not metered and therefore are equally unreliable. In total an abstraction of around 420 MCM/yr is estimated (JICA, 1997: 570 MCM).

Table C-13 summarizes the total water uses in Syria for 1997.

Table C-13: Water Uses and Availability in Syria in 1997

Basin	**Domestic Water Use (MCM/yr)**	**Agricultural Water Use (MCM/yr)**	**Industrial Water Use (MCM/yr)**	**Total Water Use (MCM/yr)**	**Renewable Water Resources (MCM/yr)**
Euphrates	132	4258	44	4434	6686
Khabour	36	3226	12	3274	>1800
Tigris	2	148	1	151	2500
Steppe	57	168	19	244	391
Yarmouk	50	256	17	323	460
Barada & Awaj	294	554	98	946	991
Orontes	151	1601	151	1903	2257
Aleppo	160	558	53	771	495
Coastal	75	887	25	987	2298
Total	**957**	**11656**	**420**	**13,033**	**17,878**

Trends in water resources management

The agricultural sector is a major source of income, foreign exchange and labor in Syria. The irrigated area produces over 50% of the total value of agricultural production on about 18.6% of the cultivated land. A large part of the wheat production, as well as all major industrial crops including cotton, tobacco and sugar beet are produced on irrigated farms. The development and utilization of water so far has been carried out on an ad hoc basis, mainly responding to various demands. The need to increase food production has resulted in the construction of dams for irrigating lands under their command; and attractive prices for food crops, particularly for wheat recently, have resulted in a rapid increase in wells and the over-exploitation of groundwater. In addition, an increase in population and the siting of industries in major cities have contributed to further exploitation of the limited water resources.

Under the latest development plans, between 60 and 70% of public investment in agriculture was allocated to irrigation development, in particular for the construction of the Taqba dam and the establishment of the Al Assad reservoir.

Irrigated agriculture in the Damascus basin has to compete for both land and water with the residential and industrial expansion of the city. Irrigated agriculture has already been seriously reduced in the Damascus basin in recent decades and is increasingly affected by pollution.

Irrigation development to a large extent depends on how Syria reaches agreements with neighboring countries on the sharing of river waters (Turkey, Lebanon, Jordan and Iraq). Identifying and implementing policies, programs, projects and techniques to improve water use efficiency and to better control surface water and groundwater exploitation are important challenges facing Syrian policy-makers. Future projects have been planned by the government for the development of major schemes: 91,000 ha in the Euphrates basin, 150,000 ha in the Khabour (tributary of the Euphrates) basin with the construction of a reservoir north of Al-Hassakeh, 150,000 ha in the Tigris basin by pumping from the Tigris river and 72,000 ha in the Orontes basin (Al Ghab).

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A. *Groundwater Level Monitoring* and
B. *Groundwater Quality Monitoring*

1. Has a monitoring network been established already (since when) ?

Between 1956 and 1977 the Ministry of Public Works and Water Resources (MPWWR) was monitoring few scattered wells, most of them were private.

Between 1977 and 1988 MPWWR was contracting Soviet firms to study the hydrologic basins of Syria. During the study of each basin there has been a groundwater monitoring network covering the basin, but data collection was stopped in most cases at the end of the contract period.

Between 1988 and 2002 a real groundwater monitoring network has been gradually established by the Ministry of Irrigation to cover all the hydrologic basins of Syria.

The Damascus Water Supply and Sewerage Authority (DAWSSA) has its own groundwater monitoring network which covers Damascus city area, Fijeh spring and Barada spring recharge areas since 1987.

2. How many observation wells are monitored by which facilities (water level: automatic recorders, pressure transducers, manually) and how often (weekly, monthly, annually) ?

The total number of observation wells that are monitored in Syria was 1952 wells in the year 2002. Monitoring is done manually and monthly. Water levels are monitored in addition to temperature, pH, and conductivity in most cases.

3. Is groundwater monitoring being conducted for specific purposes (such as monitoring programs for: water level decline in certain well field areas, pollution control for sewage treatment plants, waste disposals, etc.) ? List examples.

The general purposes of groundwater monitoring in Syria are water balance studies, environmental monitoring and studies and water resources management.

4. Are the data being stored in a data bank (where and what for) ?

In 2001 a project for the establishment of a water resources data center was launched as a cooperation project between the Japanese International Cooperation Agency (JICA) and the Ministry of Irrigation. The first phase of the project comprises a central data bank located in the Ministry of Irrigation in Damascus in addition to two data centers in Barada and Awaj basin and the coastal basin using GIS to store and process the data. The groundwater monitoring network will be equipped with recorders and will be connected to the center through download. In the second phase of the project data will flow from all the seven hydrologic basins of Syria into the central data bank in the Ministry of irrigation.

5. Are monitoring reports being prepared on a regular basis ?

No.

6. Are the monitoring data being used for management decisions ? If so, please list examples.

The main aim is to estimate the groundwater resources that can be used each year without depleting the aquifers.

7 Groundwater Monitoring in Yemen

(sources: FAO Aquastat; TNO & GDH 1995; diverse WORLD BANK documents; various internet sources)

General Aspects

Yemen covers a total area of 527,970 km². The country is divided into 17 governorates. The total population is 14.5 million (1995), of which 66 % is rural. The average demographic growth rate is estimated at 3.7%.

The cultivable land is estimated at about 3.62 million ha, which is 7% of the total area. In 1994, the total cultivated area was 1.05 million ha, or 29% of the cultivable area.

The many different landscapes of Yemen can be grouped into five main geographical/ climatological regions:

- The Coastal Plains: The Plains are located in the west and south-west and are flat to slightly sloping with maximum elevations of only a few hundred meters above sea level. They have a hot climate with generally low to very low rainfall (< 50 mm/year). Nevertheless, the Plains contain important agricultural zones, due to the numerous wadis that drain the adjoining mountainous and hilly hinterland.
- The Yemen Mountain Massif: This massif constitutes a high zone of very irregular and dissected topography, with elevations ranging from a few hundred meters to 3,760 m above sea level. Accordingly, the climate varies from hot at lower elevations to cool at the highest altitudes. The western and southern slopes are the steepest and enjoy moderate to rather high rainfall, on average 300-500 mm/year, but in some places even more than 1,000 mm/year. The eastern slopes show a comparatively smoother topography and average rainfall decreases rapidly from west to east.
- The Eastern Plateau Region: This region covers the eastern half of the country. Elevations decrease from 1,200-1,800 m at the major watershed lines to 900 m on the northern desert border and to sea level on the coast. The climate in general is hot and dry, with average annual rainfall below 100 mm, except in the higher parts. Nevertheless, floods following rare rainfall may be devastating.
- The Desert: Between the Yemen Mountain Massif and the Eastern Plateau lies the Ramlat as Sabatayn, a sand desert. Rainfall and vegetation are nearly absent, except along its margins where rivers bring water from adjacent mountain and upland zones. In the north lies the Rub Al Khali desert, which extends far into Saudi Arabia and is approximately 500,000 km² in area. This sand desert is one of the most desolate parts of the world.
- The Islands: The most important of all the islands is Socotra, where more exuberant flora and fauna can be found than in any other region in Yemen.

Water Resources

Yemen can be subdivided into four major drainage basins, regrouping numerous smaller wadis:

- the Red Sea basin;
- the Gulf of Aden basin;
- the Arabian Sea basin;
- the Rub Al Khali interior basin.

The general hydrogeological structure of Yemen is shown in *Figure C-1*.

The floods of the wadis in Yemen are generally characterized by abruptly rising peaks that rapidly recede. In between the irregular floods, the wadis are either dry or carry only minor base flows.

Surface water resources have been estimated at 2,000 MCM/year, but this quantity corresponds to the runoff from major rivers and does not include the runoff produced within the smaller catchments. Renewable groundwater resources have been estimated at 1,525 MCM/year, a large part probably coming from infiltration in the river beds. A major aquifer was recently discovered in the eastern part of the country with an estimated storage of 10 km³. This aquifer is still under study and it is not known whether the groundwater is rechargeable or whether it is entirely fossil water.

The surface runoff to the sea measured in some major wadis is estimated at 270 MCM/year, the groundwater outflow to the sea at 280 MCM/year. There might be some groundwater flowing into Saudi Arabia, but no data are available. The existence of surface drainage crossing into Saudi Arabia suggests that some sharing of surface flows could be possible, but details are not known.

The total dam capacity is estimated at 0.18 km³. In general, the dams are built for irrigation and domestic purposes, but at the same time they contribute to groundwater recharge. There are also many flood control dams which are not intended to store water, but to divert the spate floods immediately to the adjacent irrigation network (spate irrigation).

In 1990 total water withdrawal was estimated at 2,932 MCM/year, of which 92% for agricultural purposes (6.9% is withdrawn for domestic use and 1.1% for industrial use). Most of the water used was groundwater (from wells and springs), resulting in groundwater depletion as withdrawal exceeds the annual groundwater recharge. The rates of decline of the groundwater levels is alarmingly high in many zones, especially in the Yemen Highlands, where decline of between 2 and 6 m/year is commonly observed. In coastal zones this leads to the incidence of salt water intrusion. Spring-fed irrigation has reduced significantly as groundwater tables have dropped. The quantity of desalinated water was estimated at 10 MCM/year in 1989, contributing to the water supply of Aden.

In 1994, the total water managed area was estimated at 481,520 ha. A global figure for irrigation potential is not available. About 48,000 ha have been identified for further irrigation development, mostly in the coastal plains and in Wadi Hadramaut.

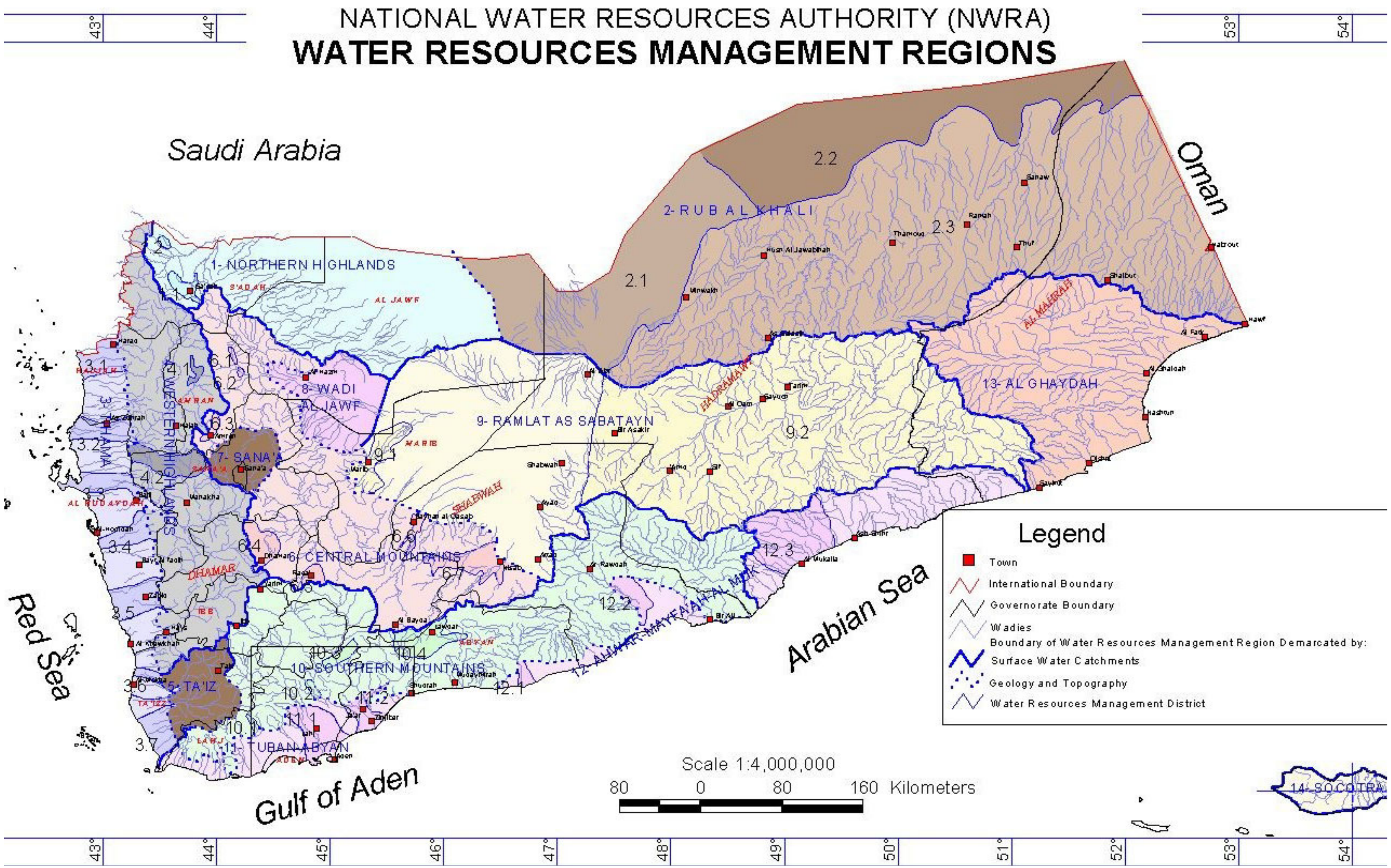

Figure C-1: Hydrogeological Sub-division of Yemen

Two main types of water management can be distinguished:

- Full/partial control irrigation: This concerns an area of 383,200 ha, all irrigated from groundwater, of which 363 200 ha from tubewells and 20,000 ha from spring water. In general, new, deeper tubewells replace those which have gone out of production because of declining water tables.
- Spate irrigation: This covers an area of 98,320 ha. Traditionally, farmers in the vicinity of wadis relied on simple earth built diversion systems and irrigation networks. With small to medium spates, these temporary embankments can be effective; with large spates, they are often swept away. In order to give better control of the spate flows, a series of public sector investments, involving the construction of permanent diversion weirs and canal distribution structures, have been made in the main wadis since the early 1970s. Most of these systems, however, have experienced maintenance and water distribution problems because scheme designs conflicted with traditional water rights.

On the remaining cultivated area of 571,266 ha, water harvesting is practiced, based on collecting and retaining overland flow in zones where soils permit agriculture. The receiving zone is always smaller than the zone where overland flow is produced, thus a multiplier effect is produced which permits agricultural production in low precipitation zones. The numerous constructed mountain terraces, also called 'the hanging gardens of Yemen', collect and retain rain and overland flow in a similar way.

Overall irrigation efficiency is low, between 35 and 45%, depending on field leveling and the water conveyance system used. Sprinkler irrigation and micro-irrigation are found on a limited number of farms and in pilot projects, using water from tubewells and springs. Almost all irrigation is surface irrigation. It is thought that efficiency could be increased to 60% by lining the canals and installing pipe distribution for surface irrigation, and to over 80% by adopting sprinkler irrigation and micro-irrigation techniques.

Farm size, including both rainfed and irrigated agriculture, is very small in general: 37% of the farms have less than 0.5 ha, 72% of the farms less than 2 ha, while only 4% of the farms have more than 10 ha.

According to the Constitution, flowing and underground water are defined as 'res communis'. However, a landowner has 'precedence' for water taken from a well on his land. In spring-irrigated areas water can be attached to land in the form of 'turns', which give rights to divert the canal into the field for a fixed period of time. The 'turn' can, however, be detached from the land and sold or rented separately. This landowner 'precedence' has permitted the private development of deep tubewell extraction, which is in some ways in conflict with Islamic principles. Islamic and customary law has no precedent for dealing with a new technology that allows landowners to extract (and sell) unlimited quantities of water from deep aquifers, and modern law has not yet regulated it either.

Since the 1970s the water supply situation in the Republic of Yemen has become critical. The main source, groundwater from wells, suffers from overstressed aquifers by large and uncontrolled abstraction and progressing groundwater pollution. Together with ill maintained distribution facilities this lead to serious shortfalls especially in the big towns, and to generally limited access of the population to safe drinking water.

As a consequence, there is high incidence of diarrhea, intestinal parasites and dysentery, which strongly indicates severe deficiencies in the water and sanitation sectors. In rural areas, where more than 70% of Yemen's population lives, less than half of the households are supplied with hygienically unobjectionable drinking water.

At an average 3.7% growth of population, water demand increases rapidly. Agriculture consumes 92% of the available quantities. Overall annual water consumption is presently estimated at 3.4 billion m^3. The still increasing depletion of water resources at a present annual rate of 900 MCM converts to a rapid declining of groundwater tables. Major population centers, such as Sana'a, Ta'iz and Sa'ada are in danger to run out of water from their traditional aquifers within the next 10 to 20 years. Decreasing resources are confronted with increasing contamination.

The institutional dimension of the water crisis refers to uncertainty about water rights and the weakness of supervising authorities for controlling the exploitation and protection of the resource. The Water Law legalizes the defined National Water Strategy and gives an outline of the administrative structure for its execution. However, the new Water Law needs to be complemented by the relevant policies, by-laws, executive procedures and guidelines in order to become workable and effective in practice.

Salinization due to irrigation exists in several regions, but no figures are available. No drainage systems are reported to exist.

<u>Institutional Aspects</u>

In view of the aggravating water crisis, the Government of the Republic of Yemen has declared the sustainable supply of the population with safe drinking water a top priority of economic and social development. The National Water Resources Authority (NWRA), established in 1995, has the prime task to develop and pursue a policy that leads to sustainable utilization of the decreasing water resources, and was given a central position to design, implement and control its components, as well as to take all appropriate steps to enhance public involvement and thus ensure social acceptance and viability of measures.

Solutions to the existing severe quantitative problems must be accompanied by quality protection measures, as the use of water resources is greatly restricted if they are polluted. The formulation of policies and of an action plan for Water Quality Control are presently under preparation in the framework of a Technical Cooperation project between NWRA and BGR (NWRA & BGR, 2003a/b/c).

The Ministry of Agriculture and Water Resources (MAWR) is responsible for formulating policies for water resources, for food security and for crops, livestock and forestry production, and for coordinating public investment and services in the sector. The General Directorate of Water Resources is located within the Ministry with four general departments: water resources; irrigation and maintenance of water installations; farm mechanization and land reclamation; irrigation studies. Most field services are provided to farmers through decentralized Regional Development Agencies (RDA), supported by technical services at national level. However, the division of responsibility between MAWR, the Agricultural Research and Extension Authority (AREA) and the RDAs with respect to water management is unclear.

Responsibility for coordinating rural water supplies lies within the Water Supply Department of the Ministry of Water and Electricity (MWE).

The General Department of Hydrology is located within the Ministry of Oil and Mineral Resources (MOMR).

Trends in water resources management

The successful and sustainable exploitation of the water resources in Yemen is threatened. The most serious and obvious problem is the rapid depletion of groundwater resources. Almost all the important groundwater systems in Yemen are being over-exploited at an alarming rate. The socioeconomic consequences of groundwater resources depletion are dramatic since groundwater will become too expensive for use in agriculture and, as a result, regional agricultural economies based on groundwater irrigation are doomed to collapse if the water resources are not adequately controlled. The groundwater stocks may be further reduced by groundwater salinization (in coastal areas) and groundwater pollution (in urban areas and areas of intensive agriculture). Environmental degradation occurs, for example in areas where springs have dried up. The scarcity of water leads to ever-increasing competition which, if uncontrolled, might lead to socio-economic problems.

There is an increasing awareness in Yemen of groundwater depletion. The Government of Yemen has committed itself to a sustainable use of the water resources, which was reiterated in an official statement issued at the UN Conference on Environment and Development of 1992 in Rio de Janeiro.

Water resources management in the country suffers because there is no unified central decision-making organization. Several authorities are dealing with water related affairs with minimum integration and coordination. To solve this problem, a Presidential Decree for the establishment of the National Water Resources Authority (NWRA) was issued in October 1995, providing for the merger of the General Directorate of Water Resources of MAWR, the General Department of Hydrology of MOMR and the Technical Secretariat of the previously existing High Water Council. The main duties of the authority will be:

- to prepare water resources policies and strategies;
- to formulate water legislation and regulations along with their enforcement;
- to undertake water resources studies, evaluation and planning;
- to carry out management at basin level, as traditional centralized management has proved to be a failure.

Measures to be implemented at field level may include the introduction of water-saving techniques (improving irrigation efficiencies, imposing a water tariff, etc.), groundwater licensing and enforcement of pollution control regulations.

Strict water quality standards have been introduced in 2000 and 2001:

- Yemeni Quality Standards No. 100/2000: Bottled Drinking Water;
- Yemeni Quality Standards No. 109/2000: Drinking Water;

- Yemeni Quality Standards No. 150/2001: Irrigation Water;
- Yemeni Quality Standards No. 149/2001: Industrial and Commercial Wastewater.

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A. Groundwater Level Monitoring and
B. Groundwater Quality Monitoring

1. Has a monitoring network been established already (since when) ?

According to the Yemeni Water Law (2002) the General Authority for Water Resources (GAWR) is responsible for monitoring in the country (Articles 12 and 17).

ESCWA (2000c) states that the “Water Quality Monitoring (WQM) currently implemented in Yemen is a basic and nominal program with severe limitations on its scope and effectiveness. The Water Quality (WQ) problems in Yemen are attributable mainly to unsatisfactory water sources, poor site selection, constructional deficiencies, discharge of untreated domestic and industrial wastewaters to the environment, seawater intrusion and over-drafting of groundwater resources. The absence of reliable water Quality Monitoring Program (WQMP) will undoubtedly lead to a series of negative impacts on the National Integrated Water Resources Management in which Yemen has invested extensively.”

According to MOMR & TNO (1995), the groundwater level monitoring network in Yemen is of limited extent and fragmented concerning its spatial distribution as well as the monitoring responsibilities. The monitoring network includes: 31 wells in the Sadah basin, 42 wells in the Surdud basin, 62 wells in the Marib zone, 36 wells in the Rada basin, 194 wells in the Tihama, and 47 wells in the Sana’a area. They are operated by various institutions (GDH, RIRDP, TDA, and NWSA. A monitoring network of unknown extent also exists in the Tuban and Abyan deltas and Wadi Hadramawt (85 wells) in the south of the country.

According to UNDESA (2004), there are presently 25 groundwater stations in the Tuban delta, 48 in Wadi Rasyan, 33 in the Abyan Delta, 35 in the Surdud catchment area, 18 in the Sada’ah catchment, 34 in the Ma’arib catchment, and 6 groundwater stations in the Sana’a area (in addition water levels are measured manually at 62 wells).

2. How many observation wells are monitored by which facilities (water level: automatic recorders, pressure transducers, manually) and how often (weekly, monthly, annually) ?

Table C-14: Groundwater Monitoring Network in Yemen (from TNO & GDH 1995)

Agency	Area	Total Number of Wells		Period of Record
		Manual	Automatic	
GDH	Marib	54	8	1987-93
GDH	Surdud	38	4	1984-93
GDH	Sadah	29	2	1984-92
TDA	Mawr	36	-	1978-92
TDA	Siham	22	-	1986-92
TDA	Rima	61	-	1975-77
TDA	Zabid	45	-	1981-92
TDA	Rasyan	30	-	1970-92
RIRDP	Rada	20	16	1977-92
NWSA	Sana'a	44	3	1990-93
ODA/LRC	Dhamar Mountain Plains	45	-	1975-76
?	Tuban Delta	?	-	?
?	Abyan Delta	?	-	?
?	Wadi Bayhan	?	-	?
?	Wadi Hadramawt	85	-	?

3. Is groundwater monitoring being conducted for specific purposes (such as monitoring programs for: water level decline in certain well field areas, pollution control for sewage treatment plants, waste disposals, etc.) ? List examples.

No information available.

4. Are the data being stored in a data bank (where and what for) ?

The National Water Resources Information System (NWRIS) database was established at the NWRA in the late 1990s.

5. Are monitoring reports being prepared on a regular basis ?

No information available.

6. Are the monitoring data being used for management decisions ? If so, please list examples.

No information available.

8 References and Related Literature

ACSAD (1997): Water Resources and their Utilization in the Arab World. – 2nd Symposium on Water Sources and their Uses in the Arab World, 8-10 March 1997; Damascus.

ALSHARHAN, A.S., RIZK, Z.A., NAIRN, A.E.M., BAKHIT, D.W. & ALHAJARI, S.A. (2001): Hydrogeology of an Arid Region: The Arabian Gulf and Adjoining Areas.- 331 p.; Amsterdam (Elsevier).

AOMAR, J. & ABDELMAJID, K. (2002) : Wastewater Reuse in Morocco. – Report prepared by the Ministry of Agriculture, Rural Development and Waters and Forests for the Water Demand Management Forum, 30 p.; Rabat.

EL BATTI, D. (2003): Evaluation de la pratique actuelle du suivi et de la protection des ressources en eau en Tunisie. – Unpublished Report prepared for ACSAD, ACSAD-BGR Technical Cooperation Project 'Management, Protection and Sustainable Use of Groundwater and Soil Resources in the Arab Region' between BGR and ACSAD, 28 p.; Tunis/Tunisia, Damascus/Syria.

ESCWA (1999a): Updating the Assessment of Water Resources in ESCWA Member Countries. – 132 p; Beirut/Lebanon.

ESCWA (1999b): The Arab Water Vision. – Document prepared for the World Water Council Meeting on 4-5 August 1999 in Marseille, 41 p.; Cairo, Marseille, Beirut.

ESCWA (2000a): Guidelines for Groundwater Protection and Pollution Control in the GCC Countries. – Report No. ENR/2000/WG.3/12, 10 p.; Beirut/Lebanon.

ESCWA (2000b): Groundwater Pollution Control Measures in Lebanon. – Report No. ENR/2000/WG.3/11, 5 p.; Beirut/Lebanon.

ESCWA (2000c): ASSESSMENT OF WATER QUALITY MONITORING AND MANAGEMENT IN YEMEN. – Mission Report submitted to the NWRA and the Ministers Council of the Republic of Yemen, First Mission (September 2000), 47 p; Beirut.

ESCWA (2001): Implications of Groundwater Rehabilitation on Water Resources Protection and Conservation: Artificial Recharge and Water Quality Improvement in the ESCWA Region. – Report No. ENR/2001/12, 54 p.; Beirut/Lebanon.

HOBLER, M., MARGANE, A., ALMOMANI, M. & SUBAH, A. (2001): Groundwater Resources of Northern Jordan, Vol.4: Hydrogeological Features of Northern Jordan. - Unpublished report prepared by Technical Cooperation Project 'Advisory Services to the Water Authority of Jordan' between BGR and WAJ, BGR archive no. 112708; Amman/Jordan.

KADI, M.A. (2002): Water Sector Development trough Effective Policies, Institutions and Investments: A Country Perspective (for Morocco). – [internet download from www.oieau.fr/ciedd/contributions/at3/contribution/aitkadi.html]

KHATER, A. R. (2003): Evaluation of the Current Practice of Groundwater Monitoring and Protection in Egypt. – Unpublished report prepared for ACSAD, 42 p.; Cairo/Egypt.

KHOURI, J. (2000): The Development of Water Legislation in Arid and Semi-Arid Zones – A Case Study: Syria. – Report prepared by ACSAD for WHO, 17 p.; Damascus.

MACKSOUD, S.W. (2002): Towards a Sustainable Groundwater Development in Lebanon. – [internet download from *www.oieau.fr/ciedd/contributions/at1/contribution/macksou.htm*]

MARGANE, A. (1995): Groundwater Resources of Northern Jordan, Vol.2, Part 2: Monitoring of Groundwater Levels in Northern Jordan. - Unpublished report prepared by Technical Cooperation Project 'Advisory Services to the Water Authority of Jordan' between BGR and WAJ, BGR archive no. 112708, 71 p., 3 app., 3 maps; Amman/Jordan.

MARGANE, A. (2002): Criteria for the Preparation of Groundwater Vulnerability Maps. - Technical Report No. 2, Unpublished report prepared by Technical Cooperation Project 'Groundwater Resources Management' between BGR and MWI, 118 p.; Amman/Jordan.

MARGANE, A. (2003a): Guideline for Groundwater Vulnerability Mapping and Risk Assessment for the Susceptibility of Groundwater Resources to Contamination. – Technical Reports Vol. 4, Unpublished report prepared by Technical Cooperation Project 'Management, Protection and Sustainable Use of Groundwater and Soil Resources in the Arab Region' between BGR and ACSAD, 177 p.; Damascus/Syria.

MARGANE, A. (2003b): Guideline for the Delineation of Groundwater Protection Zones. – Technical Report Vol. 5, prepared by ACSAD & BGR, Technical Cooperation Project 'Management, Protection and Sustainable Use of Groundwater and Soil Resources in the Arab Region', 329 p.; Damascus.

MARGANE, A. & ALMOMANI, M. [Edts.] (2002): Preliminary Draft of National Water Master Plan, Vol. IV – Groundwater Resources. - Technical Report No. 3, Unpublished report prepared by Technical Cooperation Project 'Groundwater Resources Management' between BGR and MWI, 68 p.; Amman/Jordan.

MARGANE, A., HOBLER, M., OURAN, S. & AL ZUHDY, A. (1999) Groundwater Resources of Northern Jordan – Special Report No. 5: Hydrogeological Proposal for the Delineation of a Groundwater Protection Area for the Tabaqat Fahl (Pella) Spring. - Unpublished report prepared by Technical Cooperation Project 'Advisory Services to the Water Authority of Jordan' between BGR and WAJ, BGR-archive no. 118708; Amman/Jordan and Hannover/Germany.

MARGANE, A., HOBLER, M. & SUBAH, A. (1997): Groundwater Resources of Northern Jordan, Special Report No. 3: Mapping of Groundwater

Vulnerability and Hazards to Groundwater in the Irbid Area. - Unpublished report prepared by Technical Cooperation Project 'Advisory Services to the Water Authority of Jordan' between BGR and WAJ, BGR archive no. 112708, 50 p., 10 app., 4 ann.; Amman/Jordan.

MARGANE, A., HOBLER, M. & SUBAH, A. (1999): Mapping of Vulnerability and Hazards to Groundwater in the Irbid Area, N-Jordan. – Zeitschrift Angewandte Geologie, 45, 4: 175-187.

MARGANE, A., HOBLER, M., ALMOMANI, M. & SUBAH, A. (2002): Contributions to the Hydrogeology of Northern and Central Jordan. – Geol. Jahrbuch, C 68, 52 p., 18 fig.; Hannover.

MARGANE, A. & SUNNA, N. (2002): Proposal for a National Guideline for the Delineation of Groundwater Protection Zones. – Technical Report No. 1, Unpublished report prepared by Technical Cooperation Project 'Groundwater Resources Management' between BGR and MWI, 161 p.; Amman/Jordan.

MARTIN, N. (1999): Water Availability and Water Use in Syria. – Report prepared for WORLD BANK, 31 p.; Washington/DC/USA.

MELLOUL, A.J. & ZEITOUN, D.G. (1999): A Semi-Empirical Approach to Intrusion Monitoring in Israeli Coastal Aquifer. – In: BEAR, J. et al. (eds.): Seawater Intrusion in Coastal Aquifers – Concepts, Methods and Practices, 543-558; Dordrecht/The Netherlands (Kluver).

MERGUSIE (2001): La gestion de l'eau en Tunisie. – Report prepared for the project 'Gestion intégrée de l'eau sur le bassin versant de Merguellil', 10 p ; Tunis/Tunisia. [internet download]

MISKI, A.F. & SHAWAF, S. (2003): Aspects of Groundwater Resources Management, Protection and Monitoring in Syria. – Unpublished Report prepared for ACSAD, ACSAD-BGR Technical Cooperation Project 'Management, Protection and Sustainable Use of Groundwater and Soil Resources in the Arab Region' between BGR and ACSAD, 19 p.; Damascus/Syria.

NWRA & BGR (2003a): Sustainable Policy to Ensure National Water Quality Control. – Unpublished report prepared by BGR & GKW, Final report, Vol. 2A, Technical Cooperation Project 'Support of the National Water Resources Authority (NWRA)'; Sana' a/Yemen.

NWRA & BGR (2003b): Initial Action Plan for the Implementation of National Water Quality Control Policy . – Unpublished report prepared by BGR & GKW, Final report, Vol. 2B, Technical Cooperation Project 'Support of the National Water Resources Authority (NWRA)'; Sana' a/Yemen.

NWRA & BGR (2003c): Policy and Action Plan for Water Quality Control. – Unpublished report prepared by BGR & GKW, Final report, Vol. 2D, Technical Cooperation Project 'Support of the National Water Resources Authority (NWRA)'; Sana' a/Yemen.

ONEP & GTZ (1995) : Dossier technique relatif à la délimitation des zones de protection du champ de Sidi Taïbi (1995). – Unpublished report prepared by Moroccan-German Technical Cooperation Project 'Protection of Drinking Water Resources'; Rabat/Morocco.

ONEP (2002): Protection des Captages: Cas du Champ Captant de Sidi Taibi. – [internet download from www.oieau.fr/ciedd/contributions/at1/contribution/onep1.htm]

TNO & GDH (1995): The Water Resources of Yemen – Report WRAY-35. – 108 p.; Sana'a/Yemen.

UNDP & WORLD BANK (2000): National Environmental Action Plan for Syrian Arab Republic – Draft. – 67 p., 5 ann.; Washington/DC/USA, New York/USA, Damascus/Syria.

UNDESA (2004) : Program Completion Report. - Program YEM/97/200; New York/USA.

UNESCO & ESCWA (1999): World Water Council – Arab Countries Vision Consultations. – Proceedings of a meeting held in Marseille on 4-5 August 1999, 41 p.; Cairo, Marseille, Beirut.

VARELA-ORTEGA, C. & SAGARDOY, J.A. (2001): Analysis of Irrigation Water Policies in Syria: Current Developments and Future Options. Report prepared for FAO project 'Utilization of Water Resources for Agriculture in Syria', 22 p.; Rome/Italy.

WORLD COMMISSION ON DAMS (2001): Water, Institutions and Development in Syria: A Downstream Perspective from the Euphrates and Tigris. – Knowledge Base, Serial No. 108, 18 p. [internet download from: *www.dams.org/kbase/submissions*]

WORLD BANK (2001a): Syrian Arab Republic Irrigation Sector Report. - Report No. 22602-SYR, 95 p.; Washington/DC/USA.

WORLD BANK (2001b): Morocco Water Quality Management Country Report. – 11 p.; Washington/DC/USA.

Annex C-1: Information requested for Guideline on Groundwater Monitoring

A. *Groundwater Level Monitoring* and
B. *Groundwater Quality Monitoring*

1) Has a monitoring network been established already (since when) ?

Name	*Agency*	*Date/Year monitoring started*	*Purpose*	*Number of wells/stations*

2) How many observation wells are monitored by which facilities (water level: automatic recorders, pressure transducers, manually) and how often (weekly, monthly, annually) ?

Name/Area	*Type*	*Number of wells/stations*
	automatic recorders	
	pressure transducers	
	manual readings	

3) Is groundwater monitoring being conducted for specific purposes (such as monitoring programs for: water level decline in certain well field areas, pollution control for sewage treatment plants, waste disposals, etc.) ? List examples.

Name/Area	*Purpose*

4) Are the data being stored in a data bank (where and what for) ?

Name/Area	*Agency*	*Purpose*
e.g.: Water Level Databank		

5) Are monitoring reports being prepared on a regular basis ?

Name/Area	*Date/Year*
e.g.: Report on Groundwater Monitoring in the x Area	2002

6) Are the monitoring data being used for management decisions ? If so, please list examples.

Please attach the relevant laws/by-laws/guidelines concerning groundwater level and quality monitoring (if possible in English/French).

Annex C-2: Groundwater Monitoring, Protection and Sustainable Resources Management in Syria

Document prepared by A. F. Miski & S. Shawaf

Groundwater Monitoring, Protection and Sustainable Resources Management in Syria

prepared by

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for

ACSAD-BGR Technical Cooperation Project

Management, Protection and Sustainable Use of Groundwater and Soil Resources in the Arab Region

Damascus
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This document was prepared by A. F. Miski & S. Shawaf upon request of the ACSAD-BGR Technical Cooperation Project '*Management, Protection and Sustainable Use of Groundwater and Soil Resources in the Arab Region'.*

Part A

GROUNDWATER PROTECTION ZONES IN SYRIA

1. Introduction

The Syrian Arab Republic (Syria) is administratively divided into 14 Governorates (Mohafazat), namely:

1. Governorate of Damascus or Damascus City
2. Governorate of Damascus Countryside
3. Governorate of Homs
4. Governorate of Hama
5. Governorate of Aleppo
6. Governorate of Latakia
7. Governorate of Tartous
8. Governorate of Idlib
9. Governorate of Raqqa
10. Governorate of Dair Ezzor
11. Governorate of Hasakeh
12. Governorate of Deraa
13. Governorate of Sweaida
14. Governorate of Qunaitra

Syria is hydrologically divided into 7 principal basins:

1. Barada and Awaj Basin
2. Yarmouk Basin
3. Assi Basin
4. Coastal Basin
5. Tigris & Khabour Basin
6. Euphrates Basin
7. Badia Basin

Figure (1) shows the administrative boundaries in Syria, Figure (2) the limits of the hydrologic basins. The water resources originating in side the boundaries of the Syrian Arab Republic are estimated to be 9700 MCM per year on the average.

Figure 1: Administrative Boundaries of Syria

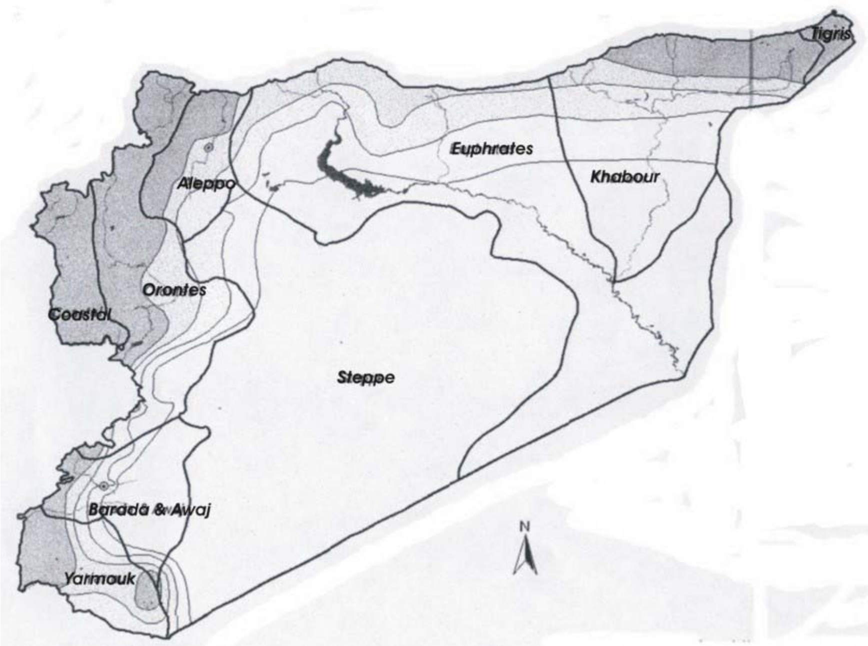

Figure 2: Hydrological Basins of Syria

2. Institutional Environment

Water is considered in Syria as a public property owned by the government. There are four Ministries dealing directly with the water issue in Syria, namely:

1- Ministry of Irrigation

2- Ministry of Housing and Utilities

3- Ministry of Agriculture and Agrarian Reform

4- State Ministry of Environment

The Ministry of Irrigation (MI) is responsible for the studies of water resources, their protection from depletion and pollution, and their allocation for different uses. It is responsible also for the study and implementation of all water structures and irrigation projects for agricultural purposes as well as their operation and maintenance.

The headquarters of MI is in Damascus, it comprises the following:

1- The Minister and four Minister Assistants, and few consultants.
2- Thirteen Central Directorates, namely:
- D. of Training, research, and informatics
- D. of Water resources
- D. of Exploitation and maintenance
- D. of Public water pollution control.
- D. of Contracts.
- D. of Legal affairs
- D. of finance
- D. of Studies
- D. of Vehicles
- D. of Planning
- D. of Internal control
- D. of Execution
- D. of Administrative affairs

In addition to the above mentioned central directorates, there are seven general directorates belonging to MI, each one of them is responsible for a hydrologic basin, these seven general directorates are:

1- The General Directorate of Irrigation (GDI) for Barada and Awaj Basin, located in Damascus.
2- GDI for Badia basin, located in Homs.
3- GDI for Assi Basin, located in Hama.
4- GDI for Coastal Basin, located in Latakia.
5- GDI for Yarmouk Basin, located in Dara'a.
6- GDI for Tigris and Khabour Basin, located in Hasakeh.
7- GDI for Euphrates + Aleppo Basin, located in Thawra.

Each general directorate of irrigation is authorized to study and implement all water projects in the relevant basin, it comprises thirteen divisions similar in function to the thirteen central directorates in the Ministry but on basin scale. The role of the central directorates is to supervise and check the studies carried out in the general directorates of irrigation and to provide expertise and consultation whenever necessary.

The Ministry of Housing and Utilities (MHU) is responsible for setting the master plans for all cities, towns, and villages in Syria as well as providing drinking water and sewerage facilities for them. This ministry is responsible also for all mass housing projects. MHU takes care of drinking water and sewerage thru fourteen general establishments of drinking water and sewerage existing in the fourteen governorates of Syria. These establishments are responsible for exploiting the drinking water resources allocated by the Ministry of Irrigation and for the distribution of drinking water in their relevant governorate as well as for sewerage networks and water purification and treatment plants.

Drinking water cost and sewerage treatment fees are collected by the above mentioned general establishments and delivered to the Ministry of finance who allocates budgets for all ministries and general establishments. Water tariff is the same allover Syria.

The main role of the Ministry of Agriculture and Agrarian Reform in the water issue is the annual allocation of areas to be irrigated or planted in light of available surface water and groundwater resources.

The role of the Ministry of Environment in the water issue has been defined in law number 50 dated 28/7/2002. This law haws given the ministry wide authorities for monitoring water quality and for the protection of the water environment.

Each one of these two ministries is represented in each governorate of Syria by a local office called Directorate.

3. Questionnaire

1) Is there a law in place to allow for the delineation of groundwater protection zones ?

The Legislation for groundwater protection zones was initiated in Syria in 1970 when decree number 2145 was issued to establish the Directorate of Public Water Pollution Control as a new directorate belonging to the already existing Ministry o Public Works and Water Resources. Decree 2145 has given wide authority to the Directorate of Public Water Pollution Control to take all necessary measures to deal with water pollution in rivers, sea, springs, wells, and all public waters (Article 3, item B-8).

In 1982, law number 16 was issued to establish the Ministry of Irrigation. One of the main tasks of this ministry of the protection of the water resources from all forms of pollution and the preparation of the relevant legislations.

In 1986, law number 17 was issued. By this law a general directorate of irrigation was created in each one of the seven hydrologic basins of Syria. Each directorate is administratively and financially independent but supervised by the Ministry of Irrigation. Each directorate is responsible for the study, development and exploitation of the water resources in the relevant basin as well as for protecting these resources from depletion or pollution.

In 1989, law number 10 was issued for the protection of Figeh spring from pollution.

The most recent legislation for groundwater protection is the decision number 386 dated 18/1/2003 issued by the Prime Minister which prohibited the drilling of wells for agricultural purposes in all the hydrologic basins of Syria. This decision defined regulations for licensing wells for drinking, industrial, and touristic purposes only. Even governmental bodies must have a license before drilling any water well. This decision has emphasized on delineating protection zones for drinking water wells as well as for springs, foggharas, and water courses. Violators of this decision are subject to severe punishments.

2) Have groundwater protection zones already been established (how many) ?

In compliance with Decree number 2145 of 1970, the Ministry of irrigation has established a committee called “Central Committee for Protection Zones, headed by the Minister Assistant. This committee comprises all specialties necessary for studying water resources protection zones. A similar committee was formed in every general directorate of the seven hydrologic basins. As a result of the work of these committees, more than 45 ministerial decisions for establishing protection zones have been issued. Each decision is accompanied with a topographic map delineating the limits of the protection zones. Out of these decisions there are 26 concerning springs and wells, the others deal with dam lakes from which water is taken for drinking purposes and with foggharas.

3) Which restrictions are imposed on land use activities in the protection zones ?

In 1980, the Ministry of Public Works and Water Resources issued Ministerial Decision number 393 including guidelines for delineating protection zones for water resources. The major parts of the guidelines were taken from the German norms. These guidelines imposed three prohibition zones for springs:

A – Intensive Prohibition zone, which must be appropriated in favor of the Ministry of Public Works and Water Resources or the General Establishment of Drinking water that is exploiting the water resource for the protection zone is delineated. In this zone all activities are prohibited with the exception of forest trees. This zone is intended to prevent any direct pollution.

B – Direct Prohibition zone, which covers part of the recharge area that is sufficient for self purification of the groundwater. The extent of this zone depends on the environmental, geological, geographical, and socio-economical conditions in the recharge area. The restrictions that are imposed on land use activities aim at protecting the water quality and they include in general:

- Protection from flooding and construction of impermeable sewage network.
- Coverage of base rock and filling of holes by clean impermeable materials.
- Prohibition of industries that have dangerous wastes.
- Prohibition of first class roads, camps, or training centers.
- Monitoring and control of the use of fertilizers and pesticides, and prohibition of hazardous types.
- No sewage water treatment plants are allowed in this zone.

C – Peripheral Protection Zone, which covers the rest of the recharge area of the spring. In case large springs having an extended recharge area, the peripheral protection zone is divided into two sub zones:

Sub Zone A: Covering areas that are within 2 Km from the spring.

Sub Zone B: Covering the rest of the recharge area. The restrictions on land use inside the peripheral protection zone are less severe than those in the direct protection zone. They aim at protecting the groundwater from contamination with chemical and radioactive materials and other dangerous materials like petroleum fractions, poisons, and mining wastes.

The Legislations for groundwater protection zones are issued as ministerial decisions by the Minister of irrigation. Only in one case which is the case of Figeh spring, the protective zones were delineated by a law signed by the President of the Republic (law Number 10 dated March, 1989) after thorough discussions in the Parliament, this was due to the vital importance of Figeh spring which is the main drinking water source for Damascus city. The law was based on profound study of the hydrogeologic and socio-economic conditions of the recharge area of Figeh spring that was performed by a French firm (SOGREA) in 1980 and resulted in the proposal of 3 protection zones: Intensive protection zone, direct protection zone, and peripheral protection zone. The later zone includes the whole recharge area of the spring amounting to 770 Km^2.

As for drinking water wells which are normally close to inhabited areas, only zones A and B are delineated.

4) How are the restrictions being enforced ?

Violations to the restrictions imposed by the ministerial decisions regarding protection zones (in case of Figeh spring law No. 10 of 1989) are monitored by employees of the Ministry of irrigation and the Ministry of Housing and Utilities who should inform the representatives of the Ministry of Local Administration and the police in order to prevent the violation. In case of serious violations, police transfer violators into court which judges in compliance with the civil Syrian law.
There are a lot of problems with local inhabitants when enforcing the legislations concerning protection zones.

5) Which methods are being used for the delineation of groundwater protection zones ?

Each year, the protection zones committee in each one of the seven hydrologic basins reports to the central committee of protection zones in the Ministry of irrigation a proposal for establishing protection zones for the water resources it deems necessary to protect in the basin. The control committee coordinates the received proposals giving priorities to the water resources for drinking water and to the resources that are more vulnerable to pollution. This committee issues eventually an annual work plan for delineating protection zones taking the technical and financial possibilities into consideration. In compliance with this plan, each basin committee implements the necessary hydrogeologic and socio-economic investigations and prepares a draft ministerial decision delineating the protection zones for the relevant water resources. The draft is then discussed in the central committee for approval by the Minister of Irrigation. When the decision is issued, the general directorate of irrigation of the relevant basin becomes responsible for the implementation of the decision.

6) What are the sizes of zones 1, 2, 3 ?

The sizes of zones 1,2, and 3 depend on many factors. The discharge of the water source and the water use are the most important factors. The availability of enforcing the protection zones on the ground is another important factor. The extent of the recharge area and the hydrogeologic and socio-economic conditions as well as the existing and future important factors. In general, the size of zone 1 which must be appropriated is few hectares, the size of zone 2 is some tens of hectares, while the size of zone 3 ranges between some square kilometers to some hundred square kilometers. For example, in the case of Figeh Spring which is totally used for drinking water the sizes of zones 1,2, and 3 are 11 ha, 57 ha, and 770 km^2 respectively. While in the case of Barada spring which is used for drinking water and irrigation, the sizes of zones 1,2, and 3 are 1.5 ha, 10 ha, and 46 km^2 respectively.

7) Which other measures are in place to protect the groundwater resources ?

There are several other measures in place to protect the groundwater resources. The most important of which are:

A- The Ministry of Irrigation cooperates with the Ministry of Housing and Utilities during the study phase of master plans for villages and towns in order to exclude protection zones from urban extension. In some cases some already approved master plan were modified to avoid urban extension inside the intensive and direct protection zones (case of Mzairib spring).

B- The Ministry of Irrigation cooperates with the Ministry of Petroleum, so that the path of crude oil pipelines and the petroleum fractions pipelines avoid water resources protection zones. When it is deemed impossible, the pipeline is constructed inside a concrete canal with suitable slopes to drain any petroleum seepage outside the protection zone like in the case of Banias spring in the coastal basin.

C- The Ministry of Irrigation coordinates with the Ministry of Environment in order to make the intensive protection zone an environmental reservation like in the case of Sinn Spring in the Coastal Basin.

D- The Ministry of Irrigation cooperates with the Ministry of Defense so that the placement of military camps are far from the protection zones of wells and springs.

E- The Central Committee for Protection Zones always tries its best in order to find suitable solutions for accidental pollution problems. For example, when Tannour Spring in Assi Basin was polluted by nitrates and became vulnerable to be depleted, the committee took measures to close wells in the recharge area of the spring, and prohibited the use of fertilizers and pesticides and permanent irrigation in the direct protection zone.

F- The Ministry of Irrigation cooperates with the Ministry of Agriculture and Agrarian Reform to guide farmers how to use treated sewage water for irrigation. Farmers are guided to use less chemical fertilizers with treated sewage water in order to protect drinking water wells from pollution in Damascus Ghouta.

G- The Ministry of irrigation endeavors to upgrade the efficiency of personnel working in the study and implementation of protection zones by sending them to training courses.

H- The Ministry of Irrigation monitors the quality of treated sewage water to get sure of its disinfection.

I- The Ministry of Irrigation endeavors continuously to update the legislations concerning groundwater protection whenever new technologies are available.

8) Is a groundwater monitoring network for groundwater quality control established and functional ?

In every hydrologic basin in Syria, there is a groundwater monitoring network. The water level is monitored monthly or every three months in all wells of the network. Samples for water quality monitoring are taken every three months from some wells of the network. Special attention is given to monitoring heavy metals. Samples are taken from important springs to monitor water, quality. In Barada& Awaj Basin, there are 140 wells for monitoring water levels, 29 of them are used for water quality monitoring.

9) Have maps of groundwater vulnerability been prepared ?

No groundwater vulnerability maps have been prepared yet in Syria. However, some studies for sea water encroachment towards fresh groundwater in the coastal basin have been conducted and appropriate measures based on these studies were taken. Vulnerability maps for some pilot areas will be prepared in the near future.

10) Are guidelines/laws/by-laws in place to control the quality of emissions into surface and groundwater (sewage water/effluent standard) ?

Specifications for industrial effluents into Barada River and Assi River are already in place. There are also Syrian specifications for effluents discharged into the sewage network aiming at ensuring the operation of the sewage water treatment plants with high efficiency.
The Directorate of Public Water Pollution Control has established guidelines defining specification of all the effluents that are to be discharged into sea, rivers, and water courses. There are ongoing studies to issue standard specifications based on these guidelines.

11) Is there a law/by-law/guideline for the design and monitoring/control of waste disposal sites ?

The guideline for the design and control of waste disposal sites is included in Decree 2145 of the year 1971 which gave the Directorate of Public Water Pollution Control (DPWPC) the authority of monitor the pollution of all public waters. This directorate has established a water quality monitoring network along the courses of the main rivers in Syria. This net work comprises:
26 Stations on Assi River
36 Stations on Barada River
13 Stations on Euphrates River
6 Stations on Kabir Shamali River
6 Stations on Yarmouk River
Monthly samples are taken from each station. The elements monitored are: Discharge, BOD, SS, Ammonia, Nitrates, PH, and temperature in addition to other pollution indicators depending on the discharged effluents. The length of record in the stations ranges between 10 to 25 years. DPWPC monitors also the industrial waste effluents upon discharging outside factory, the elements monitored depend on the type of industry. All samples are analyzed in DPWPC labs, the results are reported to the relevant ministries who order the pollution source to take the appropriate measures.

12) Is there a law/by-law/guideline for the use of pesticides/fertilizers in agriculture ?

The Ministry of State for Environmental Affair supervises the importation of all pesticides in Syria. This ministry defines the prohibited pesticides. Any importation of pesticides by public or private sector needs a license from the ministry and the customs.

The use and importation of fertilizers is guided by the Ministry of Agriculture and Agrarian Reform who guides farmers on the farm level how to use fertilizers and pesticides in a way that not causes pollution to the product or to groundwater.

The Ministry of Irrigation upon preparing the decisions for protection zones states that the use of fertilizers and pesticides in zones 2 and 3 is subject to the supervision of the directorates of agriculture when agriculture is permitted in said zones.

13) Is there a law/by-law/guideline for environmental protection/environmental impact assessment ?

The Ministry of State for Environmental Affairs was created in 1991 by presidential decree number 11. The task of this ministry is the preservation of the environment in Syria. In 199x the supreme council for Environmental Safety was established in the Cabinet and became responsible for licensing industries and structures having polluting effluents.

In 199x the Ministry of State for Environmental Affairs established a directorate for environmental impact assessment. This directorate became responsible for studying the environmental impacts of every new industrial project and for setting the necessary precautions and measures that should be applied to protect the environmental elements before licensing any project.

In 2002 law number 50 was passed by the parliament which is called the Environmental Law. The main features of this law are:

J- It enabled the Ministry of State for Environmental Affairs to set the environmental standards and specifications.
K- It created a general organization for environmental affairs and specified its tasks.
L- It developed the supreme council for Environmental Safety and defined its functions.
M- It created a fund for supporting and protecting the environment.
N- It nominated environmental experts who may be appointed by the Minister to inspect sources of pollution.
O- It considered man caused pollution as a criminal act and imposed sanctions ranging from financial penalty to ten years in jail.
P- The law permitted the already existing structures causing pollution one year to adapt with the imposed restrictions and demands.

14) How are groundwater protection demands integrated into land use planning ?

Till now, there is no national plan for land use in Syria. The Ministry of Housing and Utilities prepares master plans for urban and rural settlements. The Ministry of Irrigation and the Ministry of Agriculture and Agrarian Reform are involved in delineating the lands to be reclaimed in compliance with soil classification and water availability. There are legislations and regulations on the governorate level classifying the land use as agricultural, industrial, or urban. When studying master plans, the water resources protection zones demands listed in the relevant legislations are considered and respected.

Part B

SUSTAINABLE GROUNDWATER RESOURCES MANAGEMENT IN SYRIA

Questionnaire

1) How is 'sustainable yield' defined ?

Sustainable yield is defined as the total abstraction from groundwater that does not cause depletion to the groundwater reserves. In other works, when we can calculate for each year the renewable amount of groundwater in each basin and regulate the abstraction purposes to be within this amount, then we are exploiting our groundwater within the sustainable.

2) Table showing the abstracted amounts/water uses (groundwater and surface water) for the sectors domestic/agricultural/industrial uses, the 'safe yield' and the 'groundwater recharge' (if not identical with safe yield).

The renewable water resources originating inside the Syrian territories amount to 9929 MCM per year. When speaking about water uses, we have to add the share of Syria from Euphrates and Tigris rivers which are on the average 6627 MCM per year from Euphrates and 1250 MCM per year from Tigris, so that the total available water resources are 17806 MCM/year.

Table (1) shows the water uses in Syria for the different sectors in the year 2002:

Table (1): Water Uses in Syria in 2002

Water Use	Volume in MCM
Irrigation	13973
Domestic	1070
Industrial	561
Others (including free water surface evaporation)	1962
Total	**17566**

Source: Ministry of Irrigation- Eng. S.A.Shawaf.

3) What is the share of groundwater in the different sectors of water supply ?

Table (2) shows the share of groundwater in the different sectors of water supply in Syria in the year 2002:

Table (2): Share of Groundwater in Water Supply

Water Use	Share of Groundwater	
	MCM	%
Irrigation	8048	58
Domestic	761	71
Industrial	325	58
Total	**9134**	

Source: Ministry of Irrigation – Eng. S.A. Shawaf.

4) What are the main factors influencing the groundwater resources management decisions (demand driven, economical considerations, sociological considerations, etc.) ?

The main factors influencing the groundwater resources management are:

A. The availability of good quality groundwater in all the Syrian basins at reasonable depths lead to rely on groundwater for drinking water supply in most rural areas. Individual farmers rely on groundwater as well in case of no adequate surface water irrigation network is available.

B. The annual agricultural plan set up by the Ministry of irrigation and the Ministry of Agriculture and Agrarian reform defines the areas to be irrigated each year on the basis of surface water availability. Due to economical factors, may farmers exceed the defined areas and rely on groundwater to get more water for irrigation.

C. In dry years, when the quantities of surface water impounded in dam lakes fail to cover the irrigation demands, more pumping of groundwater becomes the sole solution in spite of the drastic water levels drawdown.

5) What are the main problems in groundwater resources management ?

The main problems of groundwater resources management in Syria are:

A. Inadequate coordination between the Ministry of Irrigation who license water wells, and the Ministry of Interior (police) who should close illegal wells. This leads to the growth of illegal wells and to the depletion of groundwater.

B. Inadequate groundwater monitoring networks.

C. The technicians who are in charge of groundwater management and monitoring need continuous education and training.

D. Pollution of groundwater by nitrates due to the use of nitrate fertilizers or treated sewage water in irrigation. Some drinking water wells have shown high nitrate content in Dara'a and Idlib governorates, the Ministry of Housing and Utilities was obliged to abandon the wells and look for another drinking water resource.

E. Salination of groundwater caused by excessive irrigation and poor drainage as in Raqqa governorate.

F. Excessive pumping of groundwater in the coastal plains between Jableh and Banias has caused sea water encroachment and deteriorated groundwater quality.

G. Deep groundwater in Badia basin has high salinity in general, the water is not suitable for drinking or for irrigation. The Ministry of Housing and the Ministry of Irrigation will start in 2003 to build pilot desalination plants to treat the water and to introduce desalination technology to Syria.

H. The lack of convenient water legislation. The draft water law is still under discussion in the parliament, when it will be issued the Ministry of Irrigation will be able to set up standard specifications for all waters and to control all water uses.

6) Is domestic water supply in the hand of governmental institutions or privatized/semi-privatized ?

Domestic water supply is in the hand of governmental institutions. In each one of the fourteen governorates of Syria, there is a general establishment for drinking water and sewerage belonging to the Ministry of Housing and Utilities. This establishment is responsible for supplying drinking water for all houses, offices and commercial activities.

7) Do the water tariffs cover the costs of installation/operation/ maintenance ? List the water tariffs for domestic/agricultural/industrial uses.

The water tariffs in Syria cover only the operation and maintenance costs. The installation costs are paid by the government from the investment budget.

There are two tariffs for water in Syria (Table 3), that are applied allover the country, one for irrigation water, and another for drinking water.

For irrigation water, annual fees are collected at the rate of 3500 S.P. (equivalent to about $ 70) per irrigated hectare. The drinking water tariff effective since 2001 is as follows:

Table (3): Water Tariffs

3 month water consumption (m^3)	**Tariff (S.P./m^3)**	
1-60	3.00	Household Consumption
61-90	4.50	Household Consumption
91-180	13.50	Household Consumption
181 → Up	19.00	Household Consumption
Commercial, Touristic & Industrial Consumption	22.00	
Government Buildings, Consumption	8.50	

When billing, 20% is added on the average to the bill of household consumption to cover sewerage services, while about 40% is added to the bill of commercial, touristic, and industrial consumption. As for government buildings consumption, 55% is added for sewerage services.

8) Which measures are being used for the augmentation of water resources (artificial recharge, wastewater reuse, watershed/rainwater harvesting, etc.) ?

The measures that are used in Syria for the augmentation of water resources are:

A. Use of treated sewage water:
In Barada and Awaj basin, 18000 hectares are irrigated by the treated sewage water resulting from Damascus sewage treatment plant. In Assi basin, 100 hectares are irrigated by the sewage water treated in Salameyeh plant. Upon the completion and operation of 10 sewage treatment plants there will be 400 MCM per year of treated water for irrigation.

B. Use of Industrial drainage water:
In Assi basin, 229 MCM per year are used for industry. 29 MCM are consumed and lost, while 200 MCM are returned to Assi River and used for irrigation after treatment.

C. Use of Irrigation drainage water:
The reuse of irrigation drainage water has less health and environmental hazards than treated sewage water. 17400 hectares are irrigated by irrigation drainage water in Ghab development project in Assi basin, the water demand is estimated to be 124 MCM per year.

D. Artificial Recharge of Groundwater:
Damascus Water Supply and Sewerage Authority (DAWSSA) in cooperation with the Ministry of Irrigation has started since 2001 to recharge the aquifer in Damascus city by Figeh spring water using large diameter wells and the same pumping wells during the flood period of Figeh spring. 2 MCM were recharged in 2002.

E. In Barada basin, hafirs have been used since 1995 for rainwater harvesting. By the year 2000 there was 34 hafirs with a total storage capacity of 2.9 MCM. Water spreading has been also practiced since 1993 in Badia basin to increase the soil humidity. 655 hectares were moistured by this way in 1997.

F. Cloud seeding: The Ministry of Agriculture started in 1992 a project for cloud seeding. Various methods have been used to assess the feasibility of the project.

9) What is the (approximate) share of groundwater rendered as not usable for domestic water supply due to poor groundwater quality either a) because of natural conditions or b) because of pollution ?

The share of groundwater rendered as not usable for domestic water supply differs from one basin to another in Syria. This share is considered low in general and is estimated to be between 10-15%.

A. The deep aquifers in Badia basin have high salinity rendering the groundwater undrinkable.

i. In the Coastal basin, excessive pumping of wells having originally acceptable salinity caused sea water intrusion to the aquifers and obliged the Ministry of Housing to rely on the water of Sinn spring to provide domestic water supply to all the cities and towns of the coastal strip, which were using local wells in the sixties for drinking.

ii. In Damascus city, some wells have penetrated gypsum lenses in Mezzeh area and were abandoned as water supply wells because the water taste is bitter.

B. The main pollutants for rendering groundwater wells not usable for domestic water supply are nitrates and ammonia resulting from excessive use of organic and chemical fertilizers.

iii. Some well sin the southern part of Damascus city have shown high nitrate content. They are either abandoned as domestic water supply resources, or the water pumped from these wells is mixed with Figeh spring water having very low nitrate content.

iv. Some wells in Yarmouk basin near Deraa city which has been used for drinking were abandoned upon showing high nitrate content after a new irrigation project was implemented.

v. The drinking water wells for Idlib city in Omk plain (Assi basin) were rendered unusable because the surrounding area which was a marsh has been dried up and became a permanent irrigation area where excessive fertilizers were used causing high nitrate content in groundwater. The Ministry of Housing provides now water supply for Idlib city from Ain Zarka spring in Assi valley.

10) Which water management policies (institutional, regulatory and resources management measures) have been implemented to achieve a status of sustainable groundwater resources management ?

The main water management policies that have been implemented to achieve a status of sustainable groundwater resources management are:

A. Water resources in Syria are considered as public properties owned by the Government. The Ministry of Irrigation has the right to license for government bodies, groups of people, or individuals to exploit water resources within legal regulations.

B. Water structures like dams, irrigation canals, drinking water distribution networks, or aqueducts are implemented owned by the Government who supervises their exploitation and maintenance.

Water structures in the private sector or mainly groundwater wells which need licensing from the Ministry of Irrigation provided that aquifer conditions are adequate.

C. Water use is managed by the Ministry of Irrigation who is authorized to allocate water for all users giving priorities to drinking water supplies, then to industrial, touristic, and irrigations for rationalizing the water use for irrigation encouraging modern irrigation methods.

D. In each one of the seven hydrologic basins of Syria, the relevant general directorate of irrigation is responsible for conducting necessary studies for the development of water resources in that basin and for the implementation of land reclamation projects taking into account the reservation of the water environment and the aquatic life.

E. The Syrian government (Ministry of Irrigation and Ministry of Housing and Utilities) has implemented many projects to develop the main springs like Sinn, Figeh, Barada, Banias, Ain Tannour and to regulate their discharge.

F. The Ministry of Irrigation conducts studies for exploring deep groundwater aquifers.

G. A draft water law has been prepared by the Ministry of Irrigation and under discussion in the parliament. This law updates all existing water legislations and aims at providing practical basis for the sustainable use of groundwater and surface water resources.

H. Capacity building of personnel working in the groundwater domain takes place thru on job training and contacts with foreign experts as well as thru sending engineers and technicians for training abroad.

Part C

GROUNDWATER RESOURCES MONITORING IN SYRIA

Questionnaire

1) Has a monitoring network been established already (since when) ?

Groundwater monitoring network in Syria has been established gradually. Three phases can be recognized:

A. Between 1956 and 1977 the Ministry of Public Works and Water Resources (MPWWR) was monitoring few scattered wells, most of them were private.
B. Between 1977 and 1988 MPWWR was contracting with Soviet firms to study the hydrologic basins of Syria. During the study of each basin there has been a groundwater monitoring network covering the basin, but data collection was stopped in most cases after the contract period has elapsed.
C. Between 1988 and 2002 a real groundwater monitoring network has been gradually established by the Ministry of Irrigation to cover all the hydrologic basins of Syria.

The Damascus Water Supply and Sewerage Authority (DAWSSA) has its own groundwater monitoring network which covers Damascus city area, Figeh spring and Barada spring recharge areas since 1987.

2) Who is operating these monitoring networks ?

In each one of the seven hydrologic basins of Syria, the relevant general directorate of irrigation belonging to the Ministry of Irrigation operates the groundwater monitoring network in the basin. As already mentioned, DAWSSA operates its own groundwater monitoring network.

3) How many observation wells are monitored by which facilities (water level: automatic recorders, pressure transducers, manually) and how often (weekly, monthly, annually) ?

The total number of observation wells that are monitored in Syria was 1952 wells in the year 2002. Monitoring is done manually and monthly. Water levels are monitored in addition to temperature, PH, and conductivity in most cases.

Table (4) shows a breakdown of the above mentioned wells by basin. These wells shown in the table, there are observation wells belonging to DAWSSA for monitoring the drinking water resources of Damascus city.

Table (4): Observation Wells in Syria

Basin	Number of Observation Wells	Year of Starting Observations
Barada and Awaj	142	1989
Badia	70	1988
Assi	210	1988
Coastal	73	1993
Yarmouk	90	1989

Basin	Number of Observation Wells	Year of Starting Observations
Dajleh and Khabour	227	1995
Euphrates + Aleppo	600+240	2002
Total	**1652**	

4) Is groundwater monitoring being conducted for specific purposes (such as monitoring programs for: water level decline in certain well field areas, pollution control for sewage treatment plants, waste disposals, etc.) ? List examples.

The general purposes of groundwater monitoring in Syria are:

A. Water balance studies;
B. Environmental monitoring and studies;
C. Water resources management.

However, the frequency and quality of data collection from observation wells may vary according to specific purposes. For example:

A. Groundwater level and quality monitoring in Barada and Awaj basin provides essential data for decision makers when allocating water resources for different uses in the governorates of Damascus and Damascus Countryside. In dry years, most of the water is allocated for drinking on the account of irrigation.
B. In Assi basin, monitoring wells were drilled around fertilizer factories in Quattina region in order to study the effect of effluents from the factories on groundwater. Monthly observations have shown PH values of groundwater ranging between 1 and 4 indicating high pollution.
C. A joint project was conducted by the Ministry of Irrigation and the Ministry of Environment and supported by the UN University (International network for Water, Environment, and Health) to study nitrates in the drinking water of some villages in Damascus Countryside. It was found that drinking water pumped from wells was polluted by nitrates in the two villages of Rihan and Haush due to the use of sewage treated water in irrigation and to the discharge of untreated sewage as well as the excessive use of fertilizers.
D. A joint project between Dutch government and the General Directorate of Coastal basin takes place at present and aims at the use of groundwater monitoring data to assess the groundwater resources and the slope of groundwater surface in the coastal area of Syria.
E. Another project is carried out by the General Directorate of Assi basin and supported by FAO to study the groundwater flow in the upper reaches of Assi River.

5) Are the data being stored in a data bank (where and what for) ?

In 2001 a project for the establishment of a water resources data center was launched as a cooperation project between the Japanese International Cooperation Agency (JICA) and the Ministry of Irrigation. The first phase of the project comprises a central data bank located in the Ministry of Irrigation in Damascus in addition to two data centers in Barada and Awaj basin and the coastal basin using GIS to store and process the data. The groundwater monitoring network will be equipped with recorders and will be connected to the center through download. In the second phase of the project data will flow from all the seven hydrologic basins of Syria into the central data bank in the Ministry of irrigation.

At present all the data are stored in local computers in each one of the general directorates of irrigation.

6) Are monitoring reports being prepared on a regular basis ?

The engineers and hydrogeologists in each general directorate of irrigation are responsible for the interpretation of the data in the relevant basin. The main aim is to estimate the groundwater resources that can be used each year without depleting the aquifers. The results are given to responsible in the Ministries of Agriculture and Irrigation who set up the annual agricultural plan and decide the areas that can be irrigated by groundwater.

In Damascus City Water Supply and Sewerage Authority (DAWSSA) the groundwater monitoring data is interpreted by a technical committee who decides in light of the data the policy of drinking water distribution in Damascus city during the drought period (June to November) each year.

7) Are the monitoring data being used for management decisions ? If so, please list examples.

Water management decision makers in Syria have realized the importance of water monitoring data. One of the targets of the project of water resources data center is to provide data on the quantity and quality of groundwater and establish water users associations who can select from the existing wells the most promising ones and construct an irrigation network that can serve all users in a better way than the already existing individual wells for farmers.

Annex C-3: Evaluation of the Current Practice of Groundwater Monitoring and Protection in Egypt

Document prepared by A. R. Khater

Evaluation of the Current Practice Of Groundwater Monitoring and Protection in Egypt

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submitted to the
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Preface

This report has been prepared upon the request of the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD), within the framework of their running project concerning "Management, Protection and sustainable Use for Groundwater and Soil Resources in the Arab Region".

The report presents an overview about the activities and achievements of Groundwater quality and quantity monitoring and protection in Egypt. The results of several pilot and important research and studies were also presented. A lot of experience can be exchanged in the Arab Region in the field of groundwater quality monitoring and groundwater protection. The "IHP-Network on Groundwater Protection in the Arab Region" can facilitate the exchange and transfer of such experience among the Arab Countries.

1. GENERAL CHARACTERISTICS

1.1 Physical Setting

Geography

The Egyptian territory is almost rectangular, with a N-S length of approximately 1,073 km and W-E width of approximately 1,270 km (Figure 1). It covers an area of about one million square kilometers.

Figure 1. Geography of Egypt

Geographically, Egypt is divided into four main regions with the following percentage areas of the country: (i) the Nile Valley and Delta, including el Fayum depression and Lake Nasser (3.6%); (ii) the Western Desert, including the Mediterranean littoral zone, Siwa, Bahariya, the New Valley, Tushka and Uweinat (68%); (iii) the Eastern Desert, including the Red Sea littoral zone and the high mountains (22%); and (iv) Sinai Peninsula, including the littoral zones of the Mediterranean (middle and east), the Gulf of Suez and the Gulf of Aqaba (6.4%).

Climate

The country lies for the most part within the temperate zone. The climate varies from arid to extremely arid. The air temperature frequently rises to over 40^0 C in daytime during summer, and seldom falls to zero in winter. The average rainfall over Egypt as a whole is only 10 mm/year. Along the Mediterranean, where most of the winter rain occurs, the annual average rainfall is about 150 mm/year, decreasing rapidly inland. The evaporation rates are high, being in excess of 3,000 mm/year.

1.2 Hydrogeologic Environment

Hydrography

The hydrography of Egypt comprises two systems: (i) a system related to the Nile; and (ii) a system related to the rainfall in the past geological times, particularly in the Late Tertiary and Quaternary.

The Nile system comprises the Valley and Delta regions which are morphologic depressions filled with Pliocene and Quaternary sediments. The Nile enters Egypt at Wadi Halfa, south of Aswan. This area is at present occupied by the Lake Nasser. From Aswan to Cairo, the river meanders until it reaches Cairo. At a distance of about 20 km north of Cairo, the river divides into two branches, each of which meanders separately through the Delta to the sea. In the Nile flood plain there are extensive man-made drainage systems, especially in the traditionally cultivated old land. Some extend to the areas reclaimed for agriculture on the desert fringes of the flood plain. The drainage systems discharge to the Nile itself or to the Northern Lakes and the Mediterranean Sea.

The other hydrographic system in Egypt is the complex network of dry streams (wadis); the formation of which dates back to past wet periods in the Tertiary and Quaternary. This system covers more than 90% of the surface area of Egypt in the Western Desert, the Eastern Desert, and Sinai. The main catchment areas drain towards to the Nile Valley and Delta, to the coastal zones, and to inland depressions.

Geomorphology

The landscape in Egypt can be broadly divided into the elevated structural plateau and the low plains (which include the fluviatile and coastal plains). These geomorphologic units play a significant role in determining the hydrogeological framework. The structural plateau constitutes the active and semi-active watershed areas. The low plains can contain productive aquifers and are also, in places, areas of groundwater discharge.

Geology

Geologically, Egypt is a portion of the northward overlap of the Nubian Arabian massif. In the southeast part of the country, the basement rocks are exposed and constitute portion of the

African carton, which was formed during the Pre-Cambrian and possibly also during the Cambrian. It constitutes of a number of crustal plates or segments separated by major N/NW-S/SE faults, as presented in Figure 2. Folding and wrench faulting introduced further complications. More information can be found in the explanatory note of the 1:2,000,000 hydrogeological map of Egypt (RIGW/IWACO, 1988, updated in 1999).

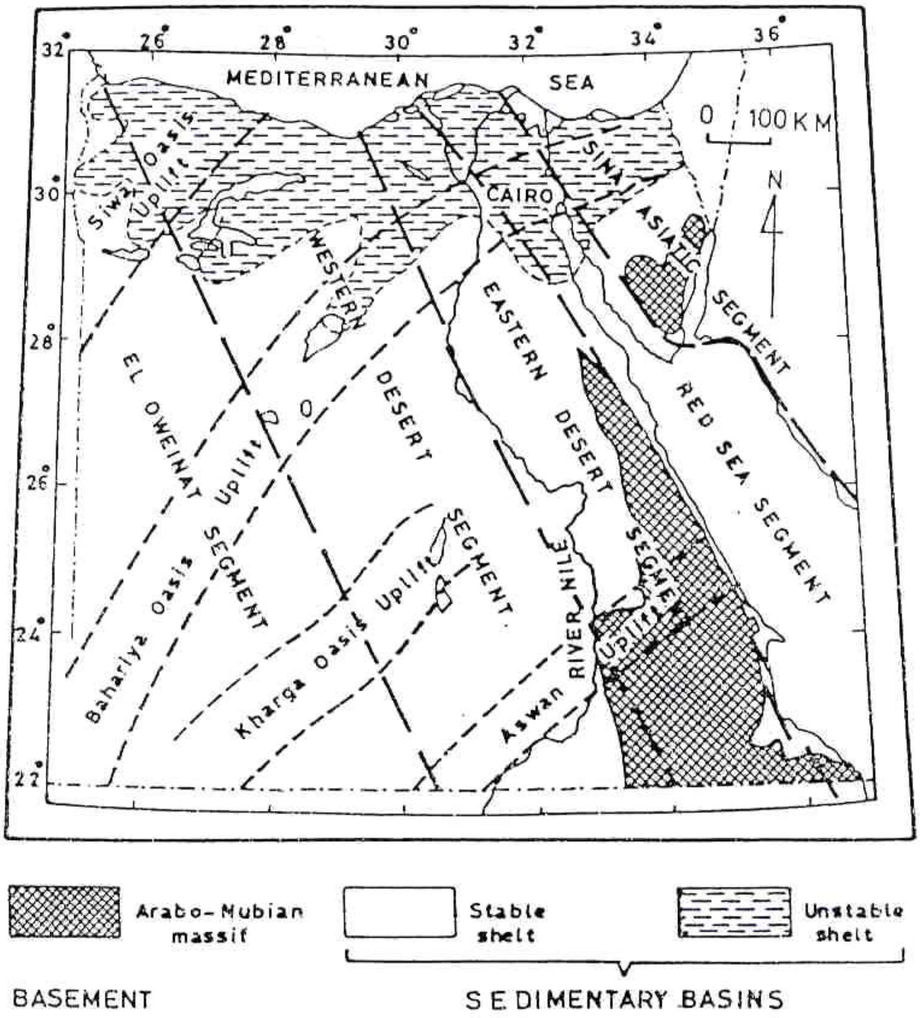

Figure 2. Tectonic Map of Egypt

Hydrogeology

The hydrogeological framework of Egypt comprises six aquifer systems (RIGW, 1993), as shown in Figure 3:

1) The Nile aquifer system, assigned to the Quaternary and Late Tertiary, occupies the Nile flood plain and desert fringes. The storage capacity of the system is about 500 million m^3.

Groundwater is essentially replenished from activities originating from the Nile. Accordingly, it cannot represent a resource in itself; but the aquifer can be considered a storage and regulation reservoir.

2) The Nubian Sandstone aquifer system, assigned to the Paleozoic-Mesozoic, occupies a large area in the Western Desert, and parts of the Eastern Desert and Sinai. Its storage capacity is estimated at 60,000 Km^3; but groundwater is almost non-renewable. Groundwater can be found at very shallow depths, where the water bearing formation (horizon) is exposed; or very large depths (up to 1,500 m), where the aquifer is semi confined. The deepest water bearing horizons are generally encountered in the north (Siwa), while the shallowest are encountered in the southern portion (East Uweinat and Kharga).

3) The Moghra aquifer system, assigned to the Lower Miocene, occupies mainly the western edge of the Delta. Groundwater recharge is limited to the portion adjacent to the flood plain through groundwater seepage.

4) The Coastal aquifer systems, assigned to the Quaternary and Late Tertiary, occupy the northern & eastern coasts. Groundwater is found in the form of thin lenses floating over saline water. The main recharge source is rainwater.

5) The karstified Carbonate aquifer system, assigned to the Eocene and to the Upper Cretaceous, predominates essentially in the north and middle parts of the Western Desert. It overlies the Nubian sandstone, and underlies the Nile aquifer system. It is essentially recharged through upward leakage from the Nubian sandstone.

6) The Fissured and Weathered hard rock aquifer system, assigned to the Pre-Cambrian, predominates in the Eastern Desert and Sinai. It is essentially recharged from its extension in Sudan, and, locally from rainfall (Sinai).

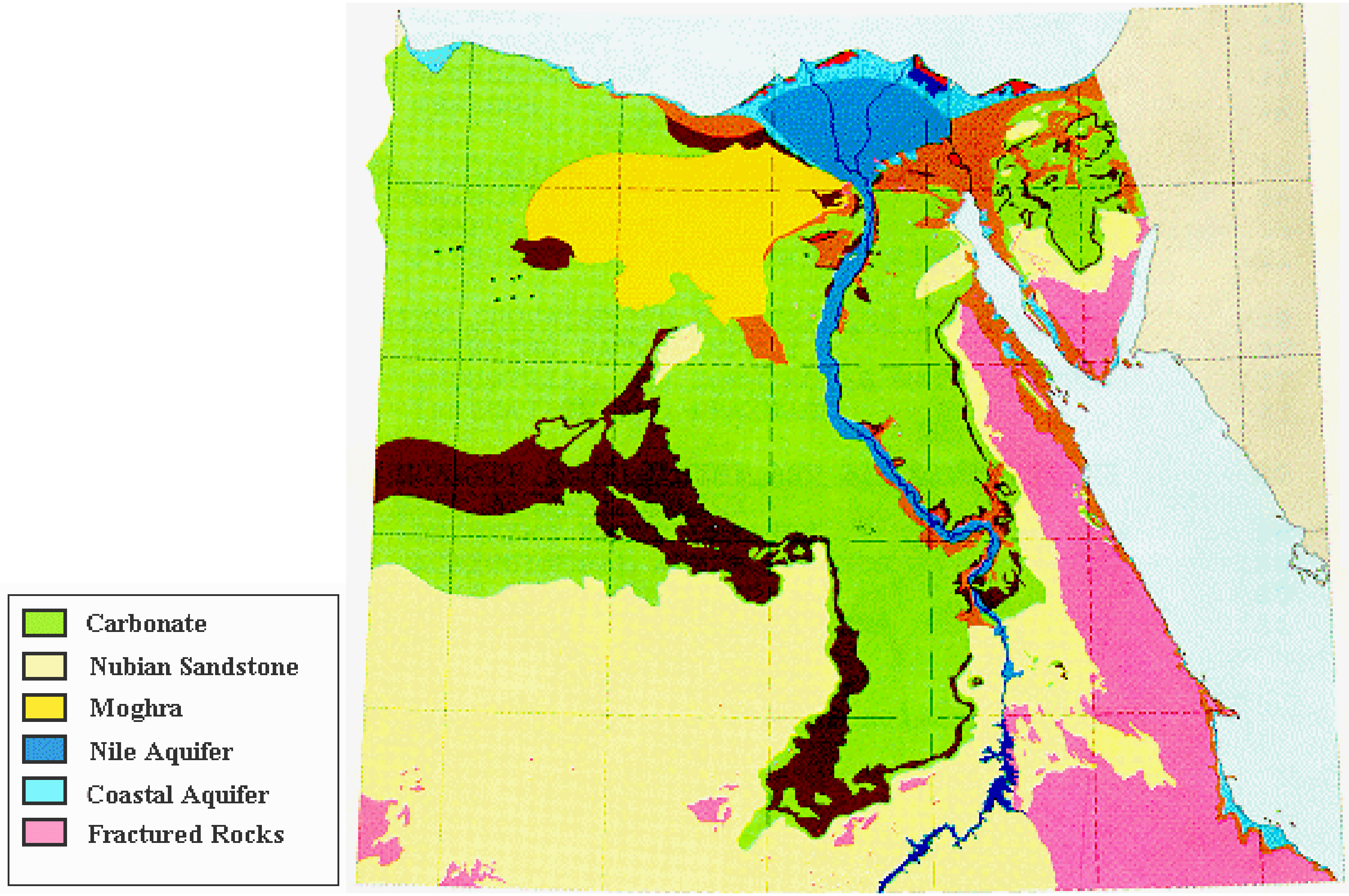

Figure 3. The Hydrogeological Map of Egypt

1.3 Population and Development

Egypt's population is estimated at 64 million (1999). About 11.5% of the population is concentrated in Cairo, 7.1% in the coastal governorates, 43.5% in the Delta governorates, 36.5% in Upper Egypt governorates, and the rest distributed among the remaining area of the country. The population density varies from 15,000 to 0.4 person/Km^2, in Cairo and the New Valley Governorates, respectively.

The percentages of the population served with water supply and sewerage connections are generally higher in the urban governorates than in the rural ones. In these communities with no access to water supply, the main source of fresh water is made available from shallow hand-dug wells that may be polluted due to poor protection means.

The continuous increase in population has resulted in urban encroachment on arable land leading to an annual loss of between 30,000 to 50,000 feddan of best agricultural land over the past 20 years. The total cultivated area at present is estimated at about 7.8 million acres, with a distribution among governorates that varies from 1-to 1,160-acres/1000 capita (Figure 8), with an average of about 0.13 acre/capita. The government policy is to reclaim an additional area of 3.4 million acres by the year 2017.

1.4 Environmental Problems

Provisions for the protection of the environment and natural resources have not been included in the country constitution. Rather, they are provided for under national laws, which in many instances were enacted to implement state sectoral policy. In this manner, a national policy, aiming at the protection of natural resources, has been enforced through a number of national laws, which regulate and control the exploitation of these resources. Similarly, measures to ensure compliance with public health standards and requirements were embodied in a number of laws.

Various environmental problems are encountered in the country due to the delay in providing environmental protection legislation and the poor enforcement of such legislation. The most important problems and their causes are summarized in the following paragraphs.

1. Air pollution due the emissions from factories and cars.

2. Pollution of surface water and northern lakes due to the disposal of primary or non-treated domestic and industrial effluent. Although the situation is not yet severe, it will soon become if no action is taken.

3. Pollution of the shallow groundwater for the same causes mentioned above, and poor solid waste disposal.

4. Increased drawdowns and salinity of groundwater on the desert fringes due to over-exploitation.

1.5 Water Resources

Potential

Egypt is an arid country with rainfall occurring only in winter in the form of scattered showers and frequent flash floods in wadis. Unless proper harvesting and management of rain and floodwater is made, this source may not be considered a reliable source of water due to its spatial and temporal variability.

The main source of fresh water in Egypt is the Nile. Based on treaties among the Nile riparian countries, Egypt share from the Nile is 55.5 BCM/year. This amount is secured by the multi-year regulatory capacity provided by the Aswan High Dam.

Groundwater is distinguished into Nile and non-Nile originating categories. The main aquifer system containing Non-Nile water is the Nubian sandstone (almost non-renewable groundwater). The total groundwater volume in storage in the Nubian sandstone is estimated at 60,000 BCM. The current total extraction amounts about 0.5 BCM/year. However the economic annual economic extraction is estimated at 5 BCM/year (based on present water allocations and economy).

Groundwater in the Nile aquifer system cannot be considered a separate source of water as the aquifer is recharged from activities based on Nile water (seepage from canals and deep percolation from irrigation application). The aquifer, however, can be utilized as a regulatory/storage reservoir. Figures 4 and 5 illustrate the current groundwater extraction and future potential.

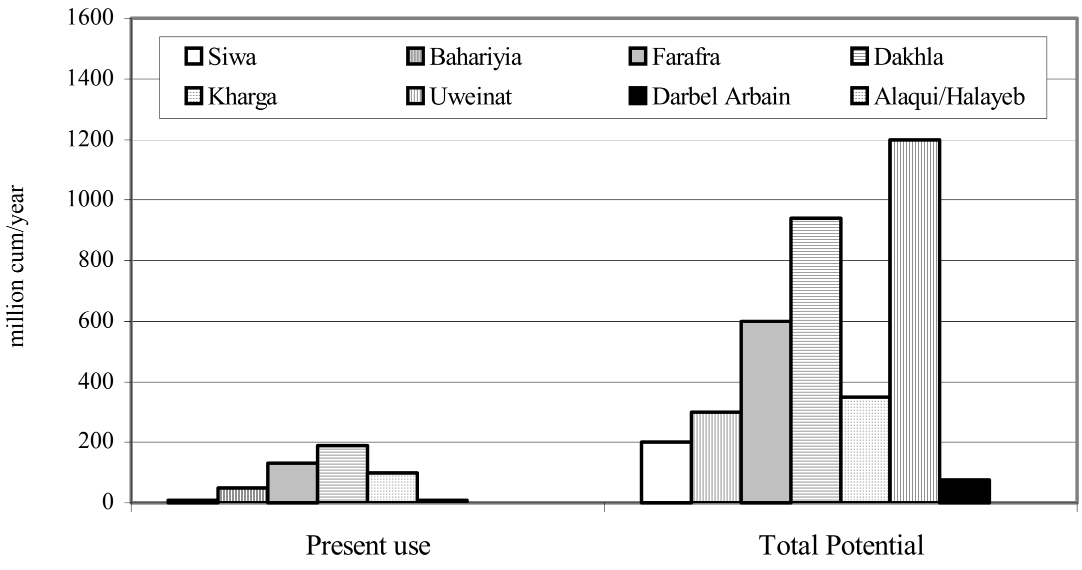

Figure 4. Groundwater in the Deserts

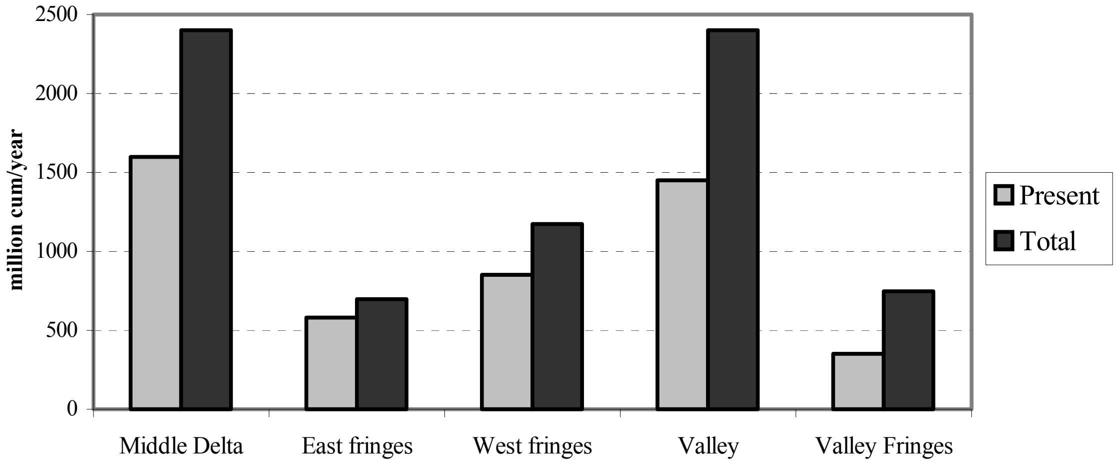

Figure 5. Groundwater in the Nile System

Water Demands

The other side of the coin, i.e. water demand, is increasing due to the increase in population and economic activities. At present all available fresh water is consumed, except groundwater in the deserts. This dictates quick responses from professionals to augment available fresh water and recycle used water, taking into consideration conservation of the environment.

National Water Policy

The objectives of Egypt's water policy are to:

1) Protect surface water and groundwater from pollution, and prevent deterioration of water quantity.

2) Control the demand for water.

3) Secure the future water supply from the Nile River by adopting a holistic approach to water management based on the river basin, integrating all water resources and use sectors.

4) Locate, identify, and develop new water resources (e.g. rainfall and flash floods).

5) Raise water use efficiency by: (i) promoting conjunctive use of surface water and groundwater; (ii) controlling use and depletion of groundwater; and (iii) promoting water use.

6) Increase water use effectiveness by: (i) establishing planning capacity, including appropriate planning approaches and tools; (ii) public and stakeholder participation in all steps of water management, including policy, planning, design, and implementation; (iii) establishing drought management plans, with implementation mechanisms; (iv) reviewing and adjusting water use legislation and regulations for proper implementation of water policy; and (v) engaging and mobilizing women and building public awareness about water management by better communications, in particular, in rural areas.

1.6 Main Issues

The main issues facing Egypt's full development can be categorized as follows:

1. Geography and climate.

2. Population distribution and density.

3. Availability of facilities related to water and sanitation.

4. Style of agricultural land ownership and food production.

5. Degradation of water resources.

Based on the characteristics of the country and analysis of major issues, Table 1 has been prepared to summarize the main constraints facing water resources management. Although the present situation is not yet critical, however, if no immediate actions for integrated water management of the resources are implemented, Egypt will soon face a critical situation. To meet this real challenge of the future, a policy accompanied with specific strategies should be formulated. The first step in this policy is to clearly define critical issues and problems.

Table 1. Summary of Issues Pertaining to Integrated Water Management

Issue	Causes
1. Partial utilization of Egypt's territories.	1.1 Nile valley morphology and type of boundaries. 1.2 Aridity and poor distribution of water resources over the country area.
2. Unbalanced population distribution and continuous immigration from rural to urban areas.	2.1 Lack of regional plans and facilities/services to the rural community. 2.2 Continuous decrease of job opportunities in the rural areas, especially in the farming sector.
3. Lack of suitable potable water and sanitation in some regions, especially the rural ones.	3.1 The economic conditions of the country. 3.2 Concentration of activities in the urban regions/governorates
4. Decrease of per capita agricultural land area and share in main food.	4.1 Heritage and distribution of land among the family. 4.2 Poor return from agriculture and transfer to cash crops. 4.3 encroachment of urban areas.
5. Biased distribution of opportunities among men and women.	5.1 Cultural, especially in the rural regions.
6. Continuous decrease of per capita water resources.	6.1 Deterioration of water quality. 6.2 Poor enforcement of water protection legislation. 6.3 Increase of water-intensive cropping. 6.4 Inefficient use of water on the farm level. 6.5 Inefficient water distribution. 6.6 Low efficiency of urban drinking water supply.

2. INSTITUTIONAL ASPECTS

Groundwater research in Egypt started in the traditionally cultivated areas in the Nile Valley and Delta in 1953, through the Bureau of Groundwater and Drainage. The groundwater activities were later on accommodated under a separate Groundwater Research inspectorate (GRI). One of the initial tasks was the establishment of a monitoring network of observation wells, aiming at a continuous (monthly) recording of the groundwater levels and (to a lesser extent) the groundwater quality. With the establishment of the Water Research Center in 1975 (Presidential Decree No. 83), the GRI became the Research Institute for Groundwater (RIGW) as one of the eleven Research Institutes under the WRC. In 1994 the WRC was promoted to University status and renamed the National Water Research Center (NWRC).

The mission of the RIGW is to carry out research to support groundwater development and management plans, in the framework of the overall integrated water resources development/management, aiming at increasing the contribution of groundwater in the water and food security programs for growing population of Egypt.

Due to the increasing importance of the groundwater resources in the national water policy, a new sector was established within the Ministry of the Water Resources named as "The Groundwater Sector". The groundwater sector is mainly responsible for policy development, regulations and enforcement of laws.

In addition to the above mentioed two main bodies responsible about groundwater in Egypt, some other institutions are envolved by a way or another in groundwater research. Table 2 presents the various activities related to groundwater management and involvement of main institutions.

Table 2. Institutions Involved in Groundwater Management Activities in Egypt

Activities	Institutions Involved	Responsibility
1. Research on National and Regional Levels	1.1 The Research Institute for Groundwater (MWRI) 1.2 The Water Resources Research Institute (MWRI) 1.3 The Desert Research Center (MOA)	
2. Local Studies and Investigations	2.1 The Research Institute for Groundwater 2.2 The Water Resources Research Institute 2.3 The Desert Research Center 2.4 Universities and individual consultants	To be finally approved by the GS and the MWRI
3. Assessment of Groundwater Potential	3.1 The Research Institute for Groundwater 3.2 The Water Resources Research Institute	To be finally approved by the GS
4. Policy development and Planning	4.1 The Groundwater Sector in cooperation with other sectors in the MWRI	To be finally approved by the Planning Sector of the MWRI
5. Licensing of wells	5.1 The Groundwater Sector	The GS
6. Design and implementation (or supervision)	[It depends on the ownership]	To be finally approved by the GS
7. Monitoring, including sampling and analysis	7.1 The Research Institute for Groundwater 7.2 Ministry of Health (adhoc) 7.3 Individuals (owners)	The research bodies and executive bodies of the MWRI
8. Operation and maintenance	[It depends on ownership]	[It depends on ownership]
9. Awareness	MWRI (GS)	MWRI (GS)
10. Regulation and enforcement of law	The Groundwater Sector	The GS

3. DEFINITION AND DELINEATION OF PROTECTION ZONES

One of the important protection requirements is the close or direct protection of groundwater in the proximity of important withdrawal sources, e.g. water wells used to supply drinking water to communities. Special restrictions are generally needed to be imposed upon polluting activities. Many approaches are used to delineate the proximity of water wells and determine the associated restrictions.

In recharge areas of well fields used for supplying potable water, groundwater pumpage for other purposes should be controlled. Control can be planned according to the recharge area (catchment) and the type of development activities. Prevention or limitation of activities around the well is made according to the expected risk from pollutants. Generally, zones of protected areas are delineated according to attenuation. Figures 6 and 7 illustrate the principle of travel time.

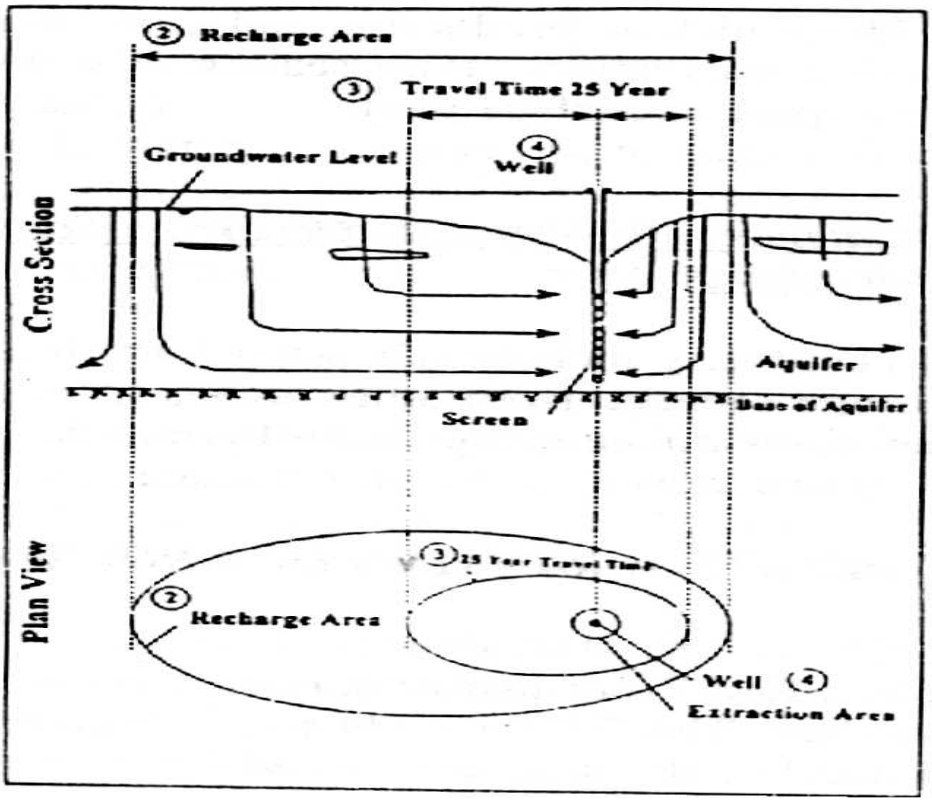

Figure 6. Illustration of Well Protection Area

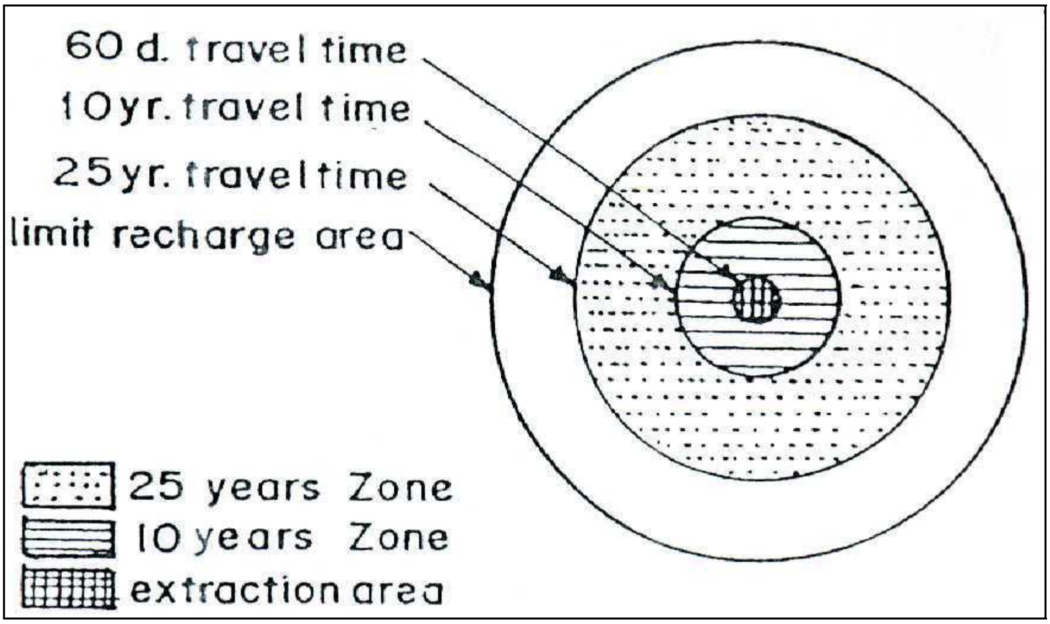

Figure 7. Zonation of Protection Areas

3.1 Current Status

Due to its existence beneath the groundwater surface, groundwater is, to some extent naturally protected from pollution. However, due to human activities in many situations this resource has been contaminated. Unfortunately, and due to the misconception of complete natural protection of groundwater efforts for its protection have long been neglected.

In Egypt, due to the historic dependence on Nile water and also due to misconception mentioned above, major actions regarding regulation and protection were restricted to surface water. When compared to surface water, it takes a long time and a big effort, to clean groundwater resources. This justifies that more attention is being paid to the protection of Egypt's groundwater resources.

The development of groundwater protection policy is a complex process. Policies need to be based on a number of information sources such as groundwater quality data, vulnerability of the aquifer, groundwater use, groundwater potential, etc.

Throughout the past decade, more attention was given to the groundwater protection aspects in Egypt. The RIGW plays an essential and important role for developing the groundwater protection criteria that are suitable to apply within Egypt. The implementation of the National Groundwater Quality Monitoring Network as well as several local networks help a lot in detecting the main sources of groundwater pollution within these areas and in preparing groundwater vulnerability, pollution load and pollution risk maps. Based on the assessment of these maps the necessary protection actions (preventive, limiting or remedial) are proposed.

In addition to that, several studies have been carried out to delineate the groundwater protection zones around drinking water supply wells. These studies were carried out on the local scale in the new communities (Tenth of Ramadan and Sadat Cities), Cairo and Sharqia governorate (East Nile Delta Region).

Unfortunately, till now no groundwater protection zones have been implemented in Egypt. In the near future, it is expected to implement these protection zones in several locations, starting with the Sadat City area.

3.2 Practice of Delineating Protection Zones

Delineation of groundwater protection zones in El Sharqia Governorate and El Sadat City will be presented in the following, two case studies.

3.2.1 Delineation of well protection zones in El Sharqia Governorate

This study carried out by the Research Institute for Groundwater (RIGW) in the framework of the activities of the "IHP-Network on Groundwater Protection in the Arab Region". For the purpose of this study, two approaches were proposed. The first is to consider the recharge area of the well, as an area with special protection needs. The second is to delineate the proximity of the well based on travel time, i.e. from the surface to the well screen, which allows the decay of pollutants before reaching the screen. In order to test the applicability of these approaches, a numerical model covering the pilot area is used.

Hydrogeological Setting of the Pilot Area

The study area is shown in Figure 8. Two types of hydrogeological units are distinguished, the Nile flood plain and the fringes. Within the Nile flood plain, the aquifer is made up of graded sand and gravel with minor clay lenses, underlain by a virtually impervious material consisting of fine-grained Pliocene sediments. A semi-confining layer consisting of silt and clay tops the aquifer. On the fringes, is aquifer is unconfined and consists of graded sand and gravel. Towards the edges, the aquifer thickness decreases considerably and consists of gravel or may be bounded by faults.

The geometry of the aquifer system is determined from geophysical surveys and data from boreholes. The maximum thickness of the aquifer is about 800 m in the north; while the minimum thickness is about 250 m on the fringes. The average hydraulic conductivity of the aquifer material is about 100 m/day.

The main direction of groundwater flow is south north. The pattern is slightly influenced by groundwater flow from the reclaimed areas becoming, locally, east west. Another component of flow takes place vertically due to the head difference between the water table and the piezometric head.

The main sources of recharge to the aquifer are seepage from the irrigation distribution system and subsurface drainage in irrigated areas. The recharge rate varies from about 1.5 to 2 mm/day in areas having no drainage networks, and from 0.5 to 1 mm/day in areas with drainage systems. Discharge from the aquifer generally takes place as a result of pumping for various purposes. The total withdrawal amounts to about 185 million m^3/year, of which about 21 million m^3/year are withdrawn for domestic uses.

Numerical Simulation

The used package (TRIWACO) is a numerical simulation model for quasi three-dimensional saturated and unsaturated groundwater flow based on the finite element technique. The package can handle a variety of steady state and transient groundwater flow problems. The program also allows for the interaction of top and bottom systems (i.e. surface water and groundwater).

A triangular element grid is generated for the area. The grid consists of 1,475 nodes and 2,844 elements, covering an area of about 2,636 km^2. Fine elements are used in the area surrounding open channels and wells to ensure accurate representation of path lines at the convergence zones. Figures 9 shows the finite element grid covering the study area.

The input data to the model are derived from the hydrogeological map (Zagazig) scale 1:100,000 and the database of the RIGW. Data include topography, aquifer thickness, clay thickness, water table levels, groundwater piezometric heads and withdrawals. Seepage from canals and drains is calculated using wetted perimeter, water table and the hydraulic resistance of the semi-pervious layer. The subsurface drainage rates and hydraulic conductivity of drains are obtained from available reports, including tests carried out by municipalities.

Delineation of the Protection Areas

Two approaches for the delineation of protection areas are examined. Both approaches are based on delineating a capture zone of the well. In the first approach, the capture zone is corresponding to a specific time length, i.e. between 40 and 100 days. In the second, the capture zone is made to correspond to the time needed to achieve steady-state conditions (recharge area). Both approaches are tested on the calibrated model.

The results obtained from the model when applying the first approach indicate the need for a protection zone of a diameter ranging between 70 and 120 m corresponding to a travel time of 100 days. This area is easy to maintain as it may correspond to the area occupied by the pumping station.

According to the second approach, the results indicate that about 65% of the study area is within the capture zone of one well or another. Results of such approach area not easy to apply as it implies the prohibition of all activities in 65% of the area.

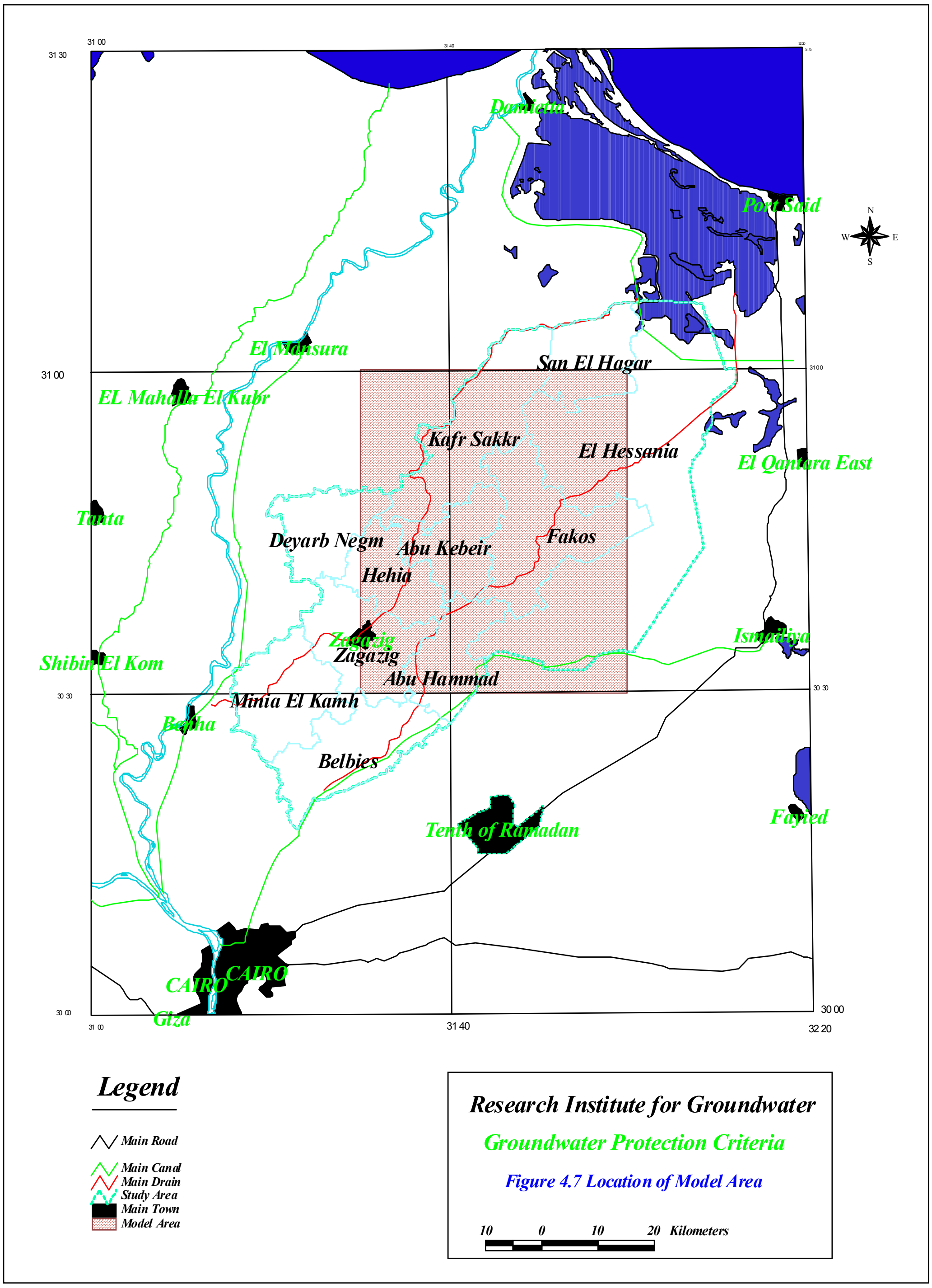

Figure 8. Location of the Study Area

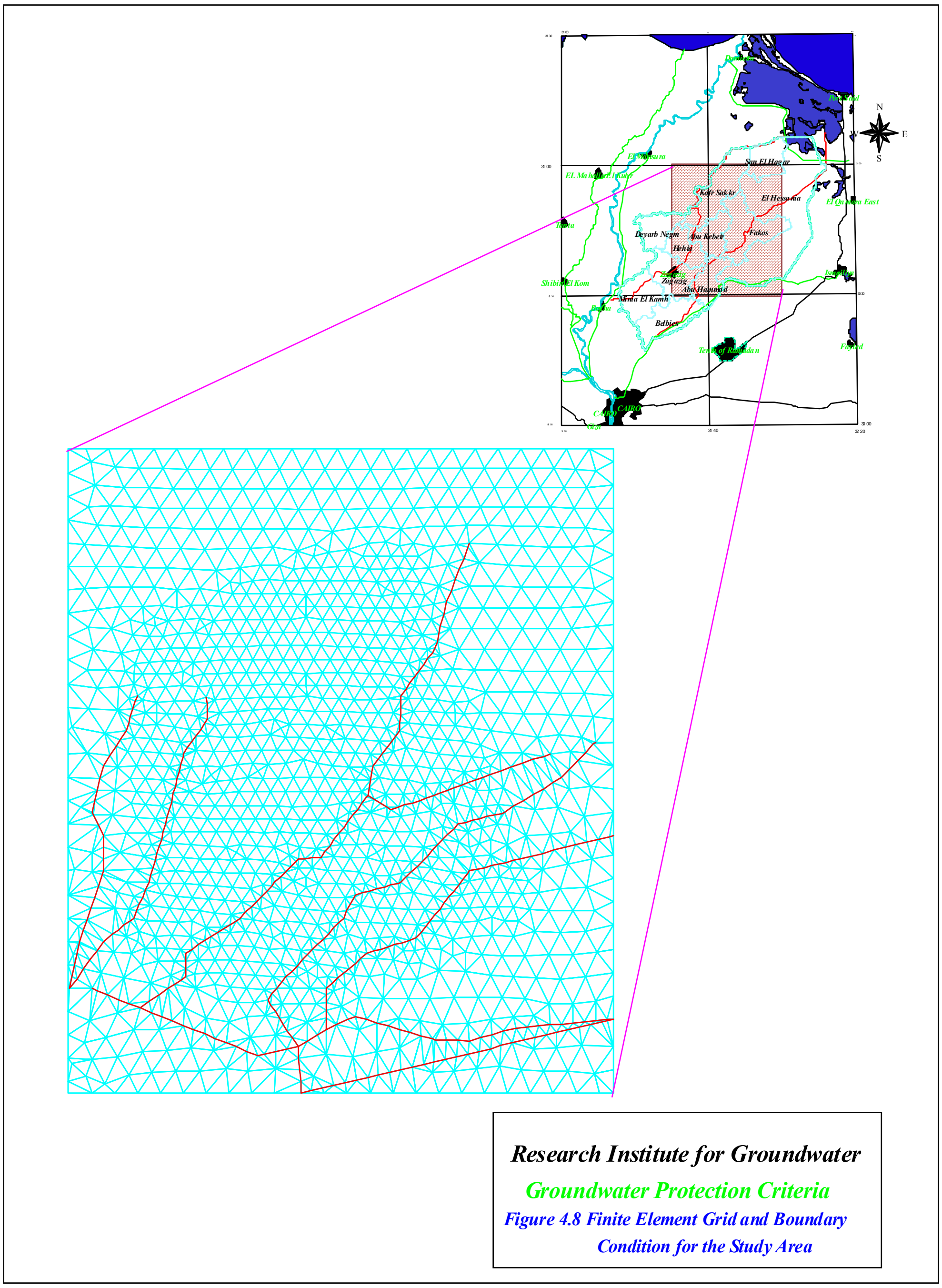

Figure 9. Finite Element Grid and Boundary Conditions for the Study Area

3.2.2 Groundwater protection zones around the drinking well field in Sadat City:

El Sadat city is located to the north of Cairo in the fringes of the western Nile Delta. The main source for water supply is groundwater. The main sources of groundwater pollution in Sadat city are: (i) landfill sites and oxidation ponds; (ii) the migration of pesticides and fertilizers from agricultural areas; and (iii) leakage of sewers from residential disposal.

Priority areas for groundwater protection were selected based on a pollution risk map (Figure 10). From the map, the high priority area is located at the downstream side of the oxidation pond and at the industrial zone. The medium priority area is located nearby the gas filling stations, while the low priority area is located upstream of the oxidation ponds, and upstream of the industrial zone and irrigation zone. For the purpose of calculation of the travel time around the two drinking well fields, a numerical model was applied. The model calculations indicate that the major part of the well fields abstractions are recharged from the eastern side (River Nile) of the area. Zones of equal travel time to the well fields are illustrated in figure 11, where each perpendicular line on each flow line represents a time step of 25 years.

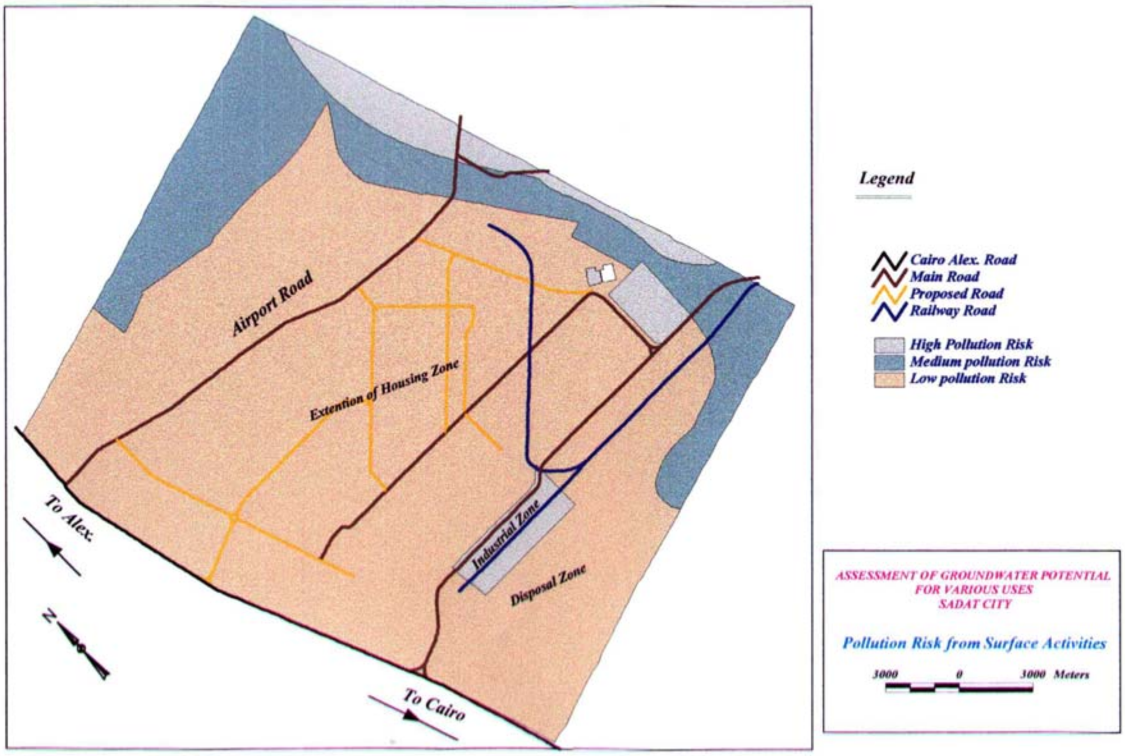

Figure 10. Pollution Risk Map of Sadat City

By comparing this zonation map with the groundwater pollution risk map, the priority areas for groundwater protection within this zonation can be identified. Subsequently, rules for land use restriction and drilling free zones must be implemented within each zone (limits of the recharge area, which equal 100 years), depending on the travel time and the pollution risk. For example, the most restrictive rules will be applied to the shortest travel time and highest pollution risk.

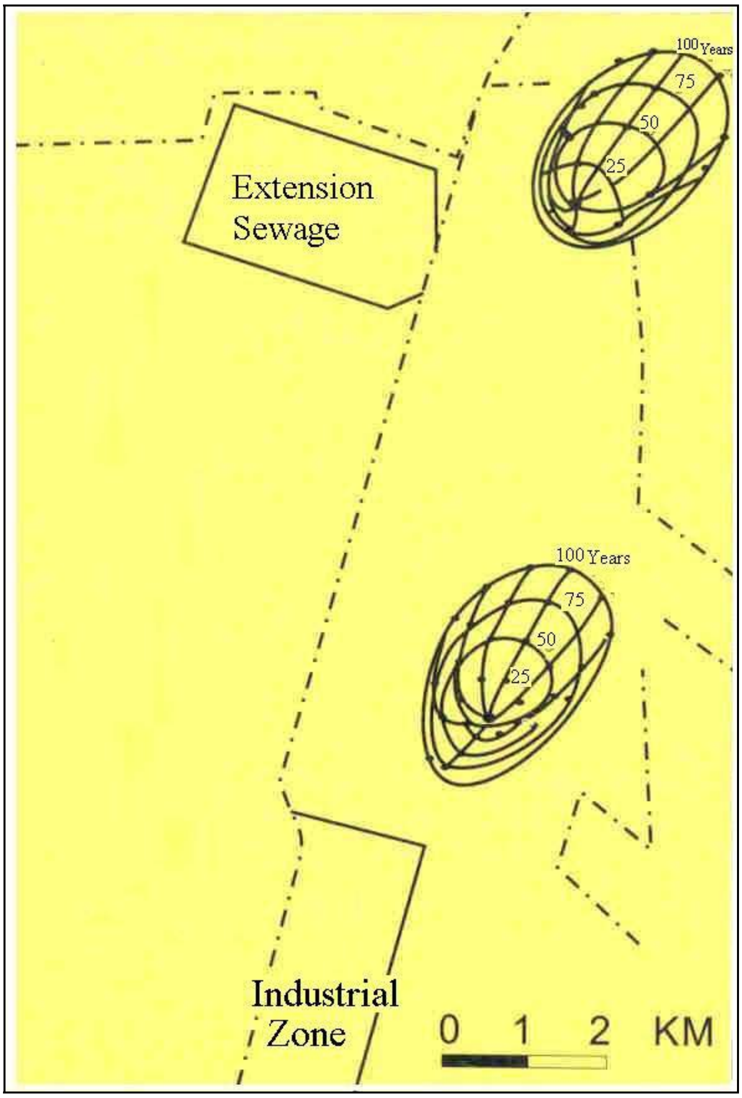

Figure 11. Design of groundwater protection zones in Sadat City

4. MONITORING OF GROUNDWATER LEVELS AND QUALITY

The groundwater monitoring system in Egypt consists of the following components:

- The National Groundwater Level Network; and
- The National Groundwater Quality Monitoring Network

4.1 The National Groundwater Level Network

An important tool for groundwater management is the network of observation wells monitoring groundwater levels. The monitoring network in the Nile Valley and Delta was established in 1953. The main objective of this network was to provide periodical monitoring of groundwater levels and groundwater quality. The acquired data are used to plan groundwater development and to predict the impact of natural and artificial processes on groundwater.

The groundwater in the Quaternary aquifer exists under unconfined as well as semi-confined conditions. In the latter case, the piezometric head of the aquifer differs from the shallow groundwater tables in the superficial semi-pervious layer. For monitoring the piezometric heads and the groundwater table till 1987 the RIGW constructed more than 1200 deep and shallow observation wells (Figure 12).

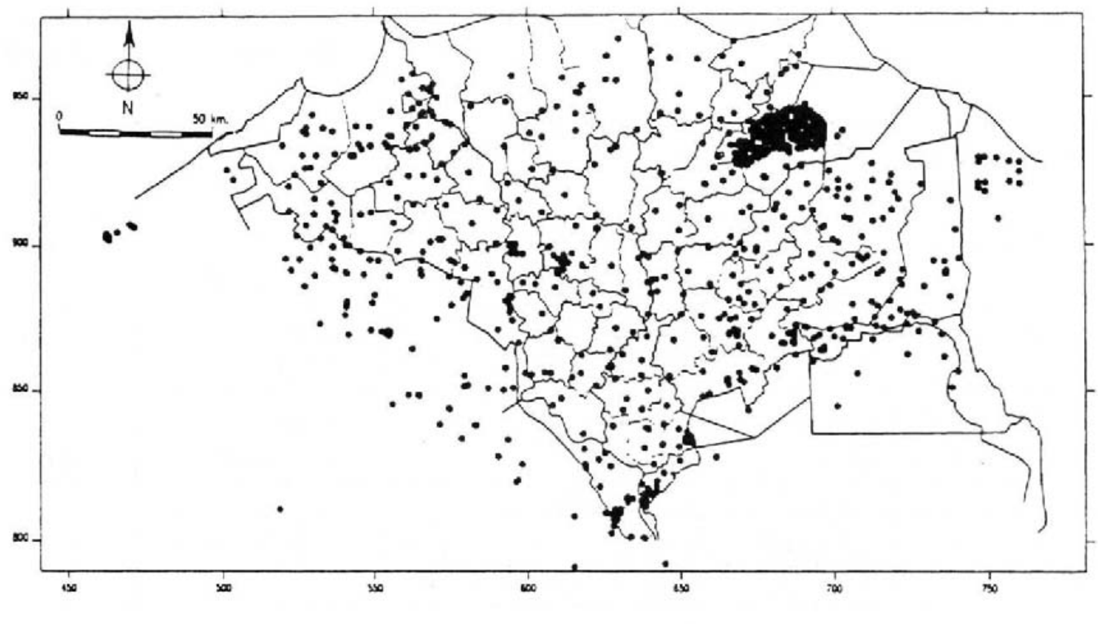

Figure 12. National groundwater level monitoring network (Nile Delta Region)

These wells are distributed throughout the Nile Valley and Delta including their fringes. The deep observation wells are generally installed in the upper part of the Quaternary aquifer which is the major groundwater bearing formation in the Nile Valley and Delta. The screens of these wells are usually placed at a depth of 20-50m below the ground surface. The shallow observation wells are installed in the semi-pervious layer overlying the Quaternary aquifer. Their screens are placed at depth ranging from about 3 to 6 m below ground level. The peizometric head in the deep and the shallow observation wells are measured at least once per month. Water samples are collected once every two years for chemical analysis (mainly major cations and anions).

By the year 1983, more than 1.5 million water level measurements and more than 2000 chemical analysis records were kept in the archives of RIGW. However these data were not easily accessible for planners and researchers. Therefore, a computerized water resources database was established in 1984 (Figures 13 and 14). At present the database is populated with the data from more than 2000 wells.

4.2 The National Groundwater Quality Monitoring Network

The national groundwater quality-monitoring network in Egypt was established in 1998. The objective of the network is to quantify the long-term quality changes, either caused by polluting activities or by salt-water intrusion. A second purpose was to describe the overall current groundwater quality status on a national scale. It is the aim of the monitoring system to provide decision -makers with information about the present and future status of groundwater quality.

At present the national groundwater quality-monitoring network comprises 200 monitoring points (Figure 15). About 60% of the monitoring wells are located in the Nile Basin, the large number of wells in the Nile Basin is due to the fact that the aquifer in the Nile Basin is extensively used and that the priority areas in this region face a potential pollution risk.

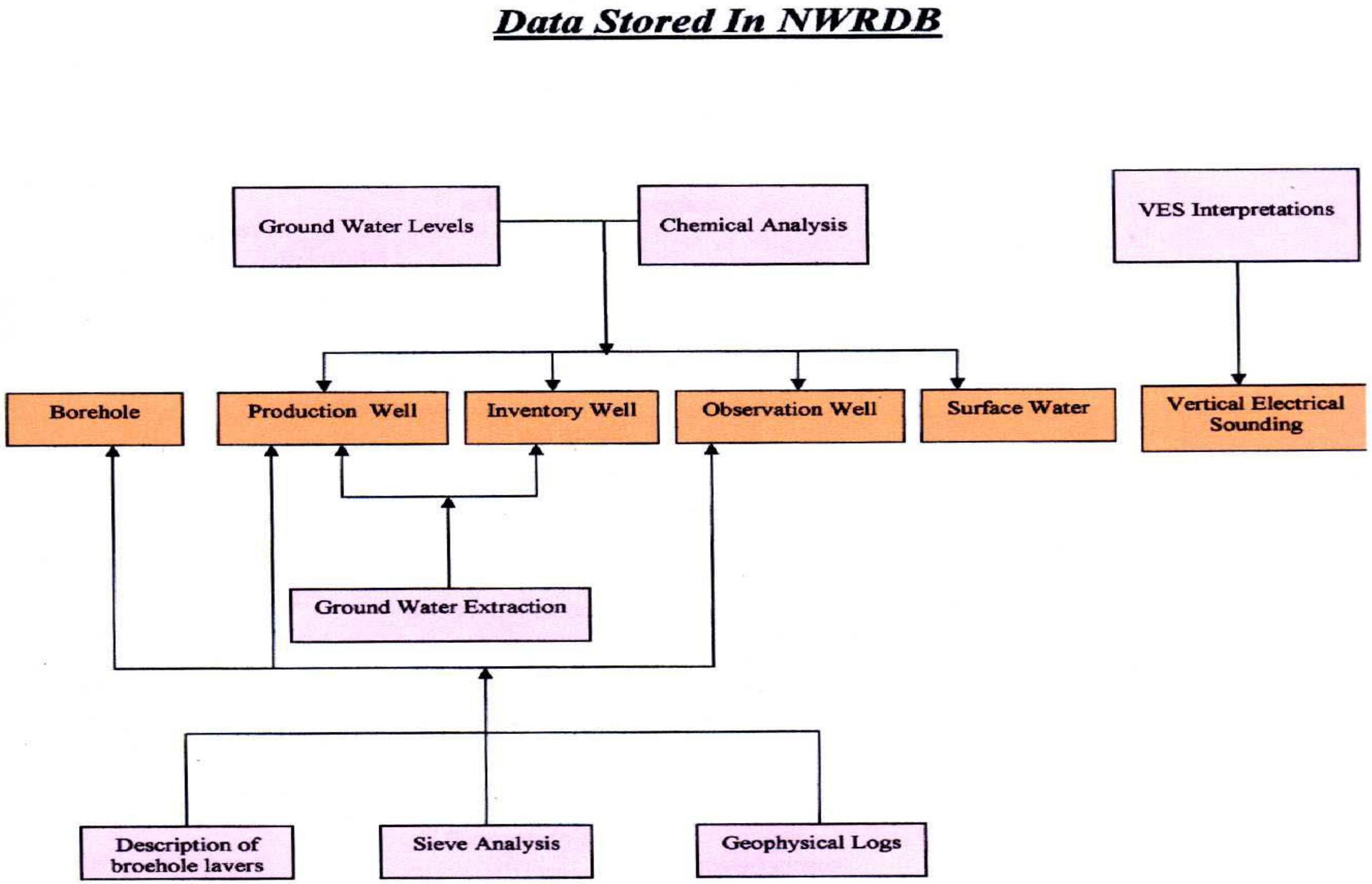

Figure 13. The Types of Data Stored in the National Water Resources Data Base

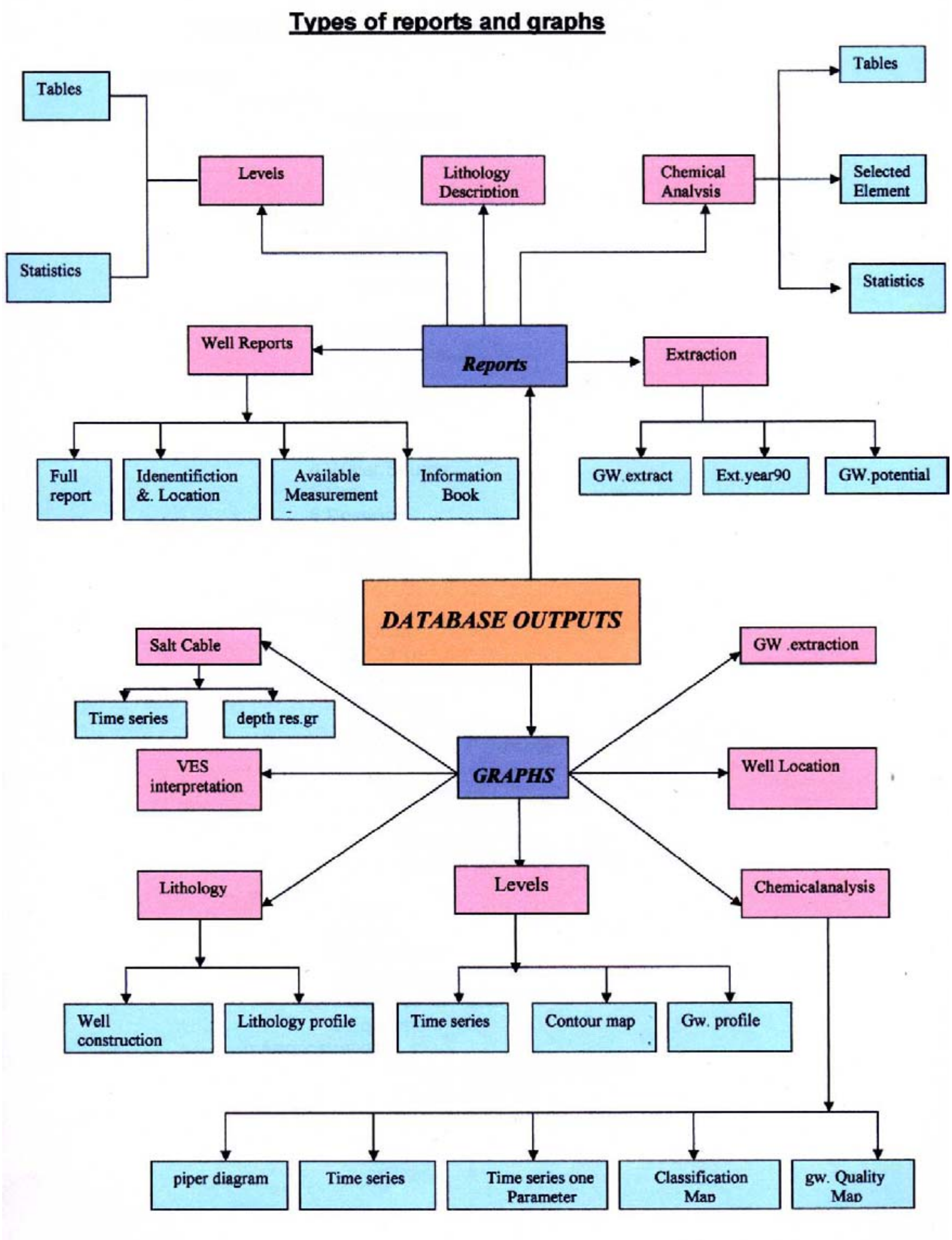

Figure 14. Types of the Outputs of the National Water Resources Data Base (Graphs and Reports)

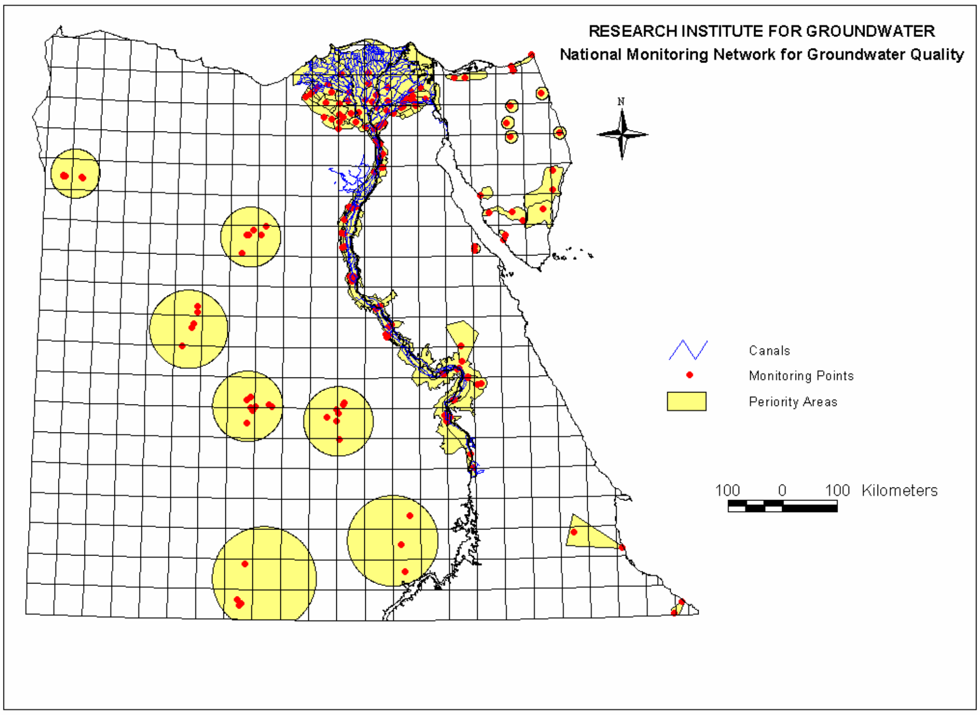

Figure 15. National monitoring network for groundwater quality

Evaluation of the Executed Sampling Rounds

Four sampling rounds have been executed (1998, 1999, 2000 and 2001). In these sampling rounds all the monitoring points were sampled and analyzed for up to 50 parameters. More than 77% of the samples taken outside reclamation areas showed good quality that could be used for drinking purposes with minimum treatment. Only 33% of the samples from the desert exceeded one or more critical limits of drinking water.

High concentrations of sulphate and nitrate have been observed in monitoring points that were located in the reclaimed area in the fringes of the Nile basin. Salinity levels of the groundwater have increased under these areas. The salinity is partly caused by leaching of natural salts and partly by application of gypsum to the soil. This salinity front is moving towards the central parts of the Nile valley and Delta. Figure 16 is a schematic representation of the main hydrochemical process in the reclamation areas on the fringes of the Nile Valley.

In the central parts of the Nile Delta and Valley the concentrations of nitrate are much lower than the fringes (Figure 17). The results of the sampling rounds detected high concentrations of manganese, iron and sulphate due to reduction and dissolution processes in the central part of the Nile Delta and Valley, Figures (18 and 19). In the western Desert the quality standards are least exceeded and only iron shows high levels. In the eastern desert and Sinai high salinity have been observed. The majority of the wells has been sampled and analyzed for pesticides. No pesticides have been detected in these samples.

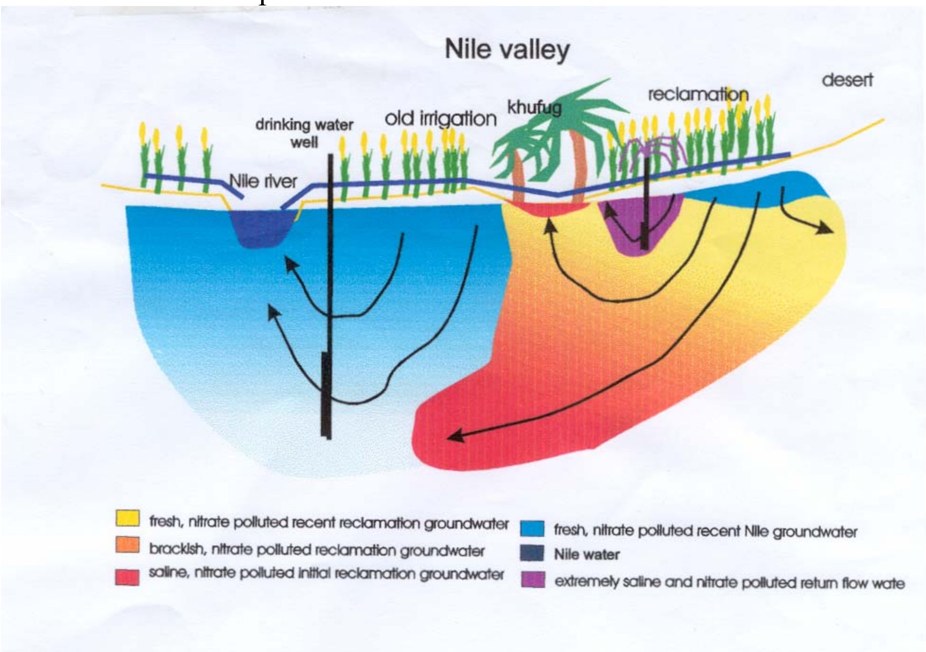

Figure 16. The main hydrochemical process in the reclamation areas

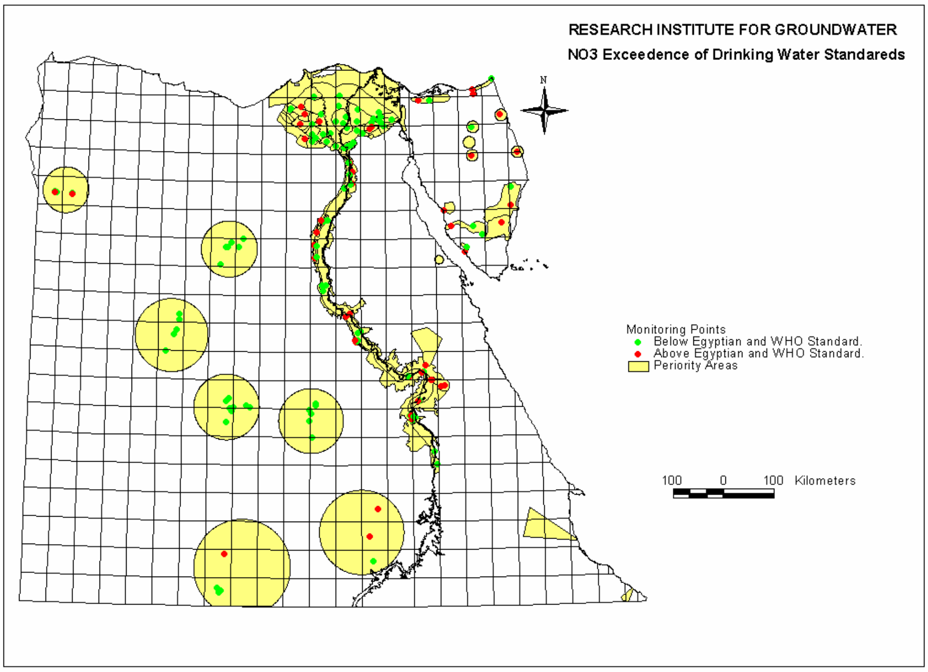

Figure 17. Nitrate concentration in the monitoring wells.

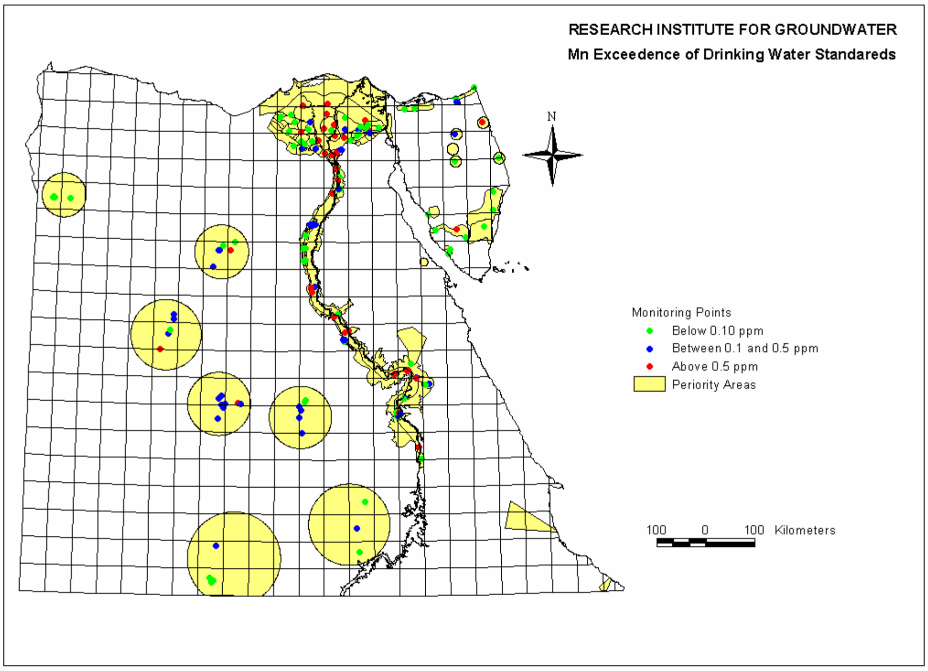

Figure 18. Manganese concentration in the monitoring wells.

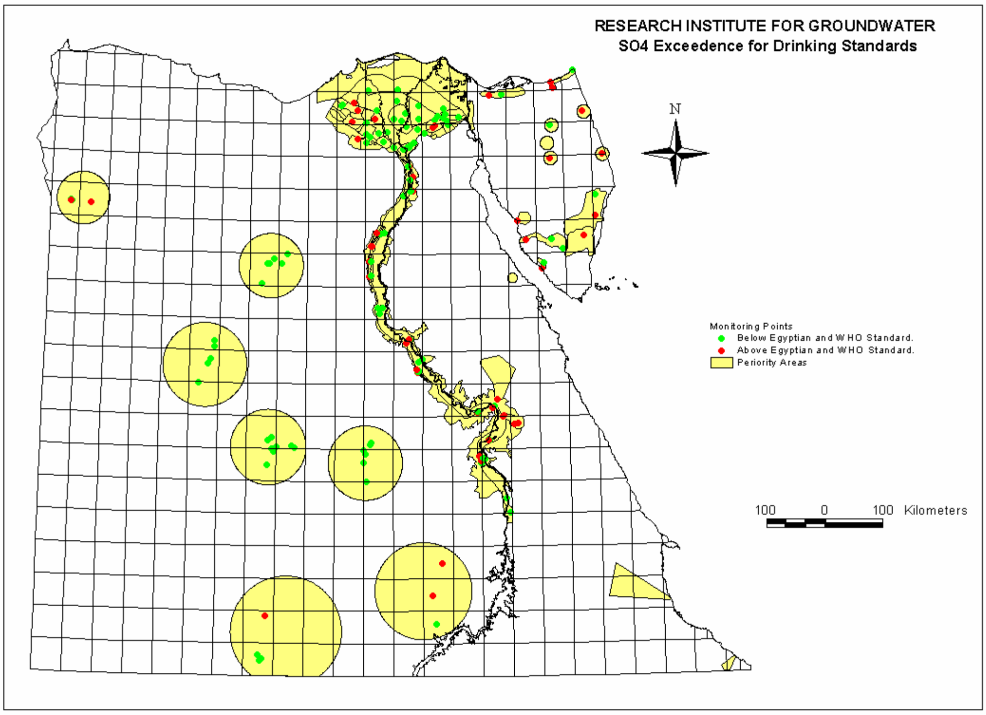

Figure 19. Sulphate concentration in the monitoring wells.

5. ASSESSMENT OF GROUNDWATER VULNERABILITY AND HAZARD TO GROUNDWATER

Groundwater vulnerability to surface originating pollution is evident. As the aquifer's vulnerability to surface originating pollution is dependent upon the intrinsic properties of the aquifer, high levels of spatial variability in the vulnerability of the aquifer is expected. In practicing groundwater quality management, mapping the vulnerability is an essential tool as many of the decisions are dependent on the spatial variability of the aquifer's vulnerability. Methods being used for vulnerability mapping are numerous. The most common is the hydrologic setting, the parametric method and the analogical relations and numerical models methods. These methods have a very little range of complexity. The best method would depend on data availability, objectives and scale.

The DRASTIC (Depth, Recharge, Aquifer media, Soil, Topography, Impact of vadous zone, hydraulic Conductivity) method for mapping the groundwater vulnerability is an internationally well-recognized approach. However, it is developed as a global method that can envelope a wide range of variability in the hydrogeological conditions. This globalization can lead to unavoidable generalization in the parameters selection as well as their ratings and weights. Accordingly, applying the DRASTIC method should involve careful consideration of the local hydrogeological conditions.

Current Status

In the last ten years, Several internsic groundwater vulnerability maps were prepared by the RIGW for the Nile Valley and Nile Delta reion on semi regional (1:500,000) and detailed (1:100,000) scales.

In the following, Two examples will be presented:

The first, will be the groundwater regional vulnerability map of the Nile Delta which has been based on the hydrologic setting taking into cosideration some other important factors.

The second, will be the development of detailed vulnerability maps for the middle, east and west Nile Delta regions by conceptually modifying the DRASTIC method according to the local hydrogeological conditions.

5.1 Regional Vulnerability of Groundwater to Pollution in the Nile Delta

Within the nile Delta Region, the groundwater vulnerability to pollution is largely determined by the thickness of the clay layer, depth to groundwater, rate of recharge and direction of natural vertical groundwater flow (see table 3).

According to these pararmeters, the Nile Delta region can be distinguished into four categories (Figure 20):

i. The reclaimed desert areas with moderate to high vulnerable groundwater, due to the presence of sandy formations with high infiltration and low adsorption capacities, although groundwater is relatively deep;
ii. The traditionally cultivated area with moderate to low or low vulnerable groundwater due to the presence of a clay cap;
iii. The transition zone between the old land and the reclaimed areas with highly vulnerable groundwater due to the presence of sandy soil and shallow groundwater table; and
iv. The northern part with very low vulnerable groundwater due to the presence of a top clay cap and upward groundwater flow.

Table 3. Factors Affecting the Groundwater Vulnerability in the Nile Delta

Thickness of clay cap (m)	Vertical groundwater flow	Rate of recharge mm/day	Depth to groundwater from surface (m)	Groundwater vulnerability	Location
0	Downward	-	<5	High	Transition zone between old and reclaimed land
0-2	Downward	>1	5-15	High	Transition zone
0	Downward	<1	>15	Moderate- High	Desert fringes
0-10	Downward	<1	<5	Moderate- Low	Floodplain and partially transition zone
>10	Downward	0.25-1	<5	Low	Floodplain
0->10	Upward	<25	<5	Low	North Delta (Floodplain)

5.2 Vulnerability of Groundwater to Pollution in the Middle, East and West Nile Delta Regions

In this study, the DRASTIC method was conceptually modified according to the hydrogeological conditions of the Nile Delta aquifer, and then its ratings and weights of the vulnerability controlling parameters were calibrated according to statistical correlation with real-time pollution events. Thus, providing an adjusted tool to map the vulnerability of the Nile Delta aquifer.

The modified vulnerability approach was developed on pilot scale basis. Therefore, it was crucial to carefully select the study areas. The basic criterion that had to be fulfilled by the selected area are representing, as close as possible, the regional situation in the three regions of the Delta (i.e. Eastern, Middle and Western regions), in terms of physical conditions (i.e. aquifer type, overburden material, thickness, conductivity, etc.), and pollution threats. Other factors that were also found of importance include dependence on groundwater as a source of fresh water, groundwater quality and pollution threats. areas using the secondary criterion. Accordingly, the final selection was; Sharqia Governorate representing the Eastern Delta region, Menofia Governorate representing the Middle Delta region, and Behira Governorate representing the Western Delta region.

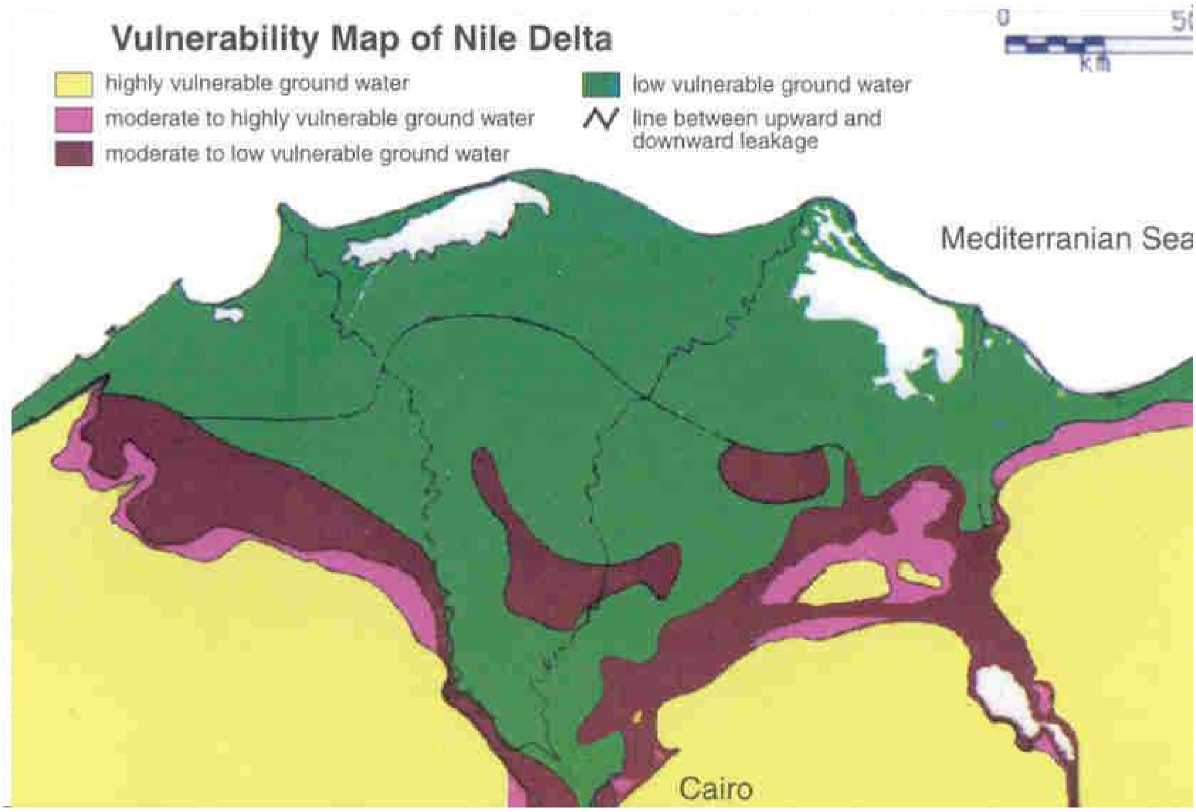

Figure 20. Groundwater Vulnerability Map for the Nile Delta

To provide the necessary information on the vulnerability parameters, a total of 116 well logs over the study areas were collected from the Data Base of the institute. These logs provided point information on the vulnerability parameters namely, depth to groundwater, aquifer media, the unsaturated zone material, type of soil layers, etc. On the other hand, and to minimize the extrapolation of the available point information, a total of 130 Vertical Electrical Sounding (VES) aggregated in 30 cross sections were implemented.

Development Of Vulnerability Mapping Approach

Conceptual analysis: The "DRASTIC" vulnerability controlling parameters were conceptually analyzed considering the local hydrogeological conditions of the Nile Delta aquifer. The following are the fundamental issues highlighted by the analysis:

- The prevailing conditions at the Middle Delta region and at the old lands of the Eastern and Western regions of the Nile Delta suggest overwhelming importance for the presence of a clay cap in judging the aquifer accessibility, i.e. relatively high water table with minimum spatial variability and significant clay cap thickness. Nevertheless, the conditions at the desert fringes and the reclaimed lands indicate that depth to groundwater plays an important role, if not the only role, in the aquifer accessibility as clay thins away while depth increases considerably. In conclusion, the inclusion of this parameter is crucial for vulnerability evaluation at the Nile Delta.

- The recharge parameter considered by "DRASTIC" is the natural recharge. Natural recharge within the study areas applies only to rainwater. This type of recharge is insignificant compared to the main recharge mechanism of excess irrigation water in the Nile Delta aquifer. As the objective is to assess the intrinsic vulnerability of the aquifer, recharge from irrigation should not be considered, being a man-made attribute. Additionally, for this parameter to considered it should have significant spatial variability, and must be dealt with at a micro level. Such level of details is practically impossible to obtain. Moreover, and assuming this effort could be achieved, it must be updated, along with the whole map, each and every season as farmers change their crops seasonally and according to the economics of the market. Accordingly, the recharge of the aquifer is considered of no significant spatial variation and is discarded in the vulnerability analysis for its relative neutral effect.

- The aquifer material, hydraulic conductivity as well as the soil material of the Nile Delta did not reflect any special conditions that require special treatment in applying the DRASTIC method, leading to including them in the vulnerability evaluation.

- The topography is included in DRASTIC to involve the division of the rechargeable surface water into runoff and percolation waters. This division is particularly important in mountainous and steep landscapes. The Nile Delta is generally flat, which raised doubts about the importance of this parameter in this particular case. Additionally, and due to the very narrow rang of slopes within the delta, no spatial variability, in the vulnerability index, will be generated from this parameter.

- The impact of the vadose zone is based on the type of material of the vadose zone, rather than its thickness. This parameter is of prime importance for evaluating the vulnerability of the aquifer. However, when applying the DRASTIC, limitations related to this parameter, are typically encountered when dealing with multi-layered vadose zone resulting in misleading results. On the other hand, careful examination of the well logs obtained from the study areas showed the dominance of the clay and sand as the practically only materials forming the vadose zone. This gave rise to the idea of representing the impact of the vadose zone as the clay thickness solely. This approach implies that any attenuation capacity provided by the sand is negligible compared to that given by the clay regardless of its thickness (very close to reality). It also allow for a fixed limited attenuation value for the case of sand only vadose zone, i.e. the value given to clay thickness equal to zero. This way, the above limitation is avoided, by considering the dominance of the attenuation capacity of the clay representing the vadose zone.

Based on the above discussions, the parameters representing the vulnerability within the Nile Delta aquifer were narrowed down to; depth to groundwater, aquifer media, soil type, clay thickness, and hydraulic conductivity.

Statistical analysis: Following the identification of the set of effective parameters controlling the vulnerability of the Nile Delta aquifer, it was necessary to calibrate their importance weights in accordance with the local conditions. The basic idea/logic behind this calibration process is to consider field-detected pollution events as the ultimate evaluator of the vulnerability of the aquifer. Hence, statistical correlations among the groundwater quality status and the different vulnerability parameters were applied to adjust the weights of vulnerability parameters to the actual field conditions.

The effect of the different pollution-generating activities was taken into consideration in a number of ways. From the spatial point of view, the most dominant source of pollution in the entire Nile Delta, by overwhelming difference, is the agricultural activities. As the selection of the sampling points was based on spatial coverage solely without any consideration of the land use, statistically, the overwhelming majority of the samples should represent similar land use activity; that is, agriculture. Additionally, the careful selection of the pilot areas considered the presence of diverse pollution sources within each area. And finally, for the Sharqia Governorate, the biasness was expected due to the presence of two extreme pollution sources namely, the intensive reuse of significantly polluted drainage water and the industrial city of 10^{th} of Ramadan. This biasness was filtered out through the presence of a wide range of vulnerability parameters under the influence of the first source and by discarding the samples from the 10^{th} of Ramadan for the second source.

The approach that was followed is to correlate among the vulnerability parameters and the groundwater pollution events rather than groundwater quality. Accordingly, samples were divided as either polluted or non polluted. Samples were considered polluted if one or more chemical constituents exceeded the drinking water standards, leading to non-specific vulnerability evaluation. The correlation coefficients were calculated through regression analysis among the accumulative percentages of polluted samples and ranges of the different vulnerability parameters. The accumulative percentages were used instead of the actual percentages for each range due to the unequal distribution of the sampling points over the different ranges of the vulnerability parameters.

Application and comparisons: The overall comparison among the results of the two approaches indicates a significant change in the spatial distribution of vulnerability categories. The modified approach has resulted in a generally less vulnerability compared to the classical approach. The distribution of polluted samples among the different categories of vulnerability as defined by the classical and modified approaches was compared. The modified approach, for the three governorates, shows significantly better distribution of pollution events among the different vulnerability categories. Figures 21 and 22 illustrate the vulnerability maps for the Behira Governorate, representing the West Delta region, as per the classical and modified approaches, respectively.

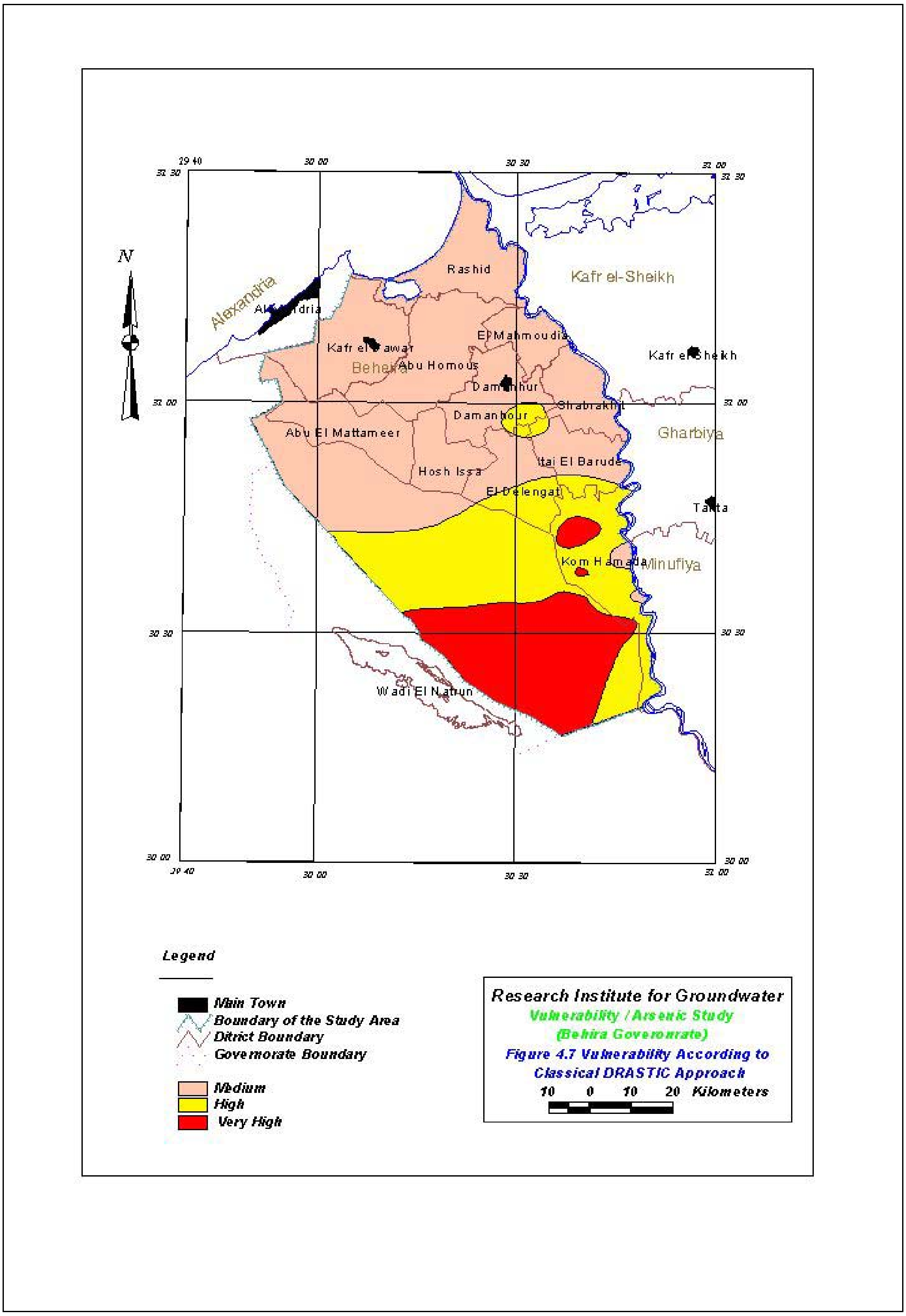

Figure 21. Vulnerability according to the classical approach.

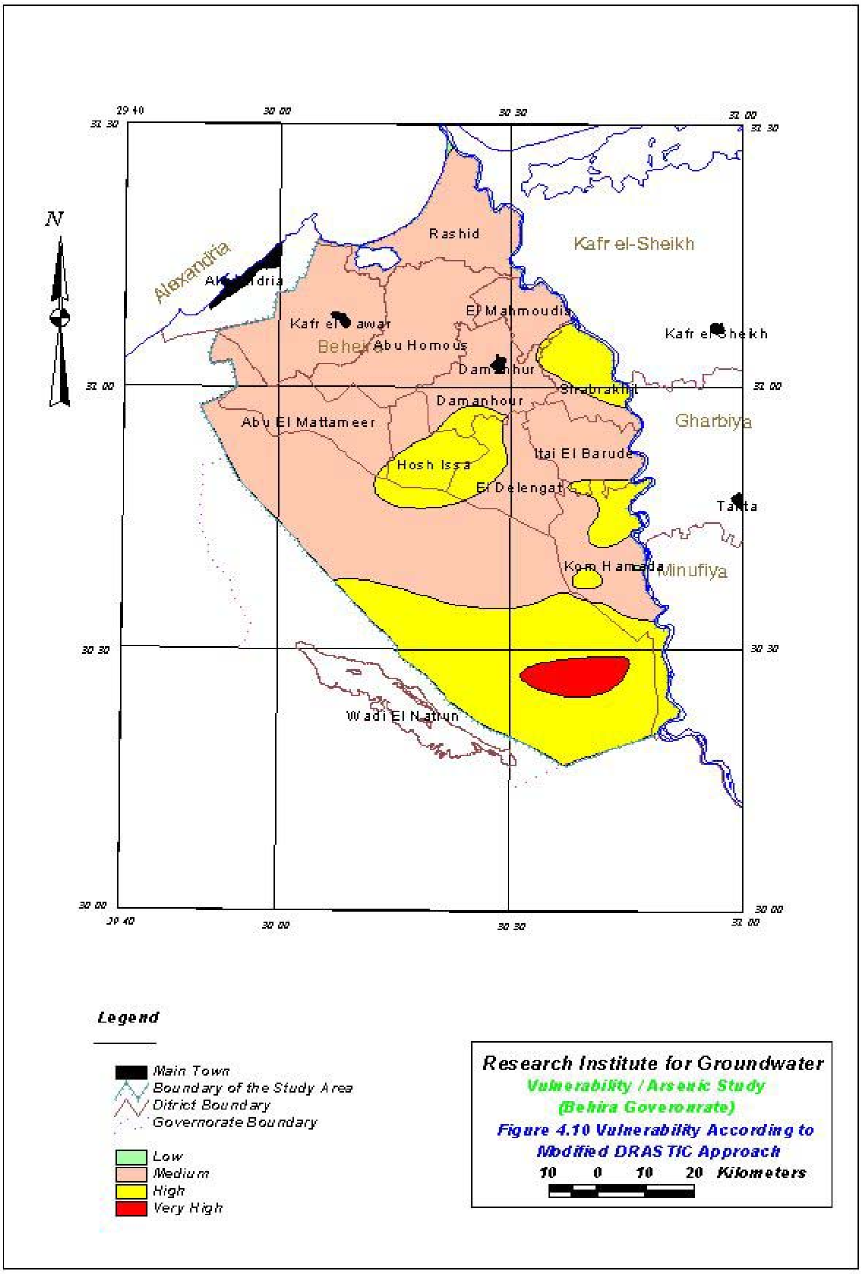

Figure 22. Vulnerability according to the modified approach.

6 LEGAL ASPECTS

Groundwater protection measures have been initialized by the introduction of a well licensing system. Groundwater extractions need to be authorized by a High Committee formed from high-ranking officials from the Ministry of Water Resources and Irrigation, and Ministry of Agriculture and Land Reclamation. The potentiality maps and the regular well inventories of the RIGW are crucial for the well-functioning of the licensing system, in addition to means for enforcement, which can still be improved.

Law 48-1982, regarding to the protection of the River Nile and Waterways from pollution, has been integrated in the Law for the Environment 4-1994. Groundwater is specifically mentioned as " waterway", also in the implementation regulations of Law 48-1982 (Decree no. 8-1983), where limits are given for different effluent being discharged in either surface water or groundwater. Compliance with law 48 has generally been weak, partly because of the imposed high standards. Nevertheless the law forms a firm base for the protection of the Egyptian groundwater resources with respect to direct discharge (e.g. by injection through wells). To combat pollution of groundwater resources from diffuse sources (fertilizers, pesticides etc.) the legal framework of the two cited laws seems to be insufficient.

Nowadays, an internal committee from the professionals within the Ministry of Water Resources and Irrigation has been formulated to revise and update Law 48, and including some items related to groundwater protection.

On the other hand, the existence of the RIGW, as a research agency and the establishment of the Groundwater Sector, as an implementing agency under the Ministry of Water Resources and Irrigation are an important step in the direction of establishing the institutional support needed for protecting the groundwater. The challenge that is being faced by both agencies is to implement groundwater protection in the Egyptian institutional setting.

Groundwater protection implies the coordination of water resources, land and water use and the environment. This dictates cooperation and coordination between the different involved agencies that are responsible for these aspects at different levels

7 RECOMMENDATIONS

Groundwater protection means preventing or limiting deterioration of groundwater quality. Such process involves a series of actions, some being preventive while others more of a corrective nature. A unique framework for groundwater protection is generally not possible as the forms of deterioration are diversified. However, considerable protection could be achieved based on the fact that prevention is always simpler and less expensive than rehabilitation. The development of a groundwater protection policy is a complex process. Policies need to be based on number of information sources including groundwater quality data, groundwater potential and use, aquifers vulnerability to pollution and sources of pollution.

In Egypt most of elements for general groundwater protection are available or under development. Integration of the various components into a national groundwater protection plan, preferably as part of a wider national water resources management plan, is a component that needs urgent action. Based on the available studies and knowledge about protection zones around the drinking water wells, it important to implement these zones especially within the high pollution risk areas. The involvement of the public, local authorities and other concerned ministries is essential.

It is recommended to encourage and support the role of the "IHP-Network on Groundwater Protection in the Arab Region" in the field of technology transfer, dissemination and exchange of experience, research results and information on the state-of-the-art of groundwater protection in the Arab Countries.

8 REFERENCES

***Khater,A; Fadl, A; Fekry,A., 2003**. "Statistically-Based Vulnerability Mapping Approach and Assessment of Specific Groundwater Quality Problems In the Nile Delta". NAWQAM Workshop, Alexandria, Egypt.*

***RIGW/IWACO, 1988.** " Hydrogeological Map of Egypt, 1:2000,000". Cairo, Egypt.*

***UNESCO, 1996.** " Proceedings of the UNESCO-NWRC-ACSAD workshop on Wadi Hydrology and Groundwater Protection". IHP-V, Technical Documents in Hydrology no.1. UNESCO Cairo Office, Egypt.*

***UNDP/ UNESCO/RIGW, 2002**. "Development of Groundwater Protection Criteria". Technical Publications of the IHP-Network on Groundwater Protection in the Arab Region, Final Report. Cairo, Egypt.*

***UNESCO, 2002.** "Status of Groundwater Protection in the Arab Region". Technical Publications of the IHP-Network on Groundwater Protection in the Arab Region. Cairo, Egypt.*

Annex C-4: Evaluation of the Current Practice of Water Protection in Tunisia

Document prepared by D. El Batti

المركز العربي لدراسات المناطق الجافة و الأراضي القاحلة
THE ARAB CENTER FOR THE STUDIES OF ARID ZONES AND DRY LANDS

A C S A D

GESTION, PROTECTION ET UTILISATION DURABLE DES RESSOURCES EN EAU **ET EN SOL DANS LA REGION ARABE**

EVALUATION DE LA PRATIQUE ACTUELLE DU SUIVI ET DE LA PROTECTION DES RESSOURCES EN EAU EN TUNISIE

Prepared for the ACSAD – BGR
Technical Cooperation Project
Management Protection and Sustainable Use of
Groundwater and Soil Resources in the Arab Region

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Des Ressources En Eau

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INTRODUCTION :

Le Code des Eaux, promulgué par la loi n° 75-16 du 31 Mars 1975, a confié la gestion du D.P.H. (Domaine Public Hydraulique englobante aussi bien les eaux de surface que souterraines ainsi que les ouvrages qui servent à leur exploitation et utilisation cf. Art.1) au Ministre de l'Agriculture, de l'Environnement et des Ressources Hydrauliques) sauf dérogation prise par décret (Art. 4 du C.D.E : Code des Eaux).

Le Domaine Public Hydraulique est donc défini par ses différents éléments qui sont :

- Sebkhas et lacs jusqu'à la limite des hautes eaux ;
- Cours d'eau de toutes sortes et les terrains compris dans leurs franc-bords ;
- Les terrains et ouvrages servant à l'exploitation, des passages d'eau et les lacs destinés au service public ;
- Les sources de toutes natures , les nappes d'eaux souterraines de toutes sortes, les aqueducs et abreuvoirs à l'usage public ainsi que leurs dépendances, les canaux de navigation, d'irrigation ou d'assainissement exécutés dans un but d'utilité publique, les terrains qui sont compris dans leurs franc-bords et les autres dépendances de ces canaux.

1 – ASPECT INSTITUTIONNEL :

1–1- Institutions :

Avec l'intégration du département de l'Environnement au Ministère de l'Agriculture qui devient depuis Septembre 2002 le Ministère de l'Agriculture, de l'Environnement et des Ressources Hydrauliques est le Ministère en charge de l'évaluation, le suivi et la protection des ressources en eau.

Toutefois, d'autres ministères interviennent dans le D.P.H tels que :

a) Le Ministère de l'Equipement, de l'Habitat et de l'Aménagement du Territoire (Direction de l'Hydraulique Urbaine : D.H.M. et l'Agence de Protection et de l'Aménagement du Littoral : APAL intervenant dans la Protection de l'Environnement du D.P.H).

b) Le Ministère de la Santé Publique (Direction de l'Hygiène du Milieu et Protection de l'Environnement : DHMPE, qui a la charge du contrôle de la qualité notamment micro-biologique des eaux de boisson du réseau public d'eau potable urbaine et rurale, des eaux embouteillées (eaux conditionnées) et des eaux thermales (Stations thermales),

c) Le Ministère de l'Intérieur et du Développement local qui veille sur le curage et la protection de l'Environnement des cours d'eau trans-communaux et les sebkhas situées dans les périmètres communaux,

d) Le Ministère du Tourisme, du Commerce et de l'Artisanat (Office du Thermalisme, Autorité de tutelle des Eaux thermo-minérales :Eaux embouteillées et stations thermales ainsi que l'Office du Tourisme qui veille à la protection de l'Environnement des zones touristiques notamment côtières et même oasiennes exploitant souvent des sources naturelles ou artificielles d'eaux souterraines et superficielles,

e) Le Ministère de la Justice et des Droits de l'Homme intervient par les tribunaux qui traitent les infractions relevées par les Agents de la Police des Eaux, aux dispositions du Code des Eaux (cf. Article 10).

1–2- Organisation et Attributions des Institutions :

Ce sont principalement les organismes publics du nouveau ministère de l'Agriculture, de l'Environnement et des Ressources Hydrauliques qui ont la charge de l'évolution, du suivi et de la Protection des Ressources en eau.

Nous passons en revue les différents organismes avec leurs principales attributions.

1–2–1– La Direction Générale des Ressources en Eau : D.G.R.E.

elle est chargée notamment de :

+ Mettre en place et gérer les **réseaux de mesure et d'observation** concernant les différentes composantes des Ressources en eau du pays.

+ Elaborer les études de base et appliquées visant l'**évaluation** et l'**établissement des bilans globaux** des ressources en eau.

+ Promouvoir les **activités de recherche** et d'expérimentation concernant les différents aspects **de développement des ressources en eau et leur protection**.

Elle est composée de 3 Directions et d'un établissement public à caractère Administratif : la Direction des Eaux de surface, la Direction des Eaux souterraines, la Direction de la Recharge Artificielle et des eaux non conventionnelles et le Bureau de l'Inventaire et des Recherches Hydrauliques (B.I.R.H).

Nous signalons ici les attributions du BIRH qui complètent celles de la D.G.R.E. à savoir :

- Le Suivi et le Contrôle de la qualité des Ressources en eau.

- Gestion de la base de données des points d'eau : Sources, puits de surface et forages.

- Gestion de l'exploitation du Domaine Public Hydraulique dans le cadre de sa protection contre tout empiètement (Article 10 du Code des eaux).

1–2–2– La Direction Générale du Génie Rural et de l'exploitation des Eaux : DG/ GREE

Elle est chargée notamment de :

+ Réaliser les études d'ordre stratégique, formuler les politiques et élaborer les plan relatifs au secteur du génie rural et de l'exploitation des eaux dans le secteur agricole

+ Suivre et évaluer les projets d'aménagement des périmètres irrigués et d'assainissement agricole

+ Rationnaliser l'utilisation des eaux, valoriser les eaux non conventionnelles en agriculture

+ Coordonner les programmes d'eau potable dans les milieu urbain et rural.

1–2–3– La Direction Générale des Barrages et des grands Travaux Hydrauliques : DG/BGTH

Elle est chargée notamment de :

+ Elaborer les études hydrauliques, les études de maîtrise des eaux de surface, les études de mobilisation des eaux,

+ Elaborer les études de grands ouvrages hydrauliques de mobilisation des eaux de surface (Grands barrages, ouvrages de transfert d'eau, barrages collinaires),

+ Elaborer les études des grands aménagements hydrauliques,

+ Réaliser les grands barrages, barrages collinaires et les grands aménagements hydrauliques,

+ Réaliser les ouvrages de protection des zones rurales et agricoles des crues des oueds,

1–2–4- La Direction Générale de l'Aménagement et de la Conservation des terres agricoles : *DG/ACTA*

Elle est chargée notamment de :

+ Elaborer les plans et les orientations pour la préservation des ressources naturelles en sols, végétation, eau et en terres agricoles,

+ Elaborer les études d'aménagement des bassins versants,

+ Etudier, contrôler et suivre l'exécution des projets de conservation des eaux et du sol.

1–2–5- Les Commissariats Régionaux de Développement Agricole :C.R.D.A.

Ce sont des Etablissements Publics à caractère Administratifs dotés de l'autonomie financière et placés sous la tutelle du Ministère de l'Agriculture de l'Environnement et des Ressources Hydrauliques. Chaque gouvernorat dispose d'un C.R.D.A. chargé notamment de :

+ Veiller sur l'application des procédures juridiques et la réglementation relatives à la protection des terres agricoles, des forêts, des eaux, de la santé animale et des végétaux,

+ Gérer, développer et protéger les ressources naturelles : eau, sol et forêts,

+ Gérer l'exploitation du Domaine Public Hydraulique,

+ Etudier et réaliser les projets d'équipement hydraulique : Barrages, Barrages collinaires, lacs collinaires, puits de surface et forages .....

+ Gérer les périmètres irrigués publics et leur fournir l'eau d'irrigation.

1–2–6– La Société Nationale d'Exploitation et de Distribution des Eaux : S.O.N.E.D.E.

C'est une Société Nationale à caractère Industriel et Commercial, dotée de la personnalité civile et de l'autonomie financière, placée sous tutelle du Ministère de l'Agriculture, de l'Environnement des Ressources Hydrauliques.

Elle est chargée d'alimenter en eau potable notamment les zones urbaines et certaines agglomérations rurales. Dans ce cadre elle étudie et réalise les projets d'eau potable à l'échelle nationale et assure la maintenance et la réhabilitation des ouvrages d'adduction ; de transport, de traitement et de distribution des eaux.

Elle dispose de directions et de services régionaux couvrant l'ensemble du territoire national.

Dans le cadre de ses attributions, la S.O.N.E.D.E. étudie et réalise :

+ Le projet national d'économie d'eau dans les secteurs d'eau potable, industrielle et touristique.

+ Les projets de dessalement des eaux saumâtres et des eaux de mer.

1–2–7– La Société d'Exploitation du Canal et des Adductions des Eaux du Nord : SECADENORD

C'est un établissement public à caractère commercial et industriel, dotée de la personnalité civile et de l'autonomie financière, placé sous tutelle du Ministère de l'Agriculture, de l'Environnement et ses Ressources Hydrauliques.

Elle est chargée notamment de :

+ La gestion, l'exploitation, la maintenance et la réhabilitation du Canal du Cap Bon – Medjerda et de ses dépendances comme les adductions et les conduites de transfert et de transport de l'eau des Barrages.

+ La fourniture de l'eau aux différents utilisateurs : C.R.D.A et SONEDE pour l'alimentation en eau des secteurs agricole, domestique, industriel et touristique.

1-2-8- Les Groupements de développement d'Intérêt Collectif **:** G.D.I.C.

Ce sont des Associations d'usagers de l'eau et peuvent être considérés comme des organismes non gouvernementaux (ONG), toutefois, elles sont placées sous la double tutelle des Autorités Régionales (Gouvernorat et Délégation) ainsi que le Ministère de l'Agriculture, de l'Environnement et des Ressources Hydrauliques.

Ces groupements de développement d'intérêt collectif (anciennement AIC) sont chargés :

+ soit de la distribution de l'eau potable rurale (y compris souvent la gestion de l'ouvrage d'approvisionnement en eau : le puits ou le forage).

+ soit de la distribution de l'eau d'irrigation dans les périmètres publics irrigués (y compris la gestion du puits de surface ou du forage).

+ soit de la distribution de l'eau potable et de l'eau d'irrigation (avec la gestion du puits ou du forage quand ils constituent la source d'eau).

Il existe plus de 2500 GDIC dont plus de 1600 GDIC d'eau potable.

1–2–9– Autres organismes :

Il s'agit essentiellement des organismes qui étaient rattachés à l'ancien Ministère de l'Environnement et de l'Aménagement du Territoire et affectés depuis Septembre 2002 soit au Ministère de l'Agriculture, de l'Environnement et des Ressources Hydrauliques tels que l'ONAS, l'ANPE et le CITET, soit au Ministère de l'Equipement , du Logement et de l'Aménagement du Territoire tel que l'APAL.

+ L'Office National de l'Assainissement : ONAS

C'est un Etablissement public à caractère commercial et industriel doté de la personnalité civile et de l'autonomie financière sous tutelle du Ministère de l'Agriculture, de l'Environnement et des Ressources Hydrauliques

Il est crée en 1974 et chargé notamment de :

- la collecte et du traitement des eaux usées en milieu urbain (eaux domestiques et industrielles),

- la lutte contre la pollution hydrique, en milieu urbain et notamment dans les zones industrielles,

- la gestion, l'exploitation, la maintenance et la réalisation des ouvrages de collecte et de traitement des eaux usées aussi bien domestiques qu'industrielles,

- la réalisation des Etudes et des travaux d'assainissement urbain et industriel, collectif et individuel,

- l'assistance des collectivités publiques et locales (notamment les communes) pour la collecte et le traitement des rejets de déchets domestiques et l'évacuation des eaux pluviales.

Il en résulte donc que l'O.N.A.S est un organisme essentiel dans la protection du Domaine Public Hydraulique avec ses composantes naturelles : oueds et nappes d'eaux souterraines et ses composantes artificielles : retenues des Barrages et canaux d'irrigation et d'assainissement.

+ L’Agence Nationale de Protection de l’Environnement : ANPE

Elle est créée en 1988, placée sous l’Autorité du Ministère de l’Agriculture, de l’Environnement et des Ressources Hydrauliques (depuis septembre 2002). C’est un Etablissement Public à caractère commercial et industriel doté de la personnalité civile et de l’autonomie financière. Elle est chargée notamment de :

- Contribuer à la préparation de la politique du Gouvernement pour la protection de l’Environnement et de son application dans le cadre du développement économique et social du pays.
- Proposer toute action visant à la protection de l’Environnement de toute pollution y compris le milieu hydrique (D.P.H).
- Préparer et mettre en place un plan d’intervention rapide en cas de pollution accidentelle mettant en péril l’équilibre du milieu naturel.
- Promouvoir la loi de protection de l’Environnement
- Appliquer les normes de rejets dans le milieu récepteur y compris le D.P.H.
- Approuver les investissements des projets de lutte contre la pollution et de la protection de l’Environnement.
- Coordonner les actions nationales et internationales dans le domaine de protection de l’Environnement.
- Contrôler et suivre les déchets polluants et les équipements destinés à leur traitement.
- Veiller sur l’application des obligations internationales dans le domaine du contrôle et de lutte contre la pollution.

D’autres attributions sont à la charge de l’ANPE pour lui permettre de s’acquitter au mieux de sa tâche dans le domaine de la protection de l’Environnement et de lutte et de contrôle de la pollution sous toutes ses formes dans tous les secteurs d’activités notamment industrielles et agricoles.

+ Le Centre International de Technologie de l’Environnement de Tunis : CITET

Il est crée en 1996, c’est un Etablissement Public à caractère commercial et industriel doté de la personnalité civile et de l’Autonomie financière, placé sous la tutelle du Ministère de l'Agriculture, de l'Environnement et des Ressources Hydraulique.

Il est chargé notamment de :

- la formation, la recherche scientifique et adaptation des technologies de l'environnement à la Tunisie.

- L'acquisition, l'adaptation et le développement des technologies de l'environnement et du renforcement des capacités humaines dans le domaine de la protection de l'environnement et du contrôle et de la lutte contre la pollution dans le cadre d'un système de développement durable.

Le centre dispose de plusieurs laboratoires équipés pour mener à bien les analyses nécessaires pour le contrôle et le suivi de la pollution notamment hydrique qu'elle soit d'origine chimique ou biologique et bactériologique.

+ L'Agence de Protection et d'Aménagement du Littoral : APAL

Elle est créée en 1995, c'est un Etablissement public à caractère commercial et industriel, doté de la personnalité civile et de l'autonomie financière, placé sous tutelle du Ministère de l'Equipement, du Logement et de l'Aménagement du Territoire.

L'APAL est chargée principalement de l'aménagement de l'espace du littoral qui englobe des sebkhas faisant partie du Domaine Public Hydraulique. Elle assure le suivi de l'application des aménagements du territoire conformément à la réglementation en vigueur, notamment le Code de l'Urbanisme et de l'Aménagement du Territoire promulgué par la loi du 28 Novembre 1994.

+ La Direction de l'Hygiène du Milieu et de la Protection de l'Environnement : **DHMPE**

C'est une structure administrative du Ministère de la Santé Publique. Elle est chargée, dans le cadre de l'hygiène publique du :

- contrôle de l'hygiène et de la sensibilisation du public dans le domaine de la protection de l'environnement sanitaire,

- contrôle de la qualité chimique, biologique et microbiologique de l'eau potable urbaine et rurale,

- suivi et le contrôle des déchets dangereux notamment des établissement hospitaliers et de leur impact sur les cours d'eau et les nappes d'eau souterraines superficielles.

+ La Direction de l'Hydraulique Urbaine : DHU

C'est une structure administrative qui relève du Ministère de l'Equipement du Logement et de l'Aménagement du Territoire. Elle est chargée notamment de :

- La planification à moyen et long terme des études et des travaux de protection des agglomérations urbaines des inondations,
- L'entretien et la maintenance des ouvrages hydrauliques contre les inondations des villes,
- La conception et le suivi de la réalisation du Plan National d'Assainissement du milieu urbain et du Plan de contrôle de la pollution hydrique.
- L'élaboration des projets de textes réglementaires relatifs aux rejets des déchets dans le milieu récepteur et notamment dans les retenues des barrages.

1-3- Le Know-how (savoir-faire) Technique acquis :

Le profil technique du Personnel chargé du contrôle et du suivi de la pollution des ressources en eau provient de divers horizons et groupe des spécialistes dans plusieurs domaines tels que :

- La géologie, l'hydrogéologie, l'hydrologie de surface, la géochimie,
- La microbiologie, la biologie, la chimie, la physique, la géophysique,
- L'hydraulique, le génie civil (les aménagistes, les géomorphologues, les pédologues, les agronomes).

En fait, le domaine de la protection des ressources en eau nécessite des équipes pluridisciplinaires chaque fois que le besoin se fait sentir à l'occasion des grands projets d'aménagement tels que :

a) La réalisation des grands barrages ou l'apport principal vient des hydrauliciens, mais les autres spécialistes comme les hydrogéologues, les biologistes, les agronomes ou les géochimistes doivent intervenir pour apporter les ajustements nécessaires pour préserver l'environnement de tout impact négatif ou du moins l'atténuer.

b) L'aménagement urbain notamment dans les zones sensibles comme le littoral ou les sebkhas (dépression salée) côtiers constituent des exutoires naturels des bassins versants d'oueds (cours d'eau temporaires) d'ou l'intervention des hydrologues et des hydrauliciens pour l'étude de l'évacuation des eaux pluviales et la protection contre les inondations.

c) La construction des stations d'Epuration qui demande l'intervention de tous les spécialistes concernés depuis :

+ l'implantation qui nécessite l'avis du géologue, de l'hydrogéologue pour éviter toute pollution des nappes d'eaux souterraines,

+ l'édification des bâtiments et des ouvrages où les Ingénieurs civils et les hydrauliciens ont leur savoir faire à faire valoir pour assurer le meilleur fonctionnement.

+ la mise en service des stations d'épuration qui nécessite la contribution de tous les techniciens spécialistes soit pour le fonctionnement des machines et des appareils de traitement, soit pour les analyses spécifiques à réaliser du flux des polluants à l'entrée et à la sortie des stations .

2– ASPECT TECHNIQUE :

2-1 Définition et Délimitation des zones de Protection :

Les zones de protection des ressources en eau peuvent être définies d'après le Code des eaux en :

***2-1-1- Périmètre d'interdiction* :** (Article 12 du Code des eaux).

Ce sont des zones où la conservation ou la qualité des eaux sont mises en danger par le degré d'exploitation des ressources existantes

En Tunisie, nous comptons 9 périmètres d'interdiction instaurés sur des nappes d'eaux souterraines dont les ressources ont atteint un degré de dégradation aussi bien qualitative que quantitative.

Leur délimitation a été effectuée sur la base d'études hydrogéologiques comportant des cartes notamment piézométriques, de salinité, et de profondeurs du plan d'eau.

Ces périmètres d'interdiction sont créés par décret après avis de la Commission du Domaine Public Hydraulique.

L'article 13 du Code des eaux stipule que dans chaque périmètre d'interdiction :

- **sont interdits :** toute exécution de puits ou de forages, ou tout travail de transformation de puits ou de forages destiné à en augmenter le débit,

- **sont soumis** à autorisation préalable du Ministre de l'Agriculture, de l'environnement et des Ressources Hydrauliques, les travaux de remplacement ou de réaménagement de puits ou forages non destinés à augmenter le débit exploité par ces puits ou forages,

- **est soumis** à autorisation et prescription du Ministre de l'Agriculture, de l'Environnement et des Ressources Hydrauliques : l'exploitation des eaux souterraines ; ces prescriptions peuvent porter sur une limitation du débit maximum à exploiter par puits ou forages ou toute autre disposition propre à éviter les impacts nuisibles et à assurer la conservation des ressources existantes.

L'article 14 du Code des eaux précise par ailleurs que par décision du Ministre de l'Agriculture, de l'Environnement et des Ressources Hydrauliques :

- Les mesures conservatoires peuvent porter sur la démolition partielle ou totale des ouvrages ainsi que la remise des lieux en l'état.

- Les travaux de réaménagement non exécutés en conformité avec les prescriptions de l'Arrêté d'Autorisation, sont punis d'une amende pouvant atteindre le dixième du montant estimé des ouvrages exécutés.

2-1-2- Périmètres de sauvegarde **:** (Article 15 du Code des eaux) :

Les périmètres de sauvegarde peuvent être délimités par décret pris après avis de la Commission du Domaine Public Hydraulique dans les nappes pour lesquelles le taux et la cadence d'exploitation des ressources existantes risquent de mettre en danger la conservation quantitative et qualitative des eaux.

A l'intérieur de ces périmètres, les travaux de recherche ou d'exploitation des nappes souterraines, à l'exclusion des travaux de réfection ou d'exploitation des ouvrages existants, sont soumis à une autorisation du Ministre de l'Agriculture, de l'Environnement et des Ressources Hydrauliques.

Seize périmètres de sauvegarde des ressources en eau ont été instaurés sur des nappes d'eaux souterraines conformément aux dispositions du Code des eaux.

2-1-3- Périmètres d'aménagement et d'utilisation des eaux :
(Article 16 du Code des eaux).

Des périmètres d'aménagement et d'utilisation des eaux peuvent être définis par décret après avis du Conseil National de l'Eau dans les zones où les ressources en eau sont ou risquent d'être insuffisantes par rapport aux besoins actuels ou prioritaires programmés.

À l'intérieur de ces périmètres, les plans de répartition des ressources hydrauliques du périmètre considéré, sont définis par arrêté du Ministre de l'Agriculture de l'Environnement et des Ressources Hydrauliques après enquête administrative auprès des personnes physiques ou morales susceptibles d'être concernées et avis du Conseil National de l'Eau, selon la nature et la localisation des besoins à satisfaire.

Le décret prévu à l'alinéa 1er du présent article peut le cas échéant mentionner les programmes de dérivation des eaux et les programmes des travaux destinés à permettre ou à assurer la mise en application du plan de répartition des eaux et déclarer d'utilité publique tout ou partie des programmes de dérivation ou des travaux ainsi définis.

L'article 17 du Code des eaux précise qu'à l'intérieur des périmètres d'interdiction et des périmètres de sauvegarde, l'Administration se réserve de droit d'effectuer sur les cours d'eau, puits et sondages existants toutes les observations et mesures destinées à suivre l'évolution des ressources en eau.

Le propriétaire ou l'exploitant de ces puits, sondages ou cours d'eau, doit en permettre l'accès aux agents qualifiés de l'Administration à l'effet d'obtenir tous renseignements sur les débits prélevés et les conditions de ce prélèvement.

De même l'article 19 du Code des eaux précise qu'à l'intérieur d'un périmètre d'aménagement des eaux tout propriétaire ou exploitant d'installation de dérivation, captage, puisage est tenu de déclarer ses installations.

Toutefois, certaines catégories d'ouvrage, dont l'influence sur le régime des eaux est négligeable, peuvent être dispensées de la déclaration visée ci-dessus par le décret créant le périmètre d'aménagement des eaux prévu à l'article 16 du Code des eaux.

2-1-4- Périmètres de Protection :

Ce sont des périmètres de protection des sources d'approvisionnement public en eau potable, contre toute atteinte à la qualité des eaux (Article 120 du Code des eaux).

Les articles 121, 122 et 123 définissent les périmètres de protection des forages, des puits, des bassins de stockage de l'eau et des retenues des barrages.

Pour les forages et les puits, l'article 121 stipule qu'un arrêté du Ministre de l'Agriculture, de l'Environnement et des Ressources Hydrauliques fixe dans chaque cas les limites de la zone de protection qui comprend :

- un périmètre de protection immédiat dont les terrains sont à acquérir en pleine propriété clôturés par l'organisme chargé du prélèvement d'eau et de sa distribution pour l'alimentation en eau potable,

- un périmètre de protection rapprochée, à l'intérieur duquel sont interdits les dépôts ou activités susceptibles de conduire directement ou indirectement à la pollution de la source et dont la nomenclature est définie par arrêté du Ministre de l'Agriculture, de l'Environnement et des Ressources Hydraulique et du Ministre de la Santé Publique,

- le cas échéant, un périmètre de protection éloignée, à l'intérieur duquel peuvent être réglementés les dépôts ou activités visés ci-dessus.

Les périmètres de protection immédiate des aires de prélèvements d'eau potable peuvent faire l'objet d'expropriation pour cause d'utilité publique.

Dans le cas où ces interdictions figurant dans les 1 et 3 paragraphes du présent article entraîneraient en fait l'inutilisation de parcelles effectivement mises en valeur, le propriétaire a le droit d'exiger l'expropriation.

- L'article 122 du Code des eaux stipule qu'autour de tout ouvrage de traitement de programme ou de bassin de stockage de l'eau destinée à la consommation, il est institué un périmètre de protection dont les limites sont fixées par un arrêté du Ministre de l'Agriculture, de l'Environnement et des Ressources Hydrauliques, cette aire de protection qui est clôturée par l'organisme intéressé peut faire l'objet d'une expropriation pour cause d'utilité publique.

- Pour les barrages retenues destinés à l'alimentation en eau potable (Article 123 du Code des eaux) il est prévu :

- un périmètre de protection immédiate composé des terrains riverains de la retenue aux plus hautes eaux sur une largeur de dix mètres à acquérir en toute propriété par l'organisme assurant l'exploitation du barrage,

- une zone de servitude de 50 mètres de largeur au-delà de la bande riveraine dans lesquels sont interdits tous faits et activités de nature à conduire directement ou indirectement à la pollution de la retenue.

2-2- Réseaux de suivi des ressources en eau :

Le suivi de la ressource en eau qu'elle soit de surface ou souterraine est effectué en Tunisie par la Direction Générale des Ressources en eau à travers les réseaux d'observations et de mesures suivants :

2-2-1- Réseau Pluviométrique :

Il comporte 800 stations pluviométriques réparties à travers tout les pays dont 80 stations équipées de pluviographes.

Ces stations pluviométriques sont suivies par des observateurs pluviométriques qui effectuent une mesure par journée de 24 heures à une heure fixe (7 heure du matin de chaque journée durant toute l'année 365 sur 365 jours).

Pour assurer le service régulier de ces observateurs, l'Administration leur sert une indemnité mensuelle forfaitaire de 7 Dinars Tunisiens (5 dollars US) soit 84 Dinars Tunisiens annuellement et par observateur.

2-2-2- Réseau Hydrométrique :

Il comporte 120 stations installées sur les principaux cours d'eau (oueds) du pays, dont une cinquantaine de stations principales équipées de téléphérique permettant le jaugeage des crues d'une façon continue et régulière.

Les observateurs hydrométriques chargés du fonctionnement de ces stations principales et certaines stations secondaires perçoivent des indemnités mensuelles variant de 40 à 80 Dinars Tunisiens (30 à 60 Dollars US).

Le Budget annuel alloué à ces observateurs pluviométriques et hydrométriques est de l'ordre de 80 000 Dinars Tunisiens (soit 60 000 Dollars US).

Toutefois les stations hydrométriques sont équipées de :

- limnigraphes,
- pluviométres (pluviographes pour certaines d'entre elles),
- postes radio pour communiquer en temps réel les mesures observées notamment en cas de crues afin de servir à l'organisation du Service d'Annonce de crues. Ce service qui doit

alerter la population riveraine des cours d'eau ou bien à l'aval des barrages en cas de lâchures.

D'ailleurs, lors des fortes pluies qu'a connues la Tunisie dernièrement en Janvier – Février 2003, le réseau hydrométrique a montré son utilité et son efficacité durant la période de crues et de débordement du lit de la Medjerda, principal cours d'eau du pays. Ce qui a permis de limiter les dégâts aux infrastructures du pays et éviter les pertes humaines notamment.

2-2-3- Réseau piézométrique :

Il comporte 3274 piézomètres répartis entre 2252 puits de surface (dont la profondeur est inférieur à 50 mètres), 920 piézomètres équipés de limnigraphes et 102 forages non équipés.

Les nappes phréatiques (se trouvant à moins de 50 m de profondeur) sont suivis à partir de 2717 puits d'observation.

Quant aux nappes profondes elles sont suivies à partir de 557 piézomètres. Les piézomètres équipés de limnigraphes permettent le suivi continu de la piézométrie.

Les piézomètres non équipés sont visités 2 fois par an à savoir :

- à la fin de la période des hautes eaux (Avril – mai)
- à la fin de la période des basses eaux (Septembre – octobre).

La conception de ce réseau piézométrique a débuté depuis quelques décennies pour certaines nappes, la D.G.R.E. dispose de suivi presque continu de leur piézométrie depuis les années 1940-50.

Mais le réseau dans sa forme actuelle s'est développé depuis les années 1970 quand la Direction Générale des Ressources en Eau a entrepris la réalisation de piézomètres réservés au réseau piezométrique et remplacer les puits de surface qui ne peuvent plus être utilisés comme piézomètres.

Actuellement, la Direction Générale des Ressources en Eau conduit un programme annuel de réalisation de piézomètres (30 piézomètre/an au cours du 10^{e} plan 2000-2006).

L'équipement des piézomètres par limnigraphes et récemment par des unités d'acquisition automatique des données, se fait régulièrement depuis quelques années avec une cadence d'une cinquantaine d'équipements par an.

2-2-4- Réseau de suivi de la qualité de l'eau :

Ce réseau, sous sa forme actuelle, a été instauré en 1997 et porte sur le suivi de la qualité des eaux souterraines, à savoir :

- les nappes phréatiques dont la profondeur est inférieur à 50 m,
- Les nappes profondes

Deux paramètres sont suivis, le résidu sec et les nitrates. Ce sont deux indicateurs sur l'évolution de la qualité des eaux souterraines exploitées notamment pour l'alimentation en eau potable rurale et urbaine et l'irrigation.

Les prélèvements se font à partir de 1200 points d'observation :

- 729 puits de surface,
- 471 forages,

Quant aux périodes de prélèvement, elle intéressent les hautes eaux (vers Avril-Mai) et les basses eaux (vers septembre –octobre).

Les basses eaux sont caractérisées habituellement par les fortes teneurs de concentration du résidu sec et des nitrates.

2-2-5- Collecte et traitement des données :

La collecte des données des paramètres mesurés par les différents réseaux : pluviométrique, hydrométrique, piézométrique et qualité de l'eau se fait au niveau des Arrondissements Régionaux des Ressources en eau rattachés aux Commissariats Régionaux de Développement Agricole (CRDA).

Un premier traitement se fait par les Arrondissements des Ressources en eau et toutes les données ainsi collectées et traitées sont transmises avec un commentaire spécifique pour les données de chaque réseau aux services techniques de la Direction Générale des Ressources en eau qui procèdent alors au traitement complémentaire de ces données avant leur publication sous forme d'Annuaires.

Ainsi, la Direction Générale des Ressources en Eau publie régulièrement les Annuaires suivants :

- **Annuaire Pluviométrique**, (publié depuis 1969),
- **Annuaire Hydrologique** (ou hydrométrique – 1974),
- **Annuaire Piézométrique** (1992),
- **Annuaire de la Qualité de l'eau** (1997).

Nous signalons aussi que la Direction Générale des Ressources en Eau publie par ailleurs d'autres Annuaires dans le cadre de suivi des ressources en eau comme :

- **Annuaire de l'exploitation des nappes profondes** (depuis 1972),
- **Situation de l'exploitation des nappes phréatiques** (dont la profondeur est inférieure à 50 m) publié périodiquement, une fois

tous les 5 ans depuis 1980. Nous avons par conséquent publié les situations de 1980, 1985, 1990, 1995 et 2000.

- **Annuaire de la Recharge Artificielle des nappes** (1992). C'est un annuaire qui collecte et traite les données des sites de recharge artificielle des nappes, réparties à travers toutes les région du pays et notamment dont les nappes sont affectées par une surexploitation de leurs ressources.

2-2-6- Conclusions générales :

L'ensemble des données collectées, traitées à partir des différents réseaux de suivi des ressources en eau et publiés sous forme d'annuaires sont à la disposition :

- des décideurs du secteur de l'eau en Tunisie, à savoir les Départements ministériels avec leurs Organismes intervenant dans le secteur,

- des chercheurs des Institutions de Recherche Scientifique et de l'Enseignement Supérieur,

- des Bureaux d'Etudes et d'Ingénieurs Conseils chargés des projets d'Etudes et d'Aménagements du secteur de l'eau tels que : Projets de construction de Barrages, d'aménagement de Périmètres irrigués, de construction de routes, Autoroutes, ouvrages de protection des villes contre les inondations, stations d'épuration des eaux domestiques et industrielles etc.

En résumé, le suivi de la ressource en eau à travers les différents réseaux existants permet aux Décideurs planificateurs d'arrêter de la façon la plus précise les différents projets de développement DURABLE que connaît la Tunisie durant les plans quinquennaux de développement socio-économique.

2-3- VULNERABILITE ET RISQUE DE DEGRADATION DE L'EAU SOUTERRAINE :

Avec un taux de 88,5 d'exploitation globale des eaux souterraines (soit 1900 Millions de m3/an d'exploitation sur 2145 Millions m3/an de ressources exploitables) et un taux de 81 % de mobilisation des eaux de surface (soit 1700 millions de m3/an mobilisés sur 2100 Millions de m3/an mobilisables), il devient impérieux de prêter une attention particulière à la sauvegarde et la conservation de nos ressources en eau, soumises de plus en plus aux risques de pollution.

2-3-1- Les risques de pollution hydrique **:**

La pollution des ressources en eau qui entraîne la dégradation de leur qualité naturelle, reste intimement liée aux différents secteurs d'activités de l'homme à savoir les secteurs domestique industriel, minier et agricole.

1) Les rejets domestiques et urbains :

Ce sont les rejets que l'on remarque le plus souvent à la périphérie des agglomérations urbaines (bien visibles pour les dépôts d'ordures ménagères) et même des agglomérations rurales érigées ou non en communes, où le lit des cours d'eau riverains (oueds souvent à sec) constitue le "lieu habituel ou préféré" de tous les rejets domestiques liquides et/ou solides.

Les déchets urbains solides comportent souvent plusieurs produits susceptibles de se fermenter pour être lessivés par la suite par les eaux pluviales entraînant la formation de filtrats à forte concentration en sulfates, chlorures et Ammoniac.

Les rejets urbains liquides (eaux usées) contiennent par contre, de fortes concentrations en alcalins et détergents produits par les lessives. Ces produits sont à l'origine du développement des concentrations élevées en bactéries.

2) Les rejets industriels :

Les rejets industriels renferment souvent des éléments extrêmement toxiques comme :

- les cyanures, sulfates et baryte provenant des industries minérales,
- les résidus riches en sulfates et en mercure provenant des industries du papier,
- les composés chloriques et phénoliques ainsi que des métaux lourds et des graisses provenant des industries pétrochimiques

La liste des éléments toxiques peut être plus exhaustive en fonction de la nature des différentes industries implantées sur tout le territoire notamment les grands centres industriels du pays tels que Tunis, Bizerte, Sfax, Kasserine et Gabès...

Les eaux de refroidissement constituent l'un des principaux résidus polluants industriels. Ces eaux contiennent souvent de fortes concentrations en sels dissous et sont à température plus élevée que celle du milieu ambiant, ce qui facilite la dissolution des sels du sol et entraîne le dépérissement et la mort de la faune et de la flore.

3) Les rejets miniers :

Ce sont les centres miniers de phosphate, de fluobar, du complexe Zinc et Plomb qui contribuent par leurs rejets de stériles concentrés en éléments toxiques, à dégrader la qualité des ressources en eau ainsi que l'environnement en général avec ses composantes du sol, de la flore, de la faune et de l'air.

Les champs d'hydrocarbures (pétrole et gaz naturel) constituent aussi un important exemple de pollution chimique résultant du mode d'exploitation de ces produits qui est associée au rejet d'eau résiduelle fortement concentrée en saumures.

4) L'épandage des fertilisants et des pesticides :

C'est une pollution due essentiellement à l'activité agricole de l'homme provenant de l'utilisation des engrais chimiques pour améliorer la production du sol ainsi que de l'utilisation des insecticides, des pesticides et de l'irrigation. Cette pollution agricole peut être chimique ou bactériologique.

La pollution bactériologique des eaux résulte de la fermentation des composants organiques (résidus agricoles, engrais organiques ou minéraux). Elle se traduit par la prolifération dans l'eau, des bactéries et des virus.

Quant à la pollution chimique, elle résulte de l'emploi des produits chimiques ou organiques solubles dans l'eau et qui s'infiltrent jusqu'à la nappe souterraine à la suite des pluies et/ou de l'irrigation. Les **nitrates** constituent les polluants agricoles les plus répandus.

5) La surexploitation des nappes aquifères côtières :

Etant donné leur équilibre hydrodynamique fragile, l'exploitation des nappes phréatiques côtières doit être menée avec beaucoup de précaution. Sinon, la rupture de cet équilibre est inévitable en cas de surexploitation de leurs réserves. Ce qui engendre par conséquent, leur contamination par les eaux marines chargée en sels.

Cette contamination des nappes côtières aboutit souvent à leur invasion complète par les eaux salées, est irréversible. Cette invasion marine des nappes touche actuellement presque la totalité des nappes côtières du pays depuis le Cap Bon au Nord Est jusqu'à Djerba-Zarzis au Sud-Est en passant par le Sahel de Sousse et de Sfax au Centre-Est.

En plus des nappes côtières, la contamination par les eaux salées a atteint certaines nappes intérieures avoisinantes des sebkhas où l'intrusion des eaux salées à partir des sebkhas suit un processus similaire à celui affectant les nappes côtières.

2-3-2- Etat Actuel de la Pollution Hydrique :

C'est la carte des sources potentielles de pollution hydrique, établie par les Services de la Direction Générale des Ressources en Eau au Ministère de l'Agriculture, de l'Environnement et des Ressources Hydraulique qui donne un aperçu global sur la répartition spatiale des sources de pollution hydrique ainsi que leur nature à travers tout le pays.

Cette carte est à sa troisième édition. La première édition remonte à 1978 et elle a représenté essentiellement les pollutions d'origine chimique et bactériologique.

L'édition de 1988, représente une réactualisation de celle de 1978, toutefois les enquêtes de terrain ayant permis la collecte des données étaient plus exhaustives afin de mieux cerner l'origine de la pollution : affectant particulièrement le Domaine Public Hydraulique D.P.H. (c'est à dire le domaine des Ressources en eaux de surface et souterraines : sources, nappes et cours d'eau de toutes sortes et ses composantes artificielles comportant tous les ouvrages hydrauliques de toutes sortes : barrages, barrages collinaires et lacs collinaires).

Quant à l'édition actuelle (datant de 1996), elle constitue une réactualisation de celle de 1988. Elle montre une prédominance de la pollution urbaine (essentiellement domestique) et organique, concentrée sur les zones côtières du Nord- Est et du Centre-Est.

La réactualisation de 1996 a permis d'enrichir le fichier déjà établi en 1988 qui donne une description détaillée des divers points de rejets avec leur localisation sur des extrait de cartes topographiques à l'échelle 1/50.000e. Ce qui permet une analyse plus fine du phénomène de pollution du D.P.H. et conduit ainsi les décideurs à prendre les mesures nécessaires pour le préserver de toute dégradation. Parmi ces mesures nous signalons l'extension du réseau d'assainissement communal qui est pris en charge de plus en plus par l'Office National de l'Assainissement : ONAS.

3- LUTTE CONTRE LA POLLUTION HYDRIQUE :
(Aspect Réglementaire)

L'accroissement de la mobilisation et de l'exploitation des ressources en eau entraîne leur dégradation aussi bien qualitative que quantitative. C'est pourquoi la Tunisie, pays aride à semi-aride qui connaît un développement important de la mobilisation et de l'exploitation de ses ressources en eau doit faire face à leur dégradation.

Pour faire face à la dégradation des ressources en eau les mesures à entreprendre peuvent être d'ordre :

- réglementaire,
- préventif et technique,
- dissuasif,

3.1. Les mesures réglementaires :

En Tunisie, nous disposons d'une bonne législation qui n'a cessé d'évoluer au cours des années 1990 afin de sauvegarder nos ressources en eau de toute dégradation, qu'elle soit qualitative ou quantitative.

Parmi les textes législatifs en vigueur nous citons :

a) Le Code des eaux : promulgué par la loi n° 75-16 du 31 Mars 1975 qui comporte pas moins d'une trentaine d'articles (cf. Art 109-139) fixant les modalités pratiques de la lutte contre la pollution hydrique.

b) Le décret n° 85-56 du 2.01.85 fixant les **conditions de rejet dans le milieu récepteur**, pris en application du Code des eaux. Ce décret a été complété par un arrêté du Ministre de l'Economie Nationale du 20.07.89 fixant les normes de rejet dans le milieu récepteur à savoir : Le Domaine Public Hydraulique, le Domaine Public Maritime et le réseau des canalisations d'Assainissement Public.

c) Le décret n° 91-362 du 13.03.91 réglementant les **procédures d'élaboration et d'application des études d'impact** pour tout projet ayant un impact sur l'environnement, notamment sur l'eau, le sol et l'air. Depuis sa promulgation, ce décret a permis d'éviter les effets indésirables de projets polluants, soit par leur annulation pure et simple, soit par la prise des mesures nécessaires pour le traitement de leurs rejets polluants.

Parmi les grandes études d'impact réalisées, nous citons :

- l'Etude de l'impact des Aménagements Hydrauliques sur le lac Ichkeul (1992-1996),
- l'Etude d'impact de la mise en terril du phosphogypse des industries chimiques de Gabès (1997-2001),
- l'Etude d'impact des Laveries de phosphates du Bassin minier de Gafsa (1999-2003).

d) L'instauration de **périmètres de sauvegarde et d'interdiction des ressources en eau**, notamment au niveau des nappes côtières surexploitées du Cap Bon, du Sahel, de Sousse et de Sfax, ainsi que certaines nappes intérieures du Centre (Kairouan, Sidi Bouzid) et du Sud (Gabès et Kébili).

3.2. Les Mesures préventives et de traitement de la pollution :

En plus de la législation spécifique à la lutte contre la pollution hydrique et qui peut être considérée comme mesure préventive, nous citons ici les principales actions de traitement, de suivi et de contrôle de la pollution hydrique.

a) Traitement de la pollution hydrique :

c'est l'action de dépollution des ressources en eau, menée essentiellement par l'Office National de l'Assainissement (ONAS) : Organisme chargé de la collecte et du traitement des eaux usées surtout d'origine urbaine et domestique.

Depuis sa création en 1974, l'ONAS ne cesse de développer ses activités pour prendre en charge l'assainissement de plus en plus de Communes.

Parallèlement à la prise en charge de l'assainissement de plus en plus de communes, l'Office National d'Assainissement ne cesse d'étendre son réseau de stations d'épuration et de conduits de collectes d'eaux usées notamment domestiques mais aussi industrielles. Ce qui contribue largement à la préservation des ressources en eau de la Tunisie, d'autant plus que la principale source potentielle de leur pollution provient des eaux usées rejetées sans traitement dans le milieu récepteur représenté par le domaine public hydraulique : D.P.H.

Il en résulte donc que l'action de l'Office National de l'Assainissement doit être poursuivie afin de préserver de mieux en mieux nos ressources en eau.

Si l'action de l'ONAS en milieu urbain demeure bénéfique pour la conservation de nos ressources en eau, il n'est pas moins important de prévoir et même promouvoir un organisme similaire à l'ONAS qui s'occuperait de l'assainissement des agglomérations rurales. D'autant plus que la desserte en eau potable rurale, connaît des améliorations notables au cours des dernières années (le taux actuel de desserte en eau potable rurale est de 82 %). Il serait donc indiqué de donner la priorité aux agglomérations rurales desservies en eau potable par la SONEDE (Société Nationale d'Exploitation et de Distribution des Eaux) pour leur prise en charge par l'ONAS ou tout autre organisme semblable.

b) Le contrôle et le suivi de la pollution hydrique :

Le contrôle et le suivi de la pollution hydrique sont assurés conformément aux dispositions du code des eaux par :

- l'établissement de cartes spécifiques comme la Carte des sources potentielles de pollution hydrique déjà citée ainsi que la Carte de Vulnérabilité des ressources en eau à la Pollution. La Tunisie dispose déjà d'une carte de vulnérabilité établie depuis 1975 à l'échelle 1/500.000 couvrant le nord du pays,

- La mise en place de réseaux de mesures et d'observation des ressources en eau tels que les réseaux de suivi des Ressources en eau déjà cités (Réseaux : Pluviométrique, hydrométrique, piézométrique, exploitation des nappes et suivi et contrôle de la qualité des ressources en eau).

c) Les périmètres de sauvegarde et d'interdiction :

Ce sont les périmètres d'interdiction (9) et les périmètres de sauvegarde (16) qui ont été instaurés sur les nappes surexploitées particulièrement des zones côtières et certaines nappes intérieures du Centre et du Sud du pays.

L'ensemble des mesures préventives et de traitement de la pollution hydrique qui ont été prises par la mise en place des réseaux de mesures et d'observations, l'instauration des périmètres de sauvegarde et d'interdiction et la construction des stations d'épuration des eaux usées, permettra d'établir un Plan Directeur de la maîtrise de la pollution hydrique, outil indispensable pour la conservation des ressources en eau.

3-3- Les mesures dissuasives :

La création de l'Agence Nationale pour la Protection de l'Environnement : ANPE, créée en 1988 est venue renforcer l'application du Code des eaux.

En effet, les contrôleurs de l'ANPE ont plus de latitude à dresser des procès-verbaux à l'encontre des contrevenants aux dispositions du Code des eaux notamment en matière de pollution de l'environnement y compris les rejets polluants dans le Domaine Public Hydraulique.

Les amendes infligées aux contrevenants peuvent être lourdes et atteindre les 100 000 Dinars (1 Dollar US = 1,4 Dinar Tunisien).

Si l'ANPE est habilitée à jouer un rôle dissuasif à l'encontre des pollueurs en appliquant le principe du pollueur-payeur, il n'en reste pas moins qu'elle a la charge de la gestion du Fonds de Dépollution (FODEP) qui permet de venir en aide surtout aux industries polluantes, ainsi que tous les pollueurs potentiels, de se doter des moyens leurs permettant de traiter leur pollution.

C'est ainsi qu'un vaste programme de dépollution est entrepris par l'ANPE au niveau des industries polluantes comme les tanneries qui ont été invitées à se doter de stations d'épuration préliminaire de leurs eaux usées avant leur rejet dans les canalisations publiques d'assainissement de l'ONAS, afin de respecter les normes de rejet instituées par l'Arrêté du 20.07.89.

3–4- Contraintes pour l'application de la réglementation :

Quelque soit le dispositif réglementaire dont dispose un pays pour le contrôle de la pollution hydrique, son application reste toujours tributaire de la volonté des Autorités (qu'elles soient politiques ou administratives) pour assister les différents services ayant à leur charge le suivi des ressources en eau quantitativement et qualitativement.

La lourde tâche revient aux services techniques de bien démontrer aux décideurs la validité de leurs arguments quant à la nécessité de sauvegarder les ressources en eau de toute dégradation de leur qualité.

Toutefois, nous signalons qu'en Tunisie, étant donné que ses ressources en eau sont limitées et sont à un stade très avancé d'exploitation et de mobilisation, les Autorités (politiques et administratives) sont très sensibles à la **question de** l'eau (notamment en période de pénurie comme la sécheresse qu'a connue au cours des dernières années 2000, 2001 et 2002).

Néanmoins, dans certaines régions sensibles du pays, les ressources en eau notamment souterraines connaissent une surexploitation parfois intensive sans que pour autant, les Autorités agissent pour aider les services chargés du suivi de l'exploitation de cette ressource à réduire cette surexploitation.

Mais comme le Code des eaux, date de 1975, l'application de ses dispositions n'a commencé qu'au cours des années 1980 pour instaurer les périmètres de sauvegarde et d'interdiction des ressources en eau. Et la création de l'Agence Nationale de Protection de l'Environnement en 1988 n'a fait que renforcer le dispositif réglementaire pour le suivi de la ressource en eau.

Néanmoins, le corps de la police des eaux reste encore limité et devait être renforcé en moyens matériels et humains.

Toutefois, il semble que les Autorités du secteur de l'eau en Tunisie préfèrent les méthodes douces plutôt que les méthodes **dissuasives** réglementaires (que permet le dispositif juridique existant).

Les méthodes douces sont surtout de sensibilisation et d'information du grand public sur les différents aspects de la ressource en eau.

De ce point de vue, la Tunisie reste un pays presque modèle pour la bonne gestion de ses ressources en eau, d'autant plus qu'il est l'un des pays les plus démunis en eau avec moins de 400 m^3 d'eau par habitant. Alors que le seuil de pauvreté en eau est de 1000 m^3 par habitant.

IV – CONCULSIONS ET RECOMMANDATIONS :

Etant donné le stade avancé de la mobilisation et surtout de l'exploitation des ressources en eau en Tunisie à savoir :

- 81 % des eaux de surface sont mobilisées ;
- 88,5 % des eaux souterraines sont exploitées ;

leur **conservation** de toute altération qualitative et/ou quantitative devient **impérative** et même **prioritaire** par rapport à la recherche de nouvelles ressources souterraines et/ou la réalisation de nouveaux projets de mobilisation d'eau de surface. Sachant que les efforts déployés pour la reconnaissance et la recherche de nouveaux horizons aquifères et/ou la mobilisation des eaux de surface, des coûts de plus en plus onéreux pour des résultats obtenus souvent modestes.

Afin d'assurer une gestion durable de la ressources en eau il y a lieu :

1) de renforcer et poursuivre les différents réseaux de suivi et de contrôle de la ressource. C'est ainsi que la Tunisie a entrepris dans le cadre du PISEAU (Programme d'investissement du secteur de l'eau 2001-2005) de consolider les actions pilotes suivantes :

- Mise en place d'un Système National de suivi des ressources en eau : SINEAU,
- Optimisation des réseaux de suivi de la ressources en eau (Réseaux pluviométrique, hydrométrique, piézométrique, qualité de l'eau, exploitation des eaux souterraines),
- Développement de la Recharge Artificielle des nappes (affectées par la surexploitation) à partir des eaux excédentaires des barrages et des eaux usées traitées (produites par l'ONAS),
- Modèles de gestion des nappes d'eaux souterraines,
- Gestion participative des nappes d'eaux souterraines ;

2) de renforcer le dispositif réglementaire par des moyens appropriés notamment humains en les dotant de moyens matériels adéquats tels que le matériel roulant pour intervenir à temps sur les lieux de pollution de la ressource en eau par les rejets de toutes sortes qui pourraient survenir par tous les temps à travers tout le pays.

S O M M A I R E

BIBLIOGRAPHIE SOMMAIRE

1 **- Code des Eaux** et textes pris pour son application,

2 **- Annuaires de Suivi des ressources en Eau** : (DGRE) Pluviométrie, Hydrométrie, Piézométrie, Exploitation des Nappes profondes, Situation de l'exploitation des nappes phréatiques, Qualité de l'eau, Recharge Artificielle des nappes souterraines.

3 **- Carte de la Vulnérabilité des Ressources en eau** : 1975 - D.G.R.E.

4 **- Carte des Sources Potentielles de Pollution Hydrique :** Editions : 1978, 1988 et 1996.

5 **- Divers Rapports internes de l'Auteur :** B.I.R.H – D.G.R.E 1990 – 2003.

6 **- Protection des Ressources en Eau :** ANPE 1996.

7 **- Etat de l'Environnement de la Tunisie** : de 1993 à 2002, publié par le Ministère de l'Environnement et de l'Aménagement du Territoire (intégré depuis Septembre 2002 aux : Ministère de l'Agriculture, de l'Environnement et des Ressources Hydrauliques et le Ministère de l'Equipement, du Logement et de l'Aménagement du Territoire).

Annex C-5: Groundwater Monitoring in Jordan

Document prepared by Nidal Khalifa

The Hashemite Kingdom of Jordan
Ministry of Water and Irrigation

Groundwater Resources and Planning Directorate

Current Practice of Groundwater Monitoring in Jordan

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ACSAD – BGR Technical Cooperation Project
Management, Protection and Sustainable Use of Groundwater and Soil Resources in the Arab Region

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1. Introduction

Water scarcity is the single most important natural constraint to Jordan's economic growth and development. Most of Jordan (about 90 %) is located in arid and semi arid climate which has lead to the limitation of water resources, specifically in groundwater. Groundwater is the major source of domestic purposes in the country. On the other hand, groundwater is also abstracted for industry and agricultural purposes.

Due to the regional hydrogeological situation of Jordan, the average precipitation is less than 300 mm/a, except in the narrow western and northern mountain of Jordan. In addition, the population growth rate of about 3.5 °/o which considered as one of the highest rate in the world, the increasing of agriculture, industrial, urbanization and rising incomes lead to continuously increasing on water demands.

In Jordan we can distinguish between two aquifer types:

- bedrock aquifers
- unconsolidated aquifers

The biggest part of the country consists of bedrock aquifers, which are the main groundwater sources. Table. 1 shows the corresponding geological and hydrogeological classification of rock units in Jordan. The main aquifers are:

- the sandstone aquifers like the Ram sandstone aquifer (Disi-aquifer) and the Kurnub aquifer
- the carbonate aquifers like A7/B2 and B4/B5 aquifers
- the basalt aquifer

Based on the renewable groundwater divides configuration as anticipated by the various investigators, twelve major groundwater basins were defined. Since mid 1960s the shallow aquifer of groundwater in Jordan has exploited and over developed by government and private sectors.

Due to over pumping of groundwater by either private or governmental sectors for domestic and intensive agricultural purposes, the aquifer balance is disturbed and declines in groundwater level accompanied by deterioration in groundwater quality has been taken a place.

Therefore, to avoid the irreversible environmental impact such that, depletion and deterioration of groundwater, the groundwater resources should be protected. Monitoring network has been established in Jordan to meet the needs and objectives of the Ministry of Water and Irrigation (MWI).

Table 1: Geological and hydrogeological classification of rock units in Jordan (after MWI 2000)

ERA	SYSTEM	EPOCH	GROUP	FORMATION	SYMBOL	LITHOLOGY	THICKNESS [m]	AQUIFER UNIT
CENOZOIC	QUATERNARY	Holocene	JORDAN VALLEY (JV)	Alluvium	Qal	clay, silt, sand, gravel		ALLUVIUM (AQUIFER) / BASALT (AQUIFER)
		Pleistocene		Lisan	JV3	marl, clay, evaporites	> 300	
	TERTIARY, Neogene	Pliocene, Miocene		Samra	basalt	conglomerates	100 - 350	
		Oligocene		Neogene	JV1-2	sand, gravel		
	TERTIARY, Paleogene	Eocene	BELQA (B)	Wadi Shallala	B5	chalky and marly limestone with glauconite	0 - 550	B4/5 (AQUIFER)
		Paleocene		Umm Rijam	B4	limestone, ckalk, chert	0 - 310	
MESOZOIC	CRETACEOUS, Upper	Maastrichtian		Muwaqqar	B3	chalky marl, marl, limestone chert	80 - 320	B3 (AQUITARD)
		Campanian		Amman-Al Hisa	B2	limestone,chert, chalk, phosphorite	20 - 140	A7/B2 (AQUIFER)
		Santonian		W.Umm Ghudran	B1	dolomitic marly limestone, marl, chert, chalk	20 - 90	
		Coniacian	AJLUN (A)	Wadi as Sir	A7	dolomitic limestome, limestone, chert, marl	60 - 340	
		Turonian		Shueib	A5/6	marl, limestone	40 - 120	A5/6 (AQUITARD)
		Cenomanian		Hummar	A4	limestone, dolomite	30 - 100	A4 (AQUIFER)
				Fuheis	A3	marl, limestone	30 - 90	A3 (AQUITARD)
				Naur	A1/2	limestone, dolomite, marl	90 - 220	A1/2 (AQUIFER)
	CRETACEOUS, Lower	Albian, Aptian, Barremian	KURNUB (K)	Subeihi	K2	sandstone, shale	120 - 350	KURNUB (AQUIFER)
		Hauterivian, Valanginian, Berriasian		Aarda	K1	sandstone, shale		
	JURASSIC		ZARQA (Z)	Azab		siltstone,sandstone, limestone	0 - >600	ZARQA (AQUIFER)
	TRIASSIC			Ramtha		siltstone,sandstone, shale limestone, anhydrite, halite	0 - >1250	
PALEOZOIC	PERMIAN			Hudayb		siltstone,sandstone, limestone	0 - >300	
	SILURIAN		KHREIM (KH)	Alna		siltstone,sandstone, shale	0 - >1000	KHREIM (AQUITARD)
				Batra		mudstone,siltstone	0 - >1600	
				Trebeel		sandstone	0 - 130	
				Umm Tarifa		sandstone, siltstone, shale	0 - >1200	
				Sahl as Suwwan		mudstone, siltstone, sandstone	0 - 200	
	ORDOVICIAN		RAM (D)	Amud		sandstone	0 - >1500	RAM SANDSTONE DISI (AQUIFER)
	CAMBRIAN			Ajram		sandstone	0 - ca: 500	
				Burj		siltstone,dolomite, limestone sandstone	ca: 120	
				Salib		arkosic sandstone, conglomerate	0 - >750	
PRECAMBRIAN				Unassigned clastic unit		sandstone, argillaceous siltstone, claystone	0 - 1000	BASEMENT COMPLEX
				Saramuj		conglomerate, sandstone	up to 420	
				Aqaba Igneous				

2. Groundwater Level Monitoring:

Groundwater level monitoring has been conducted by different institutions in the past decades. Until the foundation of Water Authority of Jordan (WAJ) in 1984 monitoring was performed by the Amman Water and Sewage Authority (AWSA), the Water Supply Corporation (WSC) and the Natural Resources Authority (NRA). Until 1989 groundwater level monitoring of wells in Jordan Valley and Wadi Araba was carried out by Jordan Valley Authority (JVA).

Presently monitoring is mainly being carried out by the Groundwater Monitoring Division in the Water Resources Planning Directorate of MWI. In addition, some wells are monitored (in most cases for relatively short time periods) by projects implemented in the MWI, WAJ, JVA, and Royal Scientific Society (RSS), Higher Council of Science and Technology (HCST) or other.

Yearly monitoring report is prepared by the Groundwater Monitoring Division for interpretation the data, and to specify the critical water level declined areas. Most groundwater projects in MWI have been used the interpreted and the new available monitoring data to evaluate the current water resources and to build up the new strategies for sustainability and future planning. For example, "Wala Dam artificial Recharge" project has been carried out based on the groundwater monitoring wells data in Wala area. This gives an indication of possibility of artificial recharge and constructed Wala Dam with a special monitoring program made for that purpose. In addition, within the framework of a Technical Cooperation Project between the Water Authority of Jordan and the Federal Institute of Geosciences and Natural Resources (BGR) in Hanover/ Germany, delineation of a groundwater protection area defined for the Tabaqat Fahel spring (Pella) based on the groundwater quality monitoring data which indicated that the water of the target area is already contaminated by organic and non organic pollutants.

Most monitoring wells objectives in Jordan are based on long term movement of the groundwater table, which is necessary for groundwater simulations and modelling surveys, in order to define the regionally effective specific yield of aquifers and to calibrate the required hydrogeological models. Therefore, these data will be used to study the changing in the water balance of a groundwater resource and serve as a planning tool for groundwater management.

About 198 observation wells are presently monitored throughout the country. One hundred and seventeen of wells are equipped with automatic recorders. At 81 well sites manual measurements are taken at irregular time intervals (Table 2). All of these observation wells are shown in Figure 1. Most of wells serve for water level monitoring of the A7/B2 aquifer. For the other aquifers the available information is rather limited. Most monitoring wells are located in the northern and central parts of Jordan.

2.1 Groundwater Level Fluctuation

The water level records give an evidence of the long term continuous decline of the groundwater level in most basins except Hammad Basin and the groundwater decline is still in progress. This water level decline is mainly caused by the over-abstraction in most aquifers.

According to the yearly monitoring report by the Groundwater Monitoring Division, the yearly average of drawdown observed in 2002 in the most critical basins are shown in Table 3 and the representative wells are shown in Figs. 2a-2d.

Table 3: yearly average of drawdown observed in 2002 in the most critical basins

Basin	Aquifer	Drawdown m/yr	Representative Well
Amman-Zarqa	B2/A7	1.1	Wadi Dhulail Observation Well No.TW-6
Dead Sea	B2/A7	1.55	Qastal Observation Well No.7
Azraq	Basalt+B4/B5	1.5	Azraq Observation Well No.12
North Side Wadies	B2/A7	4	Kufr Asad Observation Well

Table 2: Groundwater Monitoring Situation in Jordan in 2002

No.	Basin Name	GW Level Monitoring		GW Quality Monitoring	
		Recorder	Manual	Chemical	Bacteriological
1	Yarmouk	6	3	10	5
2	Reft Side Wadies	3	2	8	-
3	Jordan Valley	11	7	15	5
4	Amman - Zarqa	35	25	86	20
5	Dead Sea	21	12	37	9
6	Disi (Southern Desert)	10	5	5	-
7	North Wadi Araba	6	4	3	-
8	South Wadi Araba	7	3	4	-
9	Jafer	7	7	9	-
10	Azraq	10	10	29	-
11	Sirhan	-	-	-	-
12	Hammad	1	3	6	-
	Total	117	81	212	39

3 Groundwater Quality Monitoring

Groundwater quality monitoring has been conducted routinely since 1970s and historical data are available in the Water Information System (WIS) database. There are totally 1148 wells and 742 springs with water quality records. The records for some of the wells and springs started as earlier as 1960, but most of them started in 1970s. As time passed, some of the sites were closed or the monitoring plans were changed. The number of wells with water quality records after 1995 becomes 653 (Fig.1) and that of springs becomes 646. However, water sampling and analysis are not following a regular program.

The water quality items in the WIS data base include water salinity (as EC), pH, main cations (Na, K, Ca, and Mg) and anions (Cl, CO_3, HCO_3, NO_3, and SO4). There are few records of coliform or fecal coliform. The most important factors related to water contamination among these water quality parameters are EC and NO_3.

Water quality problem is increasing either due to salinization or pollution. Concerning groundwater mineralization, only in the area close to the recharge area groundwater resources of low mineralization are found. In the rest of the country, especially in the eastern part, groundwater are mostly highly mineralized and can only be used to a limited extend. Groundwater pollution has increased in recent years and many springs can no longer be used for public water supply (Wadi Al Seer, Salt, Tafila, Irbid, etc...)

By reviewing the historical data of groundwater quality in different areas and aquifers, it is noticed that Amman-Zarqa basin has the most serious problem with groundwater quality. The salinity of many wells and springs has increased substantially in the past years to a level far above the standard value for domestic or agricultural use.

In general the main sources are:

- sewage water (effluents from septic tanks mostly directly infiltrates into the groundwater, many sewage treatment plants have a low efficiency and the sewer networks are often leaking).
- excessive use of fertilizers, pesticides and fungicides
- leachates from waste disposal sites.
- local pollution (e.g. from small to medium size factories and industries).

Water sampling and analysis are not following a scheduled program. The frequency of sampling within each year is often irregular. Water sampling is taken commonly on arbitrary basis for most wells and every six months for selected wells. Consequently, for many important groundwater sources, water quality records are not continuous so that historical data can only be used to a limited extent. In Jordan two major quality problems can be distinguished:

3.1 Salinity Problems

The main reason of increase in groundwater salinity is irrigation return flow. The problem is most serious in Amman-Zarqa basin where over pumping of groundwater for irrigation in the upland is the origin of the reason. Solution of this problem can be incorporated into the plan of restriction of groundwater abstraction in the upland areas for irrigation use.

The B2/A7 is the main and important aquifer in Jordan; B2/A7 wells are mainly distributed in Amman-Zarqa, Dead Sea, Yarmouk, North Jordan Valley and Hasa basins. Some wells in the middle of Amman-Zarqa basin show high salinities (higher than 2000-3000 mg/l) and a few with 1500-2000 mg/l in northern parts of Amman-Zarqa basin and middle of Dead Sea basin basin. (Fig. 3a).

The Basalt aquifer is in the east part of Amman-Zarqa basin and north part of Azraq basin. There are a group of wells in the area near Mabruka and Dhuleil villages where water salinity is very high, i.e. EC > 3000 mg/l /cm (Fig. 3b).

3.2 Nitrate Problems

The nitrate problem can be put into two categories: The first one is the problem that happens simultaneously with the increase in salinity from irrigation return flow, the second is a local problem that happened in certain places where intensive pollutant source (point source) can be easily identified (fig.4a and fig. 4b), such as Zarqa River downstream of As Samra water treatment plant (WWTP), Wadi Ramtha etc.

Solution of the nitrate problem related to irrigation return flow can also be incorporated into the plan of restriction of groundwater abstraction, because almost all wells with extremely high NO_3 concentration are in the Amman-Zarqa basin. Regarding wells in other basins, because the NO_3 concentration is not too high as to affect water use at present, the realistic measure is to strengthen water quality monitoring and pay attention to the trend of increase in NO_3, as well as salinity. Other measures such as restriction on fertilizer use, improvement of irrigation method can also be proposed.

Regarding those wells at the bank of Zarqa River downstream of As Samra WWTP, improvement is expectable when the stabilization pond system is changed into activated sludge treatment system as has been planned. On the other hand, digging wells in the vicinity of this section of Zarqa River is unsuitable. For all the wells with very high NO_3 concentrations (NO_3 > 100 mg/L), because the water quality is not suitable for domestic nor irrigation use and recovery of water quality cannot be expected in short term, it is advisable that use of water from these wells should be stopped unless water treatment is conducted.

4. Relevant Laws, by-laws, guidelines and Regulations Concerning Groundwater

According to Water Authority Law No.18 of 1988 (Water Authority Law), issued by the Government of Jordan, the Water Authority of Jordan (WAJ) has the task to:

- *…conserve* the water resources,
- to set up plans and programs to implement approved water policies related to domestic and municipal waters and sanitation, to *…improve and protect the quality thereof*,
- to draw terms, standards and special requirements in relation to the preservation of water and water basins*, …protect them from pollution*,
- to carry out theoretical and applied research and studies regarding water and public wastewater to achieve the Authority's objectives including the

preparation of approved *water quality standards* for different uses and technical specifications.

Article 30 of the said law states that the …*pollution of groundwater resources is a punishable act*, leading to imprisonment or the imposition of a fine.
The "Instructions for the Commercial and Industrial Wastewater into Sewerage" (cf. WAJ's Regulations for the Quality of Industrial Wastewater), in Article 3, …*prohibit the disposal of wastewater that contains any solids, liquids or gasses containing toxic materials that may …cause a health hazard on humans, animals or plants.*
MWI's policy on Jordan's Water Strategy and Policies defines the Ministry's role in the setting of …*health standards for municipal water supply*. The Standards for Drinking Water No.286 of 2001 was issued in cooperation between WAJ and JISM.
The Standards for Industrial Wastewater No.202 of 1991, states that …*industrial wastewater must not have a negative effect on the groundwater.* Similarly, the MWI's Jordan's Water Strategy and Policies state that ...*wastewater shall be collected and treated in accordance with WHO and FAO Guidelines as the basis for effluent quality requirements for reuse in irrigation.*
The Underground Water Control By-Law No.85 of 2002, specifies in Article 16 that …*in case of water pollution or over-abstraction the Water Authority has the duty to stop the source of pollution or over-pumpage in order to reinstate the previous conditions*. According to Article 25 of the By-Law the distance between wells shall not be less than 1,000 m.

The Ministry of Water and Irrigation is involved in land use planning decisions that may have an impact on the quality of water resources. However for many of those activities, such as waste disposal sites, wastewater facilities, industrial and commercial buildings, storage facilities and handling of for hazardous substances, agricultural land use, energy generation facilities, Mines and mineral processing facilities, military facilities, etc. there are no sufficient regulations with regard to water resources protection.

5. References

BARBER, W. & CARR, D.P. (1973): Digital Modell of the Shallow Aquifer Complex of the Azraq Basin, East Jordan. - Unpubl. Rep. Raikes & Partners, FAO, SF:JOR/71/525; Rome, Amman.

CONSULTING ENGINEERS SALZGITTER (CES) & ARABTECH (1993): Ground Water Investigation in the Azraq Basin - Final Report. - Unpubl. Rep., Vol.I-III, prepared for the Water Authority of Jordan; Amman.

GIBBS, B. (1993): The Hydrogeology of the Azraq Basin, North-East Badia, Jordan. - MSc Thesis, University College London; London.

HOBLER, M., et al. (1991): Groundwater Resources of Southern Jordan, Vol. 1-5. - Unpubl. Rep. Fed.Inst.for Geosc.and Nat.Res. (BGR), Project No. 86.2068.4 and No. 88.2180.3, Report No. 108652 and 107375; Hannover.

HOWARD HUMPHREYS & SONS (1983): Monitoring and Evaluation of the Amman-Zerqa Aquifers. - Unpubl. Rep. prepared for Amman Water and Sewerage Authority; Amman

JICA (2001) : Water Resources Management Master Plan – Final Report. - Unpubl. Rep., Vol.I. Amman

MARGANE, A., et al. (1995): Groundwater Resources of Northern Jordan, Vol. 2. – Part 2 Unpubl. Rep. Fed.Inst.for Geosc.and Nat.Res. (BGR), BMZ-Project No.: 89.2105.8 , File No. 12548/94 ; Hannover.

MINISTRY OF WATER AND IRRIGATION (2003): Water information system. Amman, Jordan

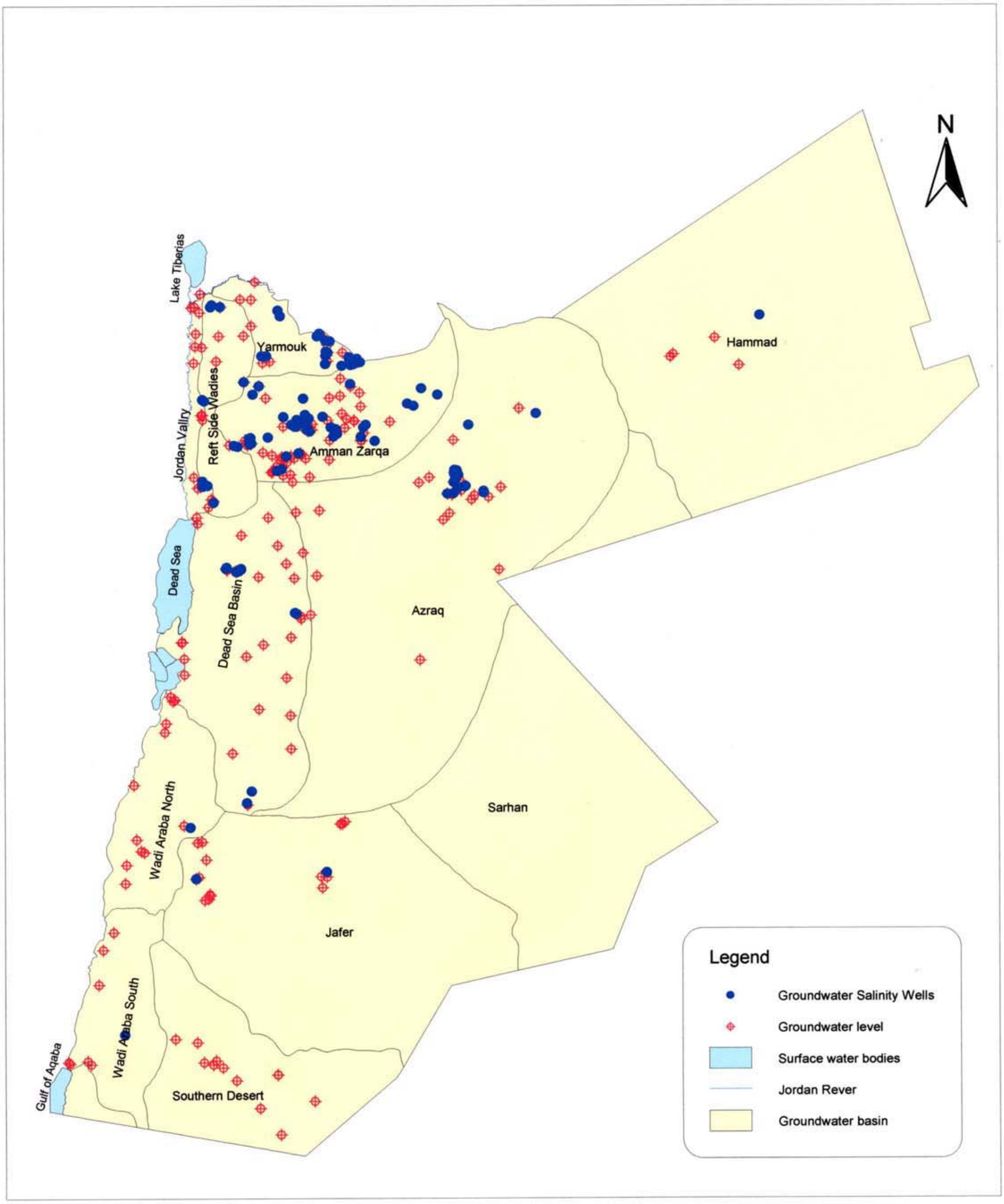

Fig. 1: Location of groundwater observation wells

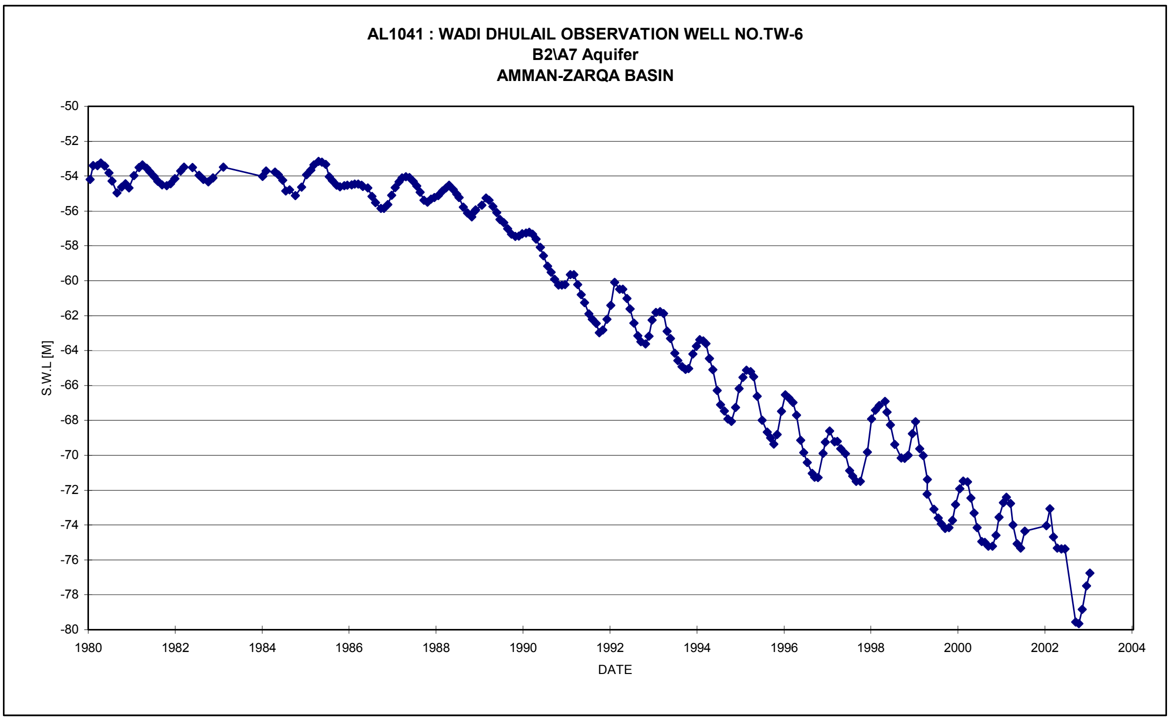

Fig. 2a Hydrograph of Wadi Dhulail Observation Well No.TW-6

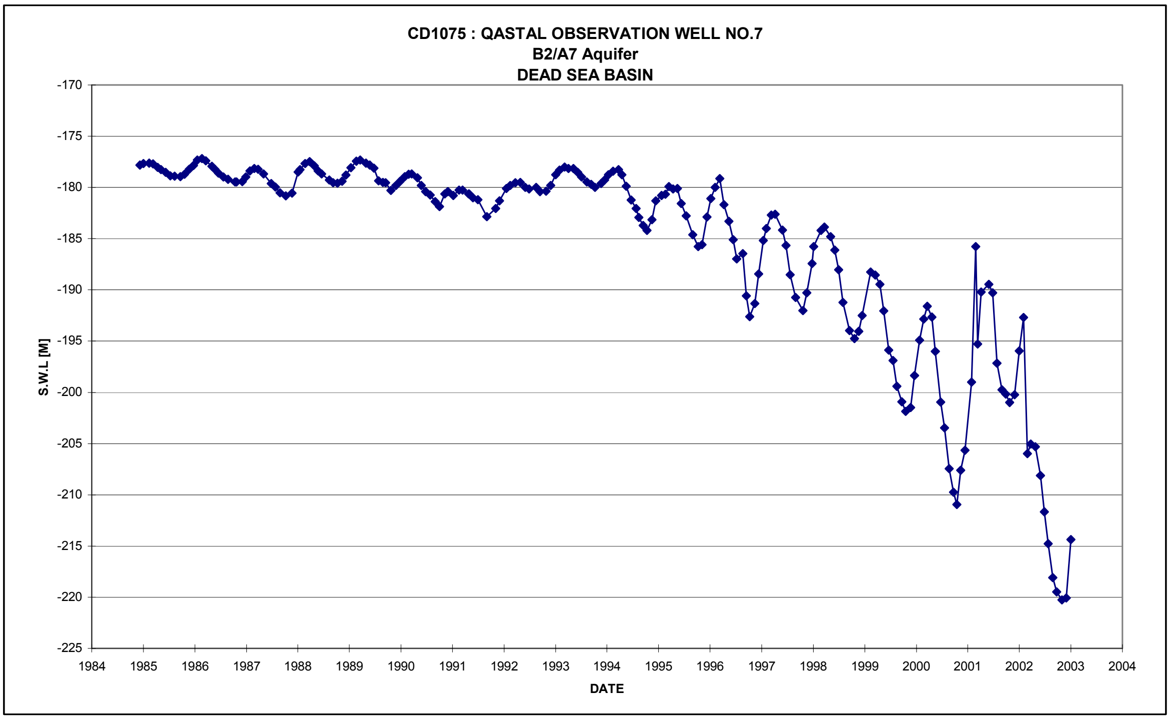

Fig. 2b Hydrograph of Qastal Observation Well No.7

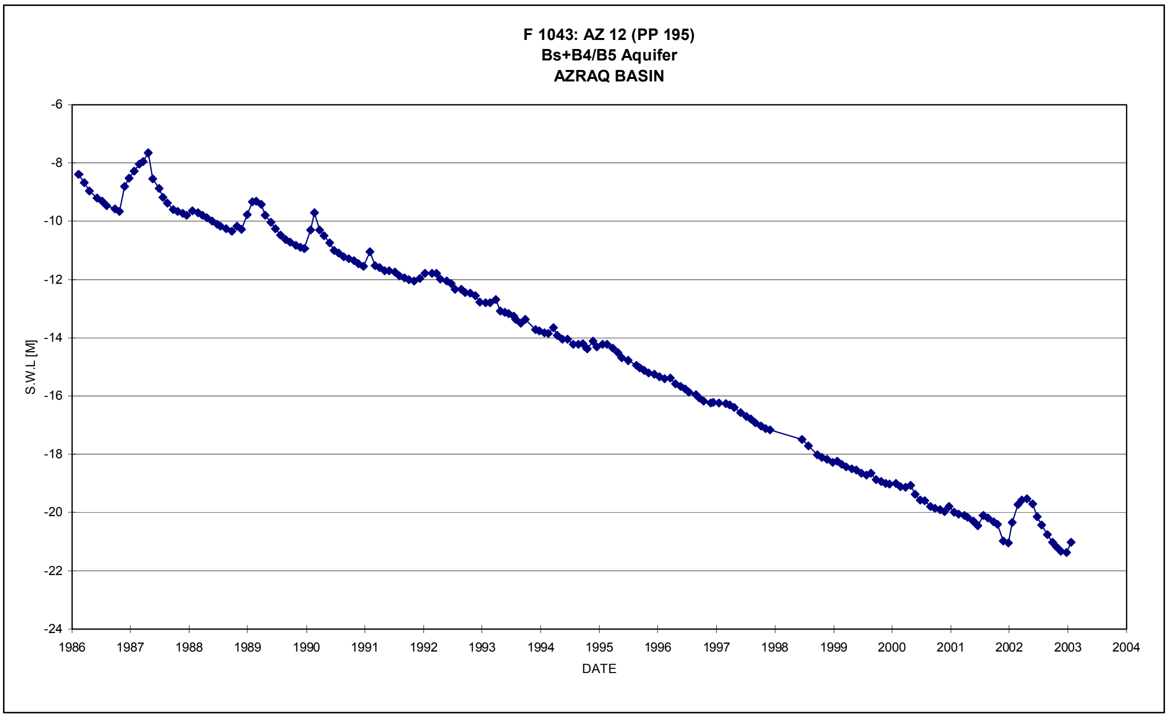

Fig. 2c Hydrograph of Azraq Observation Well No.12

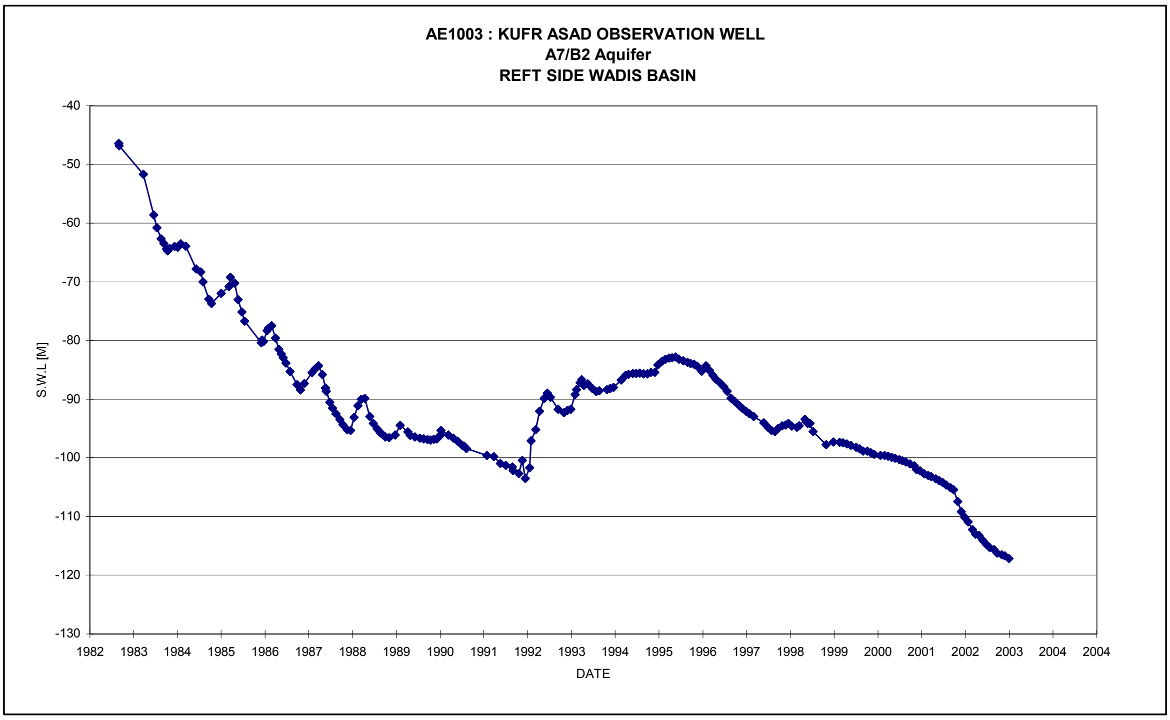

Fig. 2d Hydrograph of Kufr Asad Observation Well

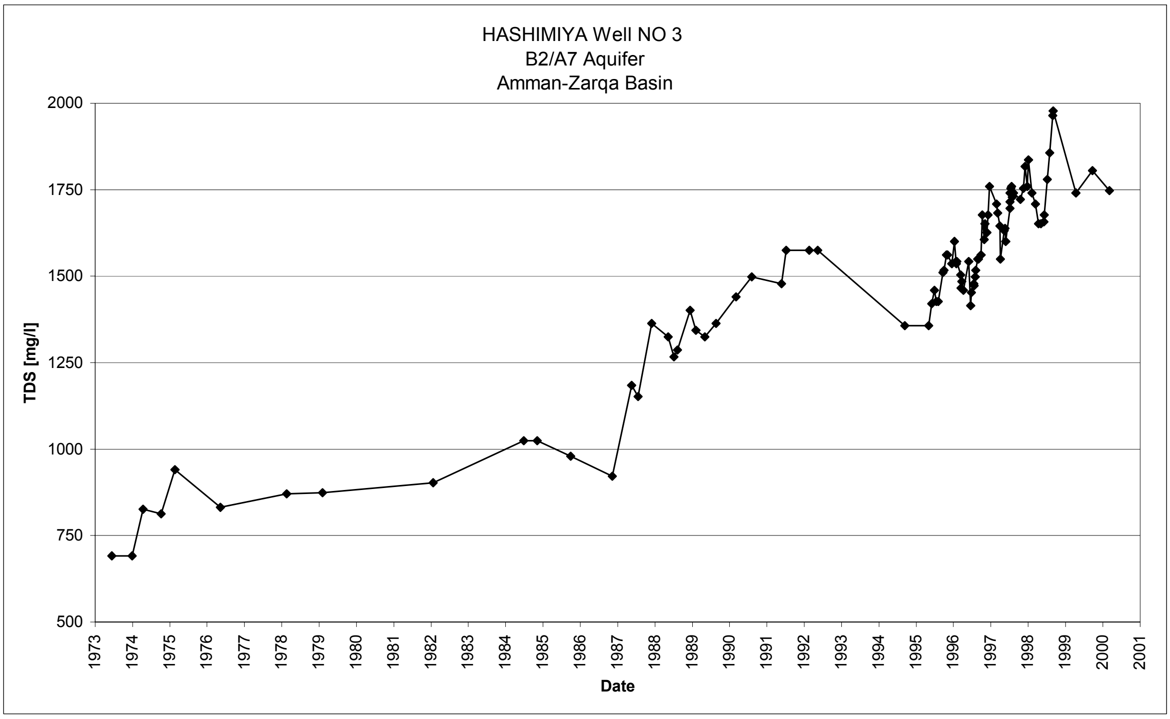

Fig.: 3a Fluctuation of Salinity in B2/A7 aquifer

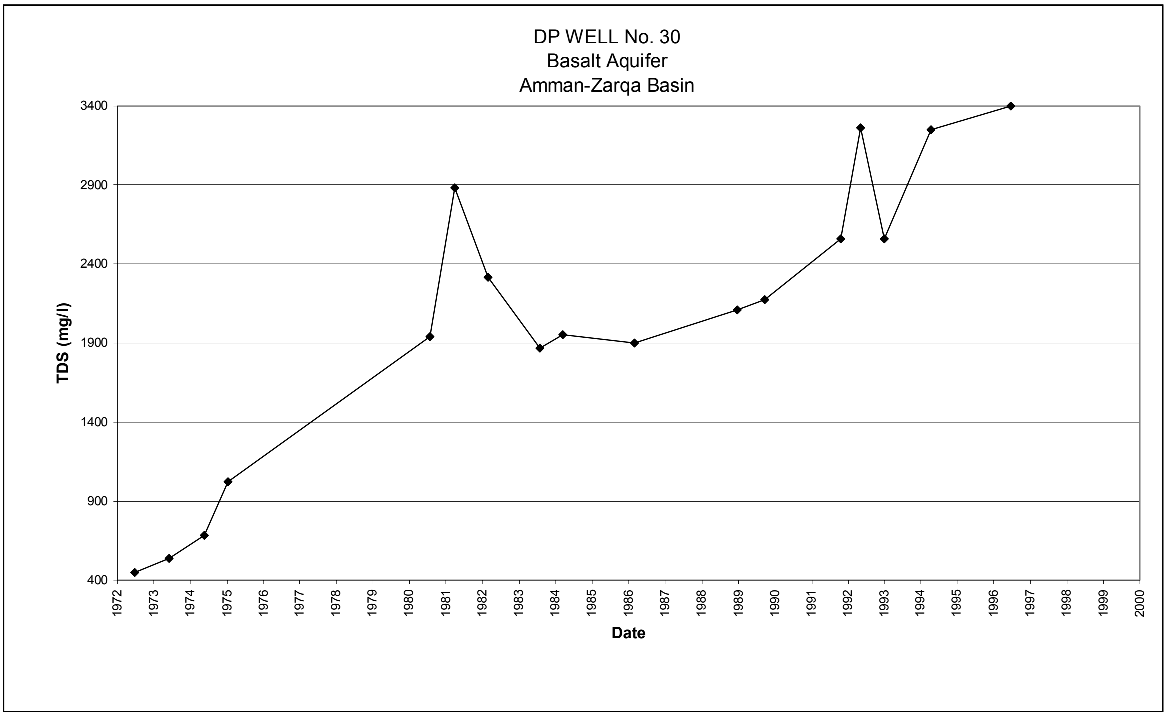

Fig.: 3b Fluctuation of Salinity in Basalt aquifer

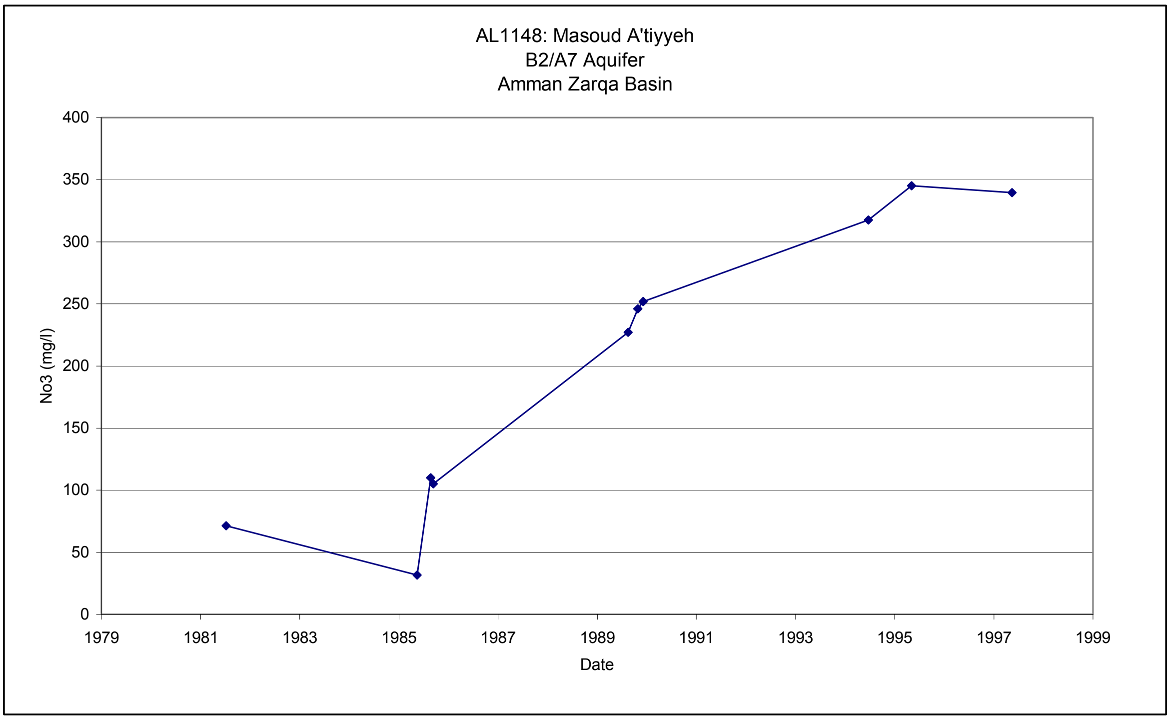

Fig.: 4a Fluctuation of the Nitrate Concentration in B4/B5 aquifer

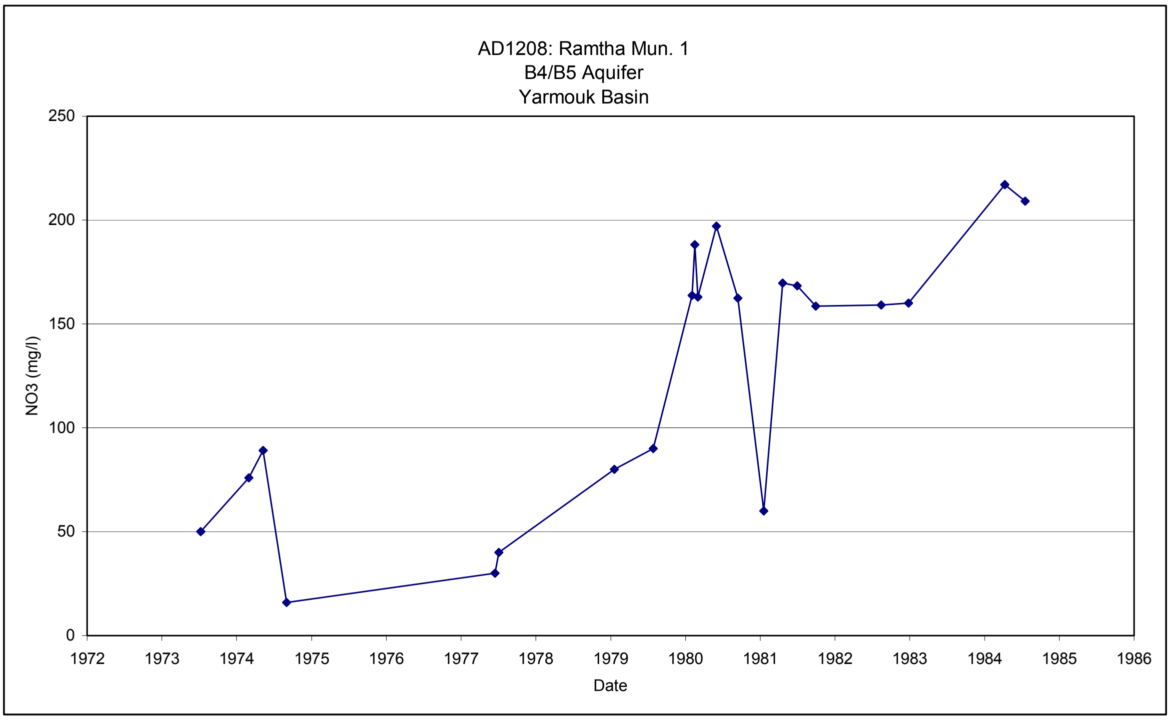

Fig.: 4b Fluctuation of the Nitrate Concentration in B4/B5 aquifer