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

Volume 6

Guideline for Sustainable Groundwater Resources Management

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Guideline for Sustainable Groundwater Resources Management

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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

Table of Contents

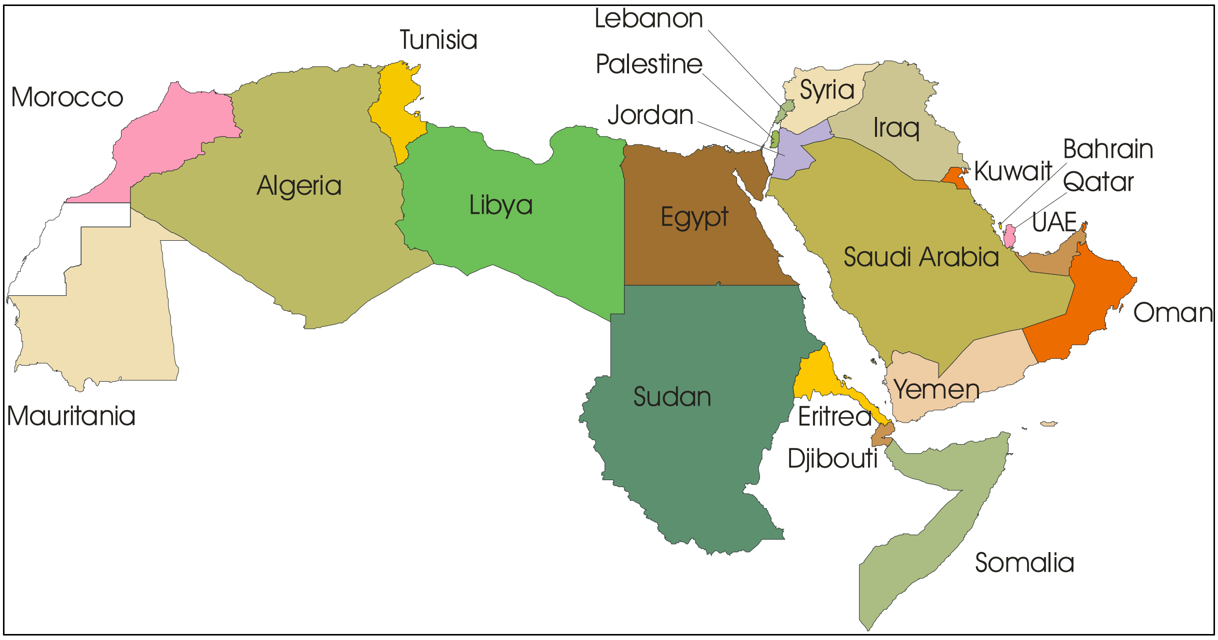
List of Figures

List of Tables

Enclosure: CD with relevant files for sustainable groundwater resources management and files related to this report

ACSAD member countries:

Algeria	Bahrain	Djibouti	Egypt
Eritrea	Iraq	Jordan	Kuwait
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 of 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 ends with its second phase in December 2003.

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

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 is the main goal of the project.

The present report deals with the issue of Sustainable Groundwater Resources Management in ACSAD member countries.

Since the renewable water resources in many ACSAD member countries are very scarce, the sustainable management 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. These effects, however, are mostly observed only several years after abstraction started, provided that sufficient monitoring is carried out. Often this may be the result of an overestimation 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 changed environmental conditions (redox, pH, etc.). Declining water levels may result in increased abstraction costs because wells have to be deepened or relocated frequently.

Additional, non-conventional water resources may be made available for certain uses and the available water resources may be used more efficiently by applying certain techniques, such as rainwater harvesting, artificial groundwater recharge, reduction of leakage losses in the supply and the sewerage network, increasing irrigation efficiency, reuse of treated wastewater, use of desalinated water, etc. Also the demand may be reduced by applying water saving techniques in the domestic, industrial and agricultural sectors.

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, such as industrial sites, oil storage/filling facilities, sewage effluents (treated and untreated sewage), waste disposal sites (legal/illegal), etc. This is noticed especially in urban and heavily industrialized areas.

Groundwater pumping can result in reduced river flows, lower lake levels, and reduced discharges to wetlands and springs, causing concerns about drinking water supplies, riparian areas, and critical aquatic habitats.

In order to manage the water resources effectively concerning quantity and quality, National Water Policies need to be established and implemented. A <u>National Policy on Water Resources Management</u> has to look at issues of water demand management (irrigation, industrial and domestic), water treatment, water reuse, water pricing, and of an integrated resource management (integrated use of surface and groundwater) whereas a <u>National Policy on Water Quality Conservation</u> would cover aspects of water resources conservation, protection and reclamation. An integration of all aspects pertaining to water quality and quantity into land use planning needs to be attained, in order to ensure acceptance of certain decisions (e.g. water tariffs, licensing of abstraction rights, water protection zones, etc.) and to create awareness among others about the existing hydrological and hydrogeological conditions and problems.

As surface-water resources become fully developed, groundwater commonly offers the only available source for new development. Therefore <u>Policies for Groundwater Resources Management</u> are very important.

The aim of this report is to help the adoption of such National Policies and to facilitate the discussion about the long-term strategies and the required measures to avoid the depletion and pollution of the groundwater resources.

To provide an effective protection of the groundwater resources, it is important to convince the land use planning authorities to take the issue of groundwater protection into consideration when deciding about locations and conditions for the establishment of facilities and activities which are possibly hazardous to groundwater, such as waste disposal sites, sewage treatment plants and sewer mains, industrial and commercial estates, storage facilities for oil products and toxic hazardous substances, etc. By locating such sites in areas where contamination cannot occur, deterioration of groundwater resources can be actively avoided.

Part A – Guideline

1 Introduction

The United Nations Conference on Environment and Development – UNCED held in June 1992 in Rio de Janeiro, has become a symbol for the common responsibility of all Governments in the world in achieving a sustainable development. The conference stated that, "The holistic management of freshwater as a finite and vulnerable resource, and the integration of sectoral water plans and programs within the framework of national economic and social policy, is of paramount importance for actions in the 1990s and beyond .... Integrated water resources management is based on the perception of water as an integral part of the ecosystem, a natural resource and social and economic good".

The Agenda 21, the action program accepted by all attending Governments, requests the states to do everything within their possibilities to provide the framework for an environmental friendly and sustainable development. In chapter 21, the concept of a sustainable development pertaining to water resources is laid down (protection of quality and quantity of freshwater resources). In chapter 40 the process of development of an indicator system for sustainable development is described.

The International Conference on Water and the Environment held in Dublin in 1992 set out four principles:

- Principle 1: 'Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment';
- Principle 2: 'Water development and management should be based on a participatory approach, involving users, planners and policymakers at all levels';
- Principle 3: 'Women play a central part in the provision, management and safeguarding of water';
- Principle 4: 'Water has an economic value in all its competing uses and should be recognized as an economic good'.

In 2000 the UN Millennium Summit was held in New York. One of the main goals (goal 7) was to ensure an effective protection of the environment.

Among the goals set forth, the following are the most relevant to water:

- To halve, by 2015, the proportion of people living on less than 1 dollar per day;
- To halve, by 2015, the proportion of people suffering from hunger;
- To halve, by 2015, the proportion of people who do not have access to safe drinking water.

The Millennium Declaration promoted the concept of reducing unsustainable exploitation of water resources by developing water management strategies at regional, national and local levels. A specific target is to have comprehensive policies and strategies for integrated water resources management in the process of implementation in all countries by 2005.

Common issues and strategies pertaining to the water sector were discussed also during the World Water Forums (1st: Marrakech, 1997; 2nd: The Hague, 2000; 3rd: Kyoto, 2003).

The issue of water scarcity and increasing pressures on a vital and vulnerable resource was addressed in the 2nd World Water Forum. Achieving water security was recognized as a global principle. Based on an extensive consultative process, a Vision for 'Water life and the environment', and a 'Framework for Action' were presented at the Forum and formed the basis for a Ministerial Declaration. The Framework for Action was developed by the Global Water Partnership.

The declaration adopted seven challenges as the basis for future action, later adding another four. These have additionally been adopted as the basis for monitoring progress by the World Water Development Report:

1. Meeting basic needs – for safe and sufficient water and sanitation;
2. Securing the food supply – especially for the poor and vulnerable through the more effective use of water;
3. Protecting ecosystems – ensuring their integrity via sustainable water resource management;
4. Sharing water resources – promoting peaceful cooperation between different uses of water and between concerned states, through approaches such as sustainable river basin management;
5. Managing risks – to provide security from a range of water-related hazards;
6. Valuing water – to manage water in the light of its different values (economic, social, environmental, cultural) and to move towards pricing water to recover the costs of service provision, taking account of equity and the needs of the poor and vulnerable;
7. Governing water wisely – involving the public and the interests of all stakeholders;
8. Water and industry – promoting cleaner industry with respect to water quality and the needs of other users;
9. Water and energy – assessing water's key role in energy production to meet rising energy demands;
10. Ensuring the knowledge base – so that water knowledge becomes more universally available;
11. Water and cities – recognizing the distinctive challenges of an increasingly urbanized world.

At the International Conference on Freshwater in Bonn in 2001, which was held in preparation of the World Summit on Sustainable Development in Johannesburg, 27 recommendations were made covering the priority themes of governance, financial resources and capacity building. Five key messages were highlighted: - 1) to meet the security needs of the poor; 2) decentralization of decision making and action to the appropriate level; 3) development of new partnerships and coalitions; 4) co-operative arrangements at river basin level and 5) better performing governance arrangements.

The World Summit on Sustainable Development held in September 2002 in Johannesburg recommended in its “Plan of Implementation” that the proportion of population that could not access appropriate sanitation systems in 1990 should be halved by 2015. It also emphasized that “poverty eradication, changing consumption and production patterns and managing the natural resource base for economic and social development are overarching objectives of, and essential requirements for sustainable development.”

The problems in the water sector are manifold. As an example those identified by the IADB in Latin and Central America are listed below (IADB, 1998). These problems are valid for many developing countries:

- The delivery of water services is typically centralized in government organizations and agencies which are often overextended, underfunded, and ill-organized to provide quality services, resulting, for example, in deteriorated infrastructure and low efficiency.
- Regulatory approaches have been traditionally favored over marketing or other incentive-based approaches. Changes in management have occurred mostly through centralized government and without the participation of the stakeholders.
- In many instances, water resources management legislation includes provisions which may no longer be relevant and may actually constrain new management initiatives. A more significant concern is the general lack of rules and regulations for monitoring and enforcing existing legislation.
- Water resources management often is hindered by a lack of adequate and reliable hydrologic, meteorological, and water quality data, as well as information on socio-economic characteristics and indicators of water use efficiency and, in general, reliable indicators to be used as a basis in conflict resolution.
- High rates of urbanization pose unique problems and challenges to water resource managers.
- Water resources management activities are diffused and fragmented and, more often than not, divorced from environmental management. Water resources management is often hindered by ignoring the many ecosystem functions and services.
- Water resources management often is hindered by shortage of adequately trained human resources at all levels.

2 Definition of Sustainability in Groundwater Resources Management

The definitions of sustainability in the water sector vary strongly and are often not only based on hydrological considerations but are influenced by political and socio-economic as well as ecological issues. A status might be considered sustainable for a certain time period if justified by other factors, such as increased economic or social benefits, even if causing large deficits in the long-term water balance.

The exploitation of water resources may be called sustainable if:

- The water resources are not excessively exploited;
- Water is available in sufficient amounts and quality to fulfill its climatological, ecological and landscape shaping functions;
- The interference with the natural system is as little as possible;
- The water demands and needs of human beings and the environment are met in a socially feasible (equitable), environmental friendly and justified manner.

In general, the use of water resources can only be sustainable if considerably less amounts are being abstracted/used than those which enter the system as renewable resources. The inflows and outflows are highly variable with time. Therefore a balance must be established for a long enough time period. The components entering the system are considered as renewable water resources. When establishing a water balance, all components of surface and groundwater must be looked at. In this context it is important to understand the interactions between surface water and groundwater.

The term sustainability sometimes pertains only to one system, surface or groundwater, in some cases only an individual aquifer. This, however, risks neglecting cross-effects between surface and groundwater. For example, what may be established as an acceptable rate of groundwater withdrawal with respect to changes in groundwater levels may reduce the availability of surface water to an unacceptable level.

When looking at sustainability it is important to state for which area this term is used. Mostly, sustainability refers to a country rather than a hydrologic or a hydrogeological basin or aquifer. However, water does not stop at borders. Water resources in a hydrologic or a hydrogeological basin are commonly used jointly (shared water resources) and part of the water flows from one country to the other (transboundary water resources). The use of shared surface water resources is often regulated by international, multilateral or bilateral treaties. However, groundwater resources are often not considered in this context, even though transboundary groundwater flow may comprise considerable amounts. In modern societies, water is often conveyed over large distances of hundreds of kilometers. Water export into other hydrologic or hydrogeological basins may result in water resources becoming unsustainable in the basin from which water is being exported.

Frequently, countries use the term of safe yield to describe sustainable groundwater resources management. TODD (1959) defines the safe yield of a groundwater basin as the amount of water that can be withdrawn from it without producing an undesired result. The term 'undesired result' refers to depletion of groundwater reserves, intrusion of water of undesirable quality, contravention of existing water rights, deterioration of economic conditions of pumping, and depletion of streamflow. The amount of safe yield therefore highly depends on what is actually considered to be an undesired result. It has to be emphasized at this point that environmental aspects, such as (ground)water pollution (the share of renewable resources lost due to contamination) and the protection of valuable ecological habitats (amount of water required to maintain them) must be included in such calculations, a fact which is all too often neglected.

As the term safe yield is rather vague it is often replaced by using the term 'optimal yield', which is the amount of abstraction which best meets a set of economic and/or social objectives associated with the uses to which the water is to be put (FREEZE & CHERRY, 1979). Consideration of the present and future costs and benefits may lead at some point in time to groundwater mining, if economically and socially justified. In other situations, the optimal groundwater development may reflect the need for conservation. Most commonly, the optimal yield lies somewhere between these extremes.

When considering sustainable management of an aquifer, the sustainability of confined aquifer systems is typically controlled by the hydraulic connection with other aquifer systems. WALTON (1970) defined the 'practical sustained yield' of an aquifer as the maximum amount of water that can be continuously withdrawn without eventually dewatering the most productive water-yielding formation. By increasing the number of pumping centers, shifting centers of pumping towards the recharge area, and spacing wells at greater distances, the management of a resource can be optimized.

SOPHOCLEOUS (1997) proposes to use the term 'sustainable yield' instead of 'safe yield', which from his point of view is misleading. He suggests using a stream-aquifer model capable of generating the transition curve from groundwater storage release to induced recharge, coupled with a projected pattern of drawdown for the system under consideration. The level of groundwater development would be calculated using specified withdrawal rates, well field locations, drawdown limits, and a defined planning horizon.

The preparation of action plans for sustainable development needs to follow a distinct procedure, as laid down in Agenda 21, chapter 40. First common goals have to be formulated and indicators developed which describe facts reached upon achieving these goals. The comparison between the actual situation and these indicators shows where and which actions are required. All conditions governing these indicators have to be included in the formulation of actions: the natural and technical conditions, the political, financial, legal and social (socio-economic) conditions and the ecological conditions.

The World Water Assessment Program (WWAP) of UNESCO which issues the World Water Development Reports (WWDR) has developed a number of indicators to monitor the success of implementing these principles around the world (UNESCO, 2003: 29-60). Likewise National Policies to be developed for sustainable water resources management in the ACSAD member countries should be evaluated at defined time intervals for their level of implementation and their effectiveness in reaching sustainability.

The following indicators for a sustainable development in the water sector are most commonly formulated:

- Water for human beings and the environment is provided in sufficient amount and quality;
- Water resources are allocated in such a way that no negative long-term effects for the society, the economy and the environment can occur;
- The emission of hazardous substances into the environment is minimized;
- The water resources are protected against pollution.

The following activities are often formulated in context with reaching a sustainable development in water resources management:

- conserve water through more efficient ways to allocate the resource giving due consideration to social equity issues;
- find better ways to solve conflicts among competing uses and users, including environmental uses and freshwater ecosystem functions and services;
- account for the social, economic and environmental value of water in the process of sustainable development and
- increase the participation of communities and the private sector in decision-making and financing.

Water resources availability is often 'measured' as available amount per capita per year (UNCSD, 1997). The water availability classification generally used so far by UN organizations is as follows (UNESCO):

- ≤ 1,000 m^3/ca/yr – catastrophically low
- 1,000 to ≤ 2,000 m^3/ca/yr – very low
- 2,000 to ≤ 5,000 m^3/ca/yr –low
- 5,000 to ≤ 10,000 m^3/ca/yr – medium/average
- 10,000 to ≤ 20,000 m^3/ca/yr – high
- > 20,000 m^3/ca/yr – very high

The UNHCR demands a minimum of 15 l/day to be available for every person. In sharp contrast to this stands the statement of the UNESCO (2003) WWAP that an annual per capita water requirement of 1,700 m^3 (4,600 l/day) of drinking water is "necessary for active and healthy life". According to PACIFIC INSTITUTE FOR STUDIES IN DEVELOPMENT, ENVIRONMENT AND SECURITY (1999) the average person needs a minimum of 50 l of water per day, with 5 l for drinking, 10 l for cooking, 15 l for bathing and 20 l for sanitation needs.

The percentage of water use is commonly used to indicate the level of 'water stress' ('Water Stress Index' or 'Falkenmark-Index':

- low water stress: use of less than 10% of available resources;
- moderate water stress: use of 10-20% of available resources;
- medium-high water stress: use of less than 20-40% of available resources;
- high water stress: use of more than 40% of available resources.

This Water Stress Index has, outside the UN organizations, little practical application since it does not take into consideration other socio-economic factors.

Following the Bonn Freshwater Conference 2001, the WWAP is in the process of developing a new index, which more realistically reflects the water scarcity in relation to a society's ability to cope with it, the 'water poverty index' (WPI). The purpose of the WPI is to provide decision-makers with an evaluation tool for assessing poverty in relation to water resource availability. The five key elements of the WPI are:

- resource: physical availability of surface and groundwater;
- access: the extent of access to this water for human use;
- capacity: the effectiveness of people's ability to manage water;
- use: the ways in which water is used for different purposes; and
- environment: the need to allocate water for ecological services.

Another index proposed in recent years is the Social Water Scarcity Index (SWSI) which is obtained by dividing the Water Stress Index by the Human Development Index (HDI). The HDI is based on life expectancy, education and per capita GNP. Using this index, countries such as UAE and Oman would move from water scarce to water stressed, whereas countries like Burkina Faso, Nigeria and Eritrea would move from relative sufficient to water stressed, and Ethiopia from water stressed to water scarce countries.

3 Factors Influencing Sustainability in Groundwater Resources Management

3.1 Aspects related to the Hydraulic Regime and Protection of the Aquifer System

An analysis of the general water balance encompasses all main components. Principally precipitation equals surface water runoff plus evaporation. Therefore, the balance in its simplest form reads:

precipitation = evaporation + runoff (surface and groundwater)

In a comprehensive water balance, however, all inflows and outflows have to be considered, such as inflows into groundwater (e.g. injections, irrigation return flow, return flow from leakage losses of sewage collection/treatment systems and water supply networks), discharges into surface water (e.g. effluents), groundwater discharges (spring flow, baseflow), transboundary inflows and outflows (of surface and groundwater as well as imports and exports) and changes in (groundwater) storage. Outflows must equal inflows plus or minus storage. Over long enough time periods the storage term is usually neglected because the water balance would adapt to storage changes, i.e. all water that is stored or withdrawn from storage must finally appear somewhere else. When all inflows and outflows are integrated into the water balance it reads:

$$P = E + R + GWA + SWA + TRO - GWR - GWI - SWD - TRI\ (\pm STO)$$

<u>inflows (-)</u>:

GWR	=	Groundwater recharge (natural and return flows)
GWI	=	Inflow into groundwater (injections, return flows)
SWD	=	Discharge into surface water (effluents from STPs, including surface water inflows)
TRI	=	Transboundary inflow (including water imports)

<u>outflows (+)</u>:

E	=	Actual evaporation (including evaporation from surface and groundwater)
R	=	Runoff (i.e. direct runoff + baseflow, corrected for other inflows; surface water outflows)
GWA	=	Groundwater abstraction (including spring abstractions)
SWA	=	Surface water abstraction
TRO	=	Transboundary outflow (including water exports)

Groundwater plays an increasingly important role in the water sector. It has a great areal distribution and is available even in areas where there is no surface water. It can be progressively developed at the place where it is needed, so that the costs for exploitation and infrastructure are often less compared to surface water. It is more or less constantly available with very little variability, independent of seasonal climatic changes so that droughts have little impact on water availability. The water quality is generally good and, at least in the past, less affected by pollution.

Human activities, such as groundwater withdrawals and irrigation, but also any change in the land use, alter the natural flow patterns, and these alterations must be accounted for in the calculation of the water budget and in any management decision. Understanding water budgets and how they change in response to human activities is an important aspect of groundwater resources management.

Groundwater withdrawals and replenishment by recharge usually are variable both seasonally and from year to year. Also other factors of the water budget are subjected to short and long-term changes. These must be taken into account in water balances. They must be established over long enough time periods during which the conditions in the area were relatively constant.

The amount of surface and groundwater which is actually technically manageable for development depends on the location and the ecological functions (that may impede water usage; *Figure 1*).

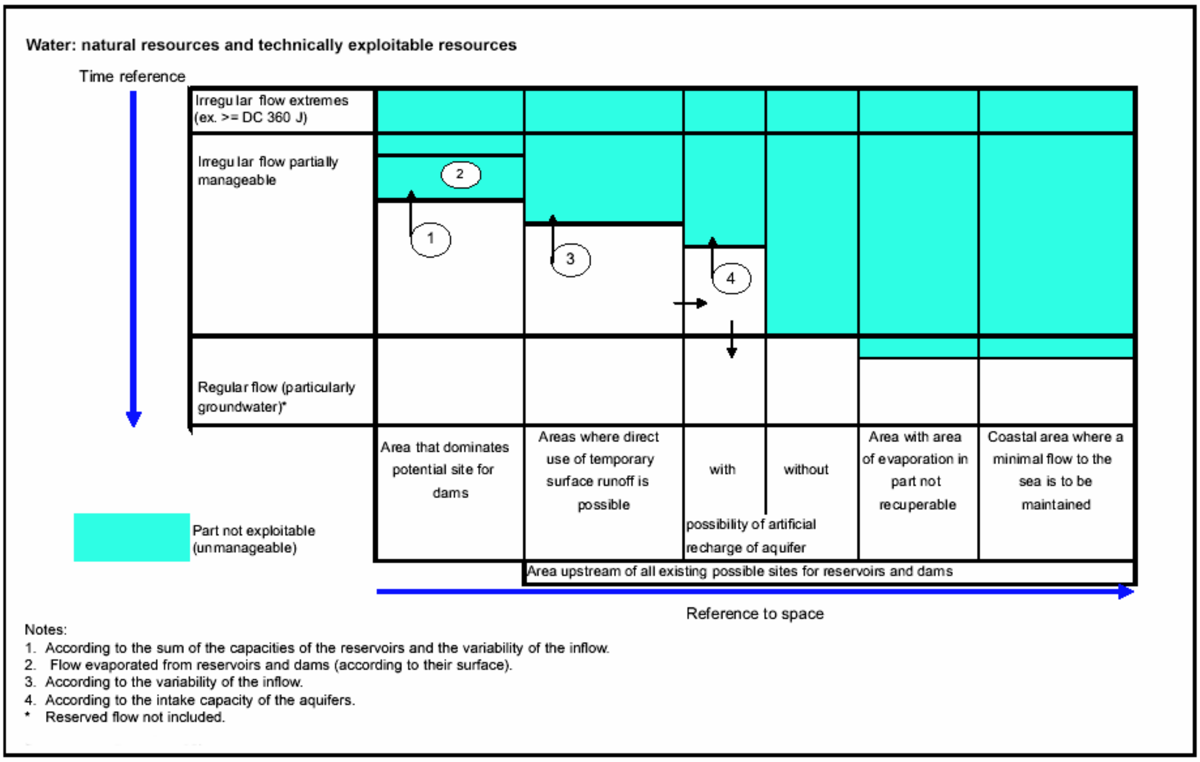


Figure 1: Exploitability of Water Resources (after FAO, 2003)

Effects of Groundwater Pumpage

When pumping from a groundwater system, the natural flow conditions are changed. The initial response to withdrawal of water is a change in storage. But also the discharge from and recharge to the system are affected. For most groundwater systems, the change in storage in response to pumping is a transient phenomenon that occurs as the system readjusts to the pumping stress. The relative contributions of changes in storage, changes in recharge, and changes in discharge evolve with time. The effects of groundwater pumping tend to manifest themselves slowly over time. Therefore sufficiently long enough monitoring records are needed for an evaluation of the long-term effects of abstraction.

An increase in groundwater abstraction sometimes results in an increase in groundwater recharge, if the water stays in the same balance area, due to decreased evapotranspiration from groundwater or due to increased storage capacities in the unsaturated zone when the water level is declining (only valid in areas where the water level under natural conditions is shallow, i.e. < 4 m), due to return flows from irrigation and leakage losses in the water supply and sewerage network and due to infiltration of effluents from sewage treatment plants (see *Figure 2*). But in most cases a considerable amount of the abstracted water is lost to evapo(trans)piration. When the water levels are declining the natural vegetation cover may also change.

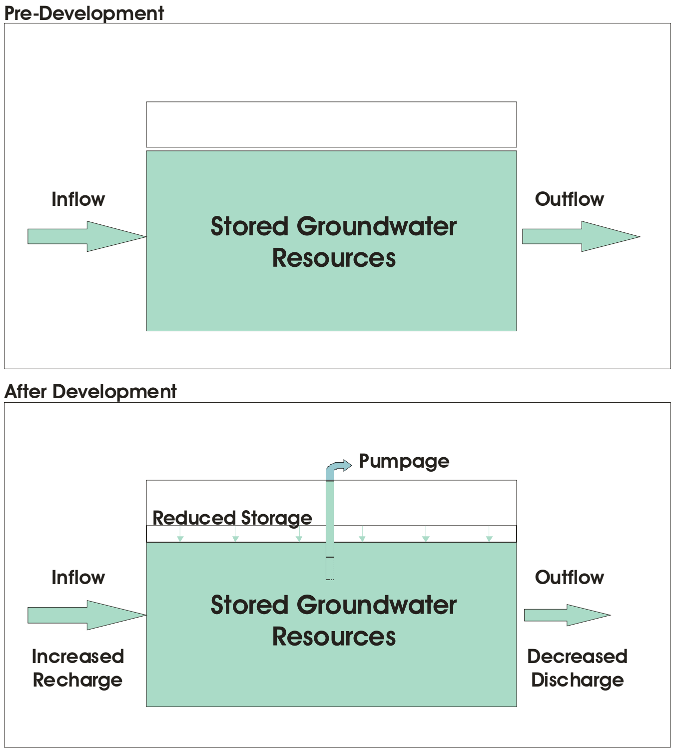


Figure 2: A – Groundwater System under Pre-Development Conditions where Inflow Equals Outflow, B – Effects of Groundwater Abstraction on a Natural Groundwater System (modified after ALLEY et al., 1999)

Short and Long-Term Changes in Water Budget Factors

Especially in countries with high regional climatic variations water resources are unevenly distributed. Besides climatic conditions, the availability of surface water resources depends on a number of factors like vegetation cover, soil, land use, slope and geology (flow pattern, baseflow, river bank storage and temporal storage in alluvial aquifers), whereas the availability of groundwater resources is influenced by the infiltration capacity (recharge), the water storage capacity (effective porosity), the ability to transmit water (hydraulic conductivity), the slope, the lithology and the tectonic setting. Changes to these factors may have considerable effects on the overall balance. Short-term changes to the climatic conditions can result in catastrophic events such as inundations or droughts. Groundwater resources tend to respond more slowly to short-term changes than do surface water resources. The effects of long-term changes to the climatic conditions are noticeable even today. In many areas with large aquifer systems which were recharged during the last glacial period, part of today's baseflow can still be attributed to discharge of this fossil water. A long-term management plan needs to take into consideration such risks inferred by climatic variations and variations of other factors that influence the long-term water balance. Sensitivity studies for the possible influence of all factors should be conducted.

Declines in head in a confined aquifer can cause the movement of poor quality water from surrounding aquifers (or confining units), which may limit development of the aquifer. As a result of groundwater development saltwater or brackish water intrusion, an influx of chemical substances or hydrochemical processes may occur in the aquifer due to the changed hydraulic and environmental conditions (redox, pH, etc.). For example, the decline of water levels is supposed to be the main driving force behind increased arsenic contents in groundwater in Bangladesh, India and elsewhere.

Impacts of Groundwater Pollution by Point Sources and Non-Point Sources

Common problems related to groundwater quality in the Arab region are described by PLOETHNER (1997). A major quality concern is the naturally high salinity in the semi-arid to arid parts of the region due to the very limited groundwater recharge. In addition to such natural constraints, groundwater quality has continuously deteriorated in many areas as a result of human activities. Groundwater quality problems especially occur:

- in the coastal zone, where the coastal aquifers are overexploited resulting in saltwater intrusion (e.g. Nile Delta/Egypt; Beirut, Chekka/Lebanon; between Saudi Ad Dahna Sahara and Qatar; Fujayrah/Bahrain/UAE; coastal zone of Oman; Tihama coastal plain/Yemen; Ras al Jabal/Tunisia);
- in areas where the hydraulic gradient is lowered in such a way that down or upward leakage from other aquifers results in the transport of highly saline or brackish water into a freshwater resource (e.g. Minjour aquifer/Riyadh/Saudi Arabia);
- in urban areas, which are not sufficiently connected to sewage collection and treatment systems or where large quantities of wastewater are infiltrating into groundwater due to leakage losses from the collection system (Amman/Jordan, Damascus and Aleppo/Syria; Gaza/Palestine; Cairo/Egypt; Sana'a/Yemen; etc.);
- in highly cultivated areas, where fertilizers and pesticides are applied in abundance (often less than 50% of the fertilizers are recovered by the plants), resulting in pollution by nitrate and pesticides (e.g. area NE of Mafraq/Jordan) and where due to inefficient irrigation methods or insufficient drainage large quantities of saline water infiltrate into the groundwater as irrigation return flow (e.g. Wadi Dhuleil/Jordan; Nile Valley/Egypt). The use of untreated or insufficiently treated wastewater for irrigation is also rather common in the Arab region;

- in industrial and commercial zones with non-existing or ineffective collection and treatment of often hazardous sewage water (e.g. Amman-Zarqa/Jordan);
- in the downstream area of waste disposal sites. Such sites are often not located upon geological criteria and the underground is permeable so that leachate can infiltrate into groundwater. There are usually no base liners, covering systems and leachate collection and treatment systems that would prevent infiltration (e.g. Ruseifa/Jordan);
- in the downstream area of mines exploiting and processing mineral resources by processes possibly hazardous to groundwater.

The highest risk in urban areas is associated with sewage water. Commonly the collection and treatment is insufficient and results in the direct infiltration and pollution of the underlying groundwater resources (Amman, Damascus, Aleppo, etc.). Often springs located in the downstream area are rendered unusable for public drinking water supply because of bacteriological contaminations. In the rural agricultural areas, increasingly high nitrate contents and total dissolved solids (TDS) values are an indication for poor agricultural management methods and careless use of water.

Effects of Land Use

Any change in the land use can result in changes in the water balance or bring about changes in the groundwater quality, for instance

- The sealing of the land surface by infrastructure and buildings results in increased runoff and decreased infiltration;
- The conversion of land from forest to agricultural or bare land (or any other decrease in vegetation cover) results in increased groundwater recharge (decreased evapotranspiration).

The possible negative effects on the environment must be carefully analyzed and maximum acceptable limits (thresholds) defined at which effects become undesirable.

As can be seen from the above, the number of factors influencing the water balance is considerable and can only be analyzed effectively by computer models which integrate all these factors. Such <u>management and decision support tools</u> are presently under development (compare *Chapter 4.2*) and should also be the basis for land use decisions.

The management of water resources is highly influenced by decisions made by other policy makers involved in the land use planning process. The agricultural land use, the construction of infrastructure, waste disposal sites, industrial estates, sewage treatment plants and networks, etc., may lead to a degradation or depletion of the water resources. Therefore an <u>Integrated Water Resources Management</u> (IWRM) is very important. It involves the coordinated planning and management of land, water, and other environmental resources for their equitable, efficient, and sustainable use.

IWRM strategies seek to ensure:

- A long-term, viable economic future for basin dependents (both national and trans-national);
- Equitable access to water resources for basin dependents;
- The application of principles of demand management and appropriate pricing policies to encourage efficient usage of water between the agricultural, industrial, and urban supply sectors;
- In the short term, the prevention of further environmental degradation and, in the longer term, the restoration of degraded resources;
- The safeguarding of the local cultural heritage and the local ecology as far as they relate to water management and the maintenance and encouragement of the potential for water-related tourism together with linkages between tourism and conservation.

IRC (1999) names eight key principles in IWRM:

1. Water source and catchment conservation and protection are essential;
2. Water allocation should be agreed between stakeholders within a national framework;
3. Management needs to be taken care of at the lowest appropriate level;
4. Capacity building is a key to sustainability;
5. Involvement of all stakeholders is required;
6. Efficient water use is essential and often an important source in itself;
7. Water should be treated as having an economic and social value;
8. Striking a gender balance is essential.

3.2 Socio-Economic Aspects

Provision of Water in Sufficient Amount and Appropriate Quality

There is considerable pressure on water resources managers from all sectors due to population growth, agricultural development needs and industrial growth.

The entire population needs to be supplied with water of suitable amount and quality. Water must be affordable for poorer people, i.e. water tariff must take into account their average income.

Population growth has a considerable influence on the long-term sufficiency of water resources to meet the growing demand. Population growth increases the demand for agricultural products and therefore the water demand for agriculture. The same counts for political changes which may cause considerable instabilities in respect of water demand and availability as may be also the case e.g. through conflicts between nations or civil wars. Also globalization brings about considerable changes in agricultural and industrial production as well as the life style, thereby changing water consumption patterns.

With increased demands, especially for urban growth centers, often the need for water imports from far away areas, where unused surface or groundwater resources are available, arises (e.g. planned water supply of Amman from Disi/Mudawwara well field or of Damascus from Euphrates River or coastal zone). This import may bring about conflicts between users from both areas, from where the water is being imported and where it is being used, even conflicts/disputes between nations, if transboundary resources are involved (e.g. Turkey/Syria/Iraq: use of Euphrates/Tigris River water; Nile Basin: use of Nile River water).

Mostly water consumption for domestic purposes is considerably less compared to agricultural purposes. Concerning water demands for agriculture, affordable supply of water is also one of the main constraints for poorer farmers. Therefore, the same principles concerning water tariffs should be applied in irrigation as in domestic water supply. Water resources development programs in the agricultural sector must acknowledge the overall water resources availability and demands of the other sectors.

Even though until now comparably low, water resources for the industrial sector are growing. Water use in this sector should be governed, like in all other sectors too, by the principle of efficient and environmental-friendly use (clean production technology). Not all water used in the industrial sector needs to fulfill water quality standards like in the domestic sector. The use of treated wastewater or water recycling should be supported.

Protection against Water-Born Diseases and Health Hazards

The consumption of water may result in water-born diseases and health hazards, caused by bacteriological or viral infections, by other pathogens (e.g. worms), by radiological contamination (natural or man-made) or by substances contained in the water which are hazardous or toxic for human consumption (or consumption by animals). Hazardous or toxic substances may either be found in water under natural conditions or resulting from human activities. The sources of pollution must be carefully evaluated and countermeasures immediately undertaken in order to prevent a spreading of pollution as clean-up operations of contaminated groundwater resources are extremely difficult and costly. A (ground)water resources management plan has to take into consideration where such hazards occur and exclude such water resources from water usage, unless sufficiently treated.

Pollution reduces the total available amounts of water resources and has therefore a considerable impact on resources management.

Protection against Drought Periods

The high climatic variability brings about often severe events of drought. A careful and sustainable planning must provide for sufficient water supplies even during such periods for all kinds of uses. The variability and occurrence in space and time must be thoroughly investigated in order to be able to integrate this factor into a (ground)water resources management plan. Early warning systems against hazards such as periods of drought should be an integral part of a water resources management plan.

Protection against Inundations

The same applies to the other climatic extreme, which can result in flooding. Measures against inundation comprise large enough retention reservoirs (dams) and levees along rivers. Mostly reservoirs are erected upstream of confluences of major rivers. A possible negative effect of such reservoirs is that they increase evapo(transpi)ration and may cause soil salinization in the surrounding of the reservoir. Such effects must therefore be analyzed before implementation.

Tourism and Recreation

Water provided for touristic purposes mostly accounts for only a few percent of total water consumption. Water, however, plays also a prominent role for tourism and recreation since it often is the source of scenic landscapes, thereby attracting tourists. Such tourist and recreation spots comprise springs, wetlands, river courses and lakes. If it is in the national interest to further tourism and recreation, these places need to be preserved in good conditions. Often this is achieved by declaring nature preservation areas, resulting in certain restrictions for other land uses. The water needs for these uses need to be taken into consideration in a (ground)water resources management plan.

3.3 Ecological Aspects

Climatology

In many areas, especially those of the Arab region, the climate is highly variable, causing on the one hand long periods of drought, but on the other hand also resulting in severe flooding event. It is difficult to manage such variabilities properly and take them into consideration in a (ground)water resources management plan. Changes in the local water budget may result in considerable micro or regional climatic changes.

What is often no taken sufficiently into account in water balances is the fact that a large share of the water resources stored in aquifers is of fossil origin. It is often wrongly assumed that the groundwater which is presently discharged at springs, in river courses or in topographic depressions is an expression of the actual natural replenishment. However, groundwater flow velocities are very slow in comparison to surface water, sometimes below 1 m/year. In aquifers of large extent it may therefore take extremely long time until groundwater reaches the discharge area, in some cases several thousand years. Discharge at a far away point may therefore often be completely or partly of fossil origin.

Biodiversity and Wildlife Protection

In case of water resources overexploitation individual species might be at risk of extinction in wetland areas or other landscapes depending on water (e.g. the Oryx antelope in the Azraq oasis of Jordan). In order to keep such endangered species alive, the environmental conditions have to be maintained.

The protection of the wildlife largely depends on the conservation of the habitat for species. Water abstraction from surface or groundwater may significantly change the environmental conditions in those habitats and thus endanger the therein living species. If the conservation and protection of such wildlife is a national policy, (ground)water resources management has to take the support for such habitats into consideration.

Forest Conservation

Forests underlie considerable stresses in the Arab region, due to water scarcity and high climatic variability. Forests in previously extensively forested areas were cut during the past century and before (e.g. the official present-day forest cover in Syria is 1.3%). Afforestation is very difficult and needs to be supported by efforts to provide sufficient amounts of water to the vegetation in order to survive in the long term. The deforestation in many parts of the Arabian region has led to soil erosion in higher topographic areas and to a reduction of evaporation because water can more easily infiltrate and less water is consumed by evapotranspiration. The former vegetation and soil cover has played an important role for the microclimate and the retention of water. Due to this fact, the discharge of surface water today is taking place much faster which in turn may cause flooding events to occur much more frequently.

Consumption of Natural Resources

The exploitation of mineral resources can cause severe damages to the environment, especially to the water resources. The dissolution of hazardous substances from mine tailings, the discharge of hazardous substances from mineral resources processing plants and the lowering of water levels for opencast mines are only three such examples. Contaminations may spread over vast areas, sometimes rendering entire aquifers unusable for certain uses, especially for drinking purposes.

Mineral resources exploitation may also have a number of other effects on the environment, such as increased landslide risk, spreading of aerosols containing hazardous substances, etc.

The pollution of groundwater resources contributes significantly to the reduction in the availability of (ground)water resources (of suitable quality).

4 Methods to Evaluate Sustainability in Groundwater Resources Management

For a comprehensive assessment of the groundwater resources the following steps are needed:

- Determination of extent, thicknesses and saturation limits of aquifers and aquitards in the groundwater system;
- Determination of hydraulic properties and characterization of groundwater flow;
- Identification of groundwater exploitation potentials;
- Assessment of groundwater quality;
- Assessment of groundwater vulnerability to pollution and of hazards to groundwater; assessment of land use;
- Evaluation of threats to the (ground)water system (pollution risk; depletion risk; threats to ecological habitats; etc.);
- Determination of possibilities of artificial groundwater recharge and its possible impact on the quality of the natural water resources;
- Assessment of socio-economic factors influencing water management policies.

4.1 Data Required

4.1.1 Data Required for Hydrological and Hydrogeological Assessments

Physical Information

- Topographic maps showing the stream drainage network, surface water bodies, land uses, social and cultural features, and locations of structures and activities related to water (land use maps and databases);
- Geologic maps of surficial deposits and bedrock;
- Hydrogeological maps showing extent and boundaries of aquifers and confining units;
- Maps of tops and bottoms of aquifers and confining units;
- Saturated thickness maps of unconfined (water table) and confined aquifers;
- Average hydraulic conductivity maps for aquifers and confining units and transmissivity maps for aquifers;
- Maps showing variations in storage coefficient for aquifers;
- Estimates of age of groundwater at selected locations in the aquifers.

Hydrologic Information

- Long-term precipitation data, and their variability over time and space;
- Long-term evaporation data, and their variability over time and space;
- Long-term streamflow data, including measurements of gain and loss of streamflow between gauging stations, and their variability over time and space;
- Maps of the stream drainage network showing extent of normally perennial flow, normally dry channels, and normally seasonal flow;
- Long-term estimates of total groundwater discharge to streams, and their variability over time and space;
- Measurements of long-term spring discharges, and their variability over time;
- Long-term measurements of surface water diversions and return flows;
- Quantities and locations of inter-basin diversions;
- Historical and spatial distribution of pumping rates in aquifers, and their seasonal variability;
- Amount of groundwater consumed for each type of use and spatial distribution of return flows;
- Well hydrographs and historical piezometric head (water level) maps for all aquifers;
- Location of recharge areas (areal recharge from precipitation, losing streams, irrigated areas, recharge basins, and recharge wells), and estimates of long-term recharge.

Chemical Information

- Geochemical characteristics of earth materials and naturally occurring ground water in aquifers and confining units;
- Spatial distribution of water quality in aquifers, in vertical and horizontal direction;
- Temporal changes in water quality, particularly for contaminated or potentially vulnerable unconfined aquifers;
- Sources and types of potential contaminants (where, when and what for used);
- Chemical characteristics of artificially introduced waters or waste liquids/leachate;
- Maps of land cover/land use at different scales, depending on study needs;
- Streamflow quality (water-quality sampling in space and time), particularly during periods of low flow;

Other Data (related to Agricultural and Industrial Water Demands)

- Irrigation water demand, and its variability over space and time (seasonal pumping pattern);
- Cultivated crops, and variability of cropping patterns and cultivation methods over time and space;
- Irrigation methods, irrigation efficiency;
- Soil degradation and its occurrence over space and time;
- Industrial water demand, and its variability over space and time (seasonal pumping pattern);
- Share and type of water used (recycled water, treated wastewater, etc.) and their variability over space and time.

4.1.2 Data Required for Socio-Economic Supporting Assessments

- Population numbers, and their spatial distribution variability (growth, migration trends) over time and space;
- Distribution of income; trends;
- Statistics on access to safe drinking water and sanitation;
- Statistics on water related health hazards and water-born diseases; trends;
- Water tariffs and other fees and costs related to water use;
- Events of drought, places of occurrence, time duration and effects on population (maps, database);
- Events of flooding, places of occurrence, time duration and effects on population (maps, database);
- Statistical data on tourism; places visited and level of attractiveness.

4.1.3 Data Required for Ecological Supporting Assessments

- Data about endangered species and their relation to the occurrence of water;
- Wildlife protection areas (maps and supporting information);
- Forest protection areas (maps on forest classification/protection areas and supporting information);

- Mineral resource occurrence and exploitation (maps, data on exploited amounts, lists of substances used in the extraction and processing); evaluation of the possible impact on water resources.

4.2 Technical Methods

Previously, water resources assessments and management decisions were often facilitated by Water Master Plans. These plans were, however, mostly available as hardcopies and therefore not easy to update regularly. Over the past decade digital versions of water master plans were developed using modern database and GIS techniques. A good example is the digital water master plan of Jordan that has recently been established with the support of German development aid.

Decision Support Systems (DSS) have been developed over the past decade with the aim to facilitate decision-making processes in the water sector and a large variety of such systems has been established. Most of these tools are designed for specific issues of water use, such as

- DSS for surface water distribution for agricultural uses (irrigation water management);
- DSS for groundwater resources development (e.g. groundwater flow models);
- DSS for groundwater protection and quality conservation (e.g. solute transport models);
- DSS for water distribution networks;
- DSS for water resources allocation (in agriculture, for domestic water or for the entire water sector).

The development of models which try to integrate all aspects related to integrated and sustainable water resources management has, however, only just started. The following chapter gives an overview over some of these models.

4.2.1 Selected Examples for Decision Support Systems

CDSS – Colorado’s Decision Support Systems

(source: http://cdss.state.co.us/index.asp)

The Colorado's Decision Support Systems (CDSS) were developed to provide credible information on which to base informed decisions concerning management of Colorado's water resources. CDSS is sponsored by the Colorado Water Conservation Board (CWCB) and the Colorado Division of Water Resources (DWR), under the overall guidance of the Colorado Department of Natural Resources (DNR).

It is composed of the following elements:

- HydroBase is the CDSS and DWR's central database, is the heart of Colorado's Decision Support Systems, containing the following:
    - Real-time streamflow and call data;
    - Historic data such as streamflows, water rights, diversions, climate, well permits, etc.;
    - Geographic locations of stream gages, water rights, climate gages, etc.;
    - Database subsets are available by water division and district for use on PC.
- Planning models simulating surface water (StateMod) and groundwater (MODFLOW) flows, and consumptive use (StateCU);
- Data Management Interfaces (DMIs) allow CDSS data to flow from a database to a model using an automated data-centered approach;
- Water Right Administration Tool provides real-time and historic administrative data;
- Geographic Information System showing all physical data and model results.

The CDSS Surface Water Model StateMod, is a water allocation model used to analyze historic and future water management policies. It includes the following:

- Generic data-driven application of the Prior Appropriation Doctrine to water allocation;
- Graphical user interface (GUI) for editing data, running the model, and presenting output;
- Monthly and daily simulation capability;
- Calibrated data and documentation for each CDSS basin.

WaterWare

(source: http://ncl.ac.uk/wrgi/wrsrl/index.html)

WaterWare is the outcome of EUREKA EU 487, a collaborative research program involving three universities, a research institute and two commercial companies. The aim was to develop a comprehensive, easy-to-use decision-support system (DSS) for integrated river basin planning which would be capable of addressing a wide range of issues such as:

- determining the limits of development;
- evaluating the impact of new environmental legislation;
- deciding what, where and when new resources should be developed;
- assessing the environmental impact of water-related development;
- formulating strategies for river and groundwater pollution-control schemes;

- etc.

WaterWare is a software developed by the Water Resource Systems Research Laboratory (WRSRL) and Environmental Software and Services (ESS) as an integrated, model-based information and decision and support system for water resources management. It is implemented in an open, object-oriented architecture, and supports the seamless integration of databases, GIS, models, and analytical tools into a common, easy-to-use framework. This includes a multimedia user interface with Internet access, a hybrid GIS with hierarchical map layers, object data bases, time-series analysis, reporting functions, an embedded expert system, and a hypermedia help- and explain system. The system integrates information systems components built around a hybrid GIS and object-oriented data bases with a multi-media interface.

Linked to this data layer are a set of models, which can perform scenario analysis, i.e., answer WHAT-IF and HOW-TO questions for various water quantity and quality issues, as well as related engineering, environmental, and economic aspects. WaterWare includes a number of simulation and optimization models and related tools, such as:

- a rainfall-runoff and water budget model;
- an irrigation water demand estimation model;
- a graphical river network editor;
- dynamic and stochastic water quality models;
- a groundwater flow and transport model;
- a water resources allocation model;
- an expert system for environmental impact assessment.

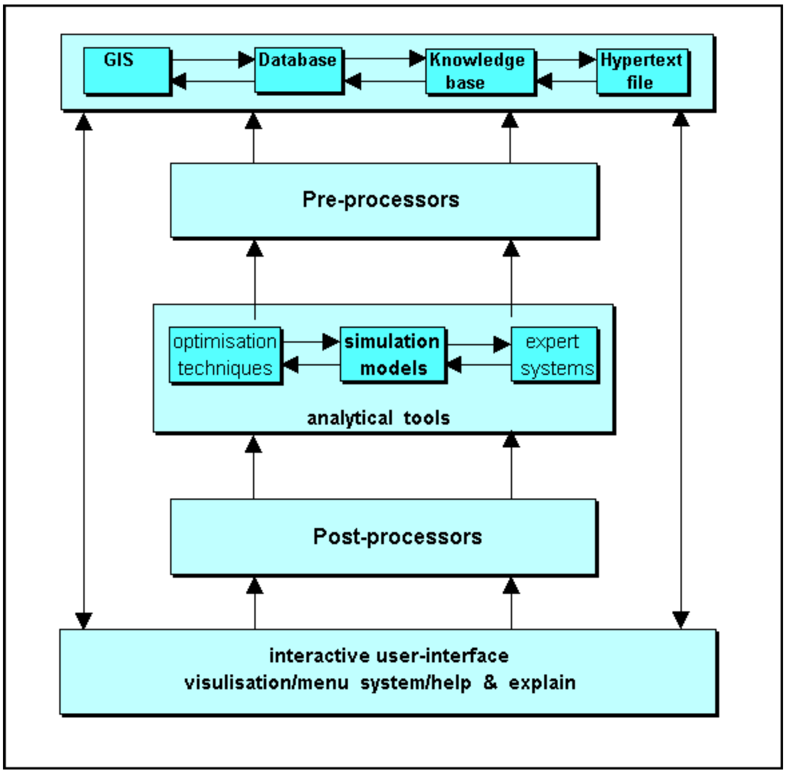


Figure 3: Structure of WaterWare Modeling Software.

These tools are embedded into a user interface that translates the specific functionality of a given model into a decision support tool: the components models and tools are restructured in terms of decision variables and performance variables, relating to the objectives, criteria, and constraints of various decision problems.

WaterWare is a modular and data driven system. It can be configured for customized installation with different sets of models and tools. Through shared data formats, and the respective filter programs, third-party tools can be used with the system for special tasks, for example, image processing or statistical analysis of observation data. Standard interfaces to data bases and the GIS make the integration of additional new models easy.

RiverWare

(after ZAGONA et al., 1998)

A general river basin modeling environment for operations and planning requires a high degree of software flexibility to allow users to model any river basin, manage data input and output efficiently enough for near real-time operations, and provide a selection of solution algorithms, all through a user-friendly interface. RiverWare is an extensible, maintainable software framework which provides a modeling environment to meet all the modeling needs of managers and operators of river and reservoir systems.

To meet this challenge, the U.S. Bureau of Reclamation (USBR) and the Tennessee Valley Authority (TVA) are investing in a project with the Center for Advanced

Decision Support for Water and Environment Systems (CADSWES) at the University of Colorado (CU) in Boulder to develop a general river basin modeling tool which can be used for a wide range of applications. The tool, called RiverWare, has been developed and applied to several basins by the two sponsoring agencies, and continues to be enhanced and improved.

To meet the goal of providing a modeling tool that can be applied to any river basin for both operational and planning applications, the RiverWare software was designed to meet the following general requirements:

- Be flexible enough to use for a variety of applications including daily scheduling, operational forecasting and long-range planning. This requires a range of time step sizes and appropriate physical process modeling variability to support this range.
- Support various modeling solution methodologies. An organization's decision as to which basic modeling approach to use, simulation or optimization, depends on the specific goals of the model as well as the traditional way of looking at their system. Offering a variety of approaches allows each organization to continue historical practices as well as explore new approaches.
- Allow tailoring of applications by providing many basin features and many alternative methods for modeling these features. Even more important than the range of available features and methods is the extensibility of the software to provide ease in adding new methods. It must be recognized that there will always be applications that require enhancing the software and that most agencies have some computational methods to which they are wedded for institutional reasons.
- Represent policy as input data. Many older models are obsolete because the operating policies were hard-coded and mixed in with the physical process model where they cannot be easily changed, or in some cases, cannot even be understood. Easy policy evaluation and modification by the user must be seen as a basic requirement for all new modeling tools.
- Provide an easy-to-use interface. A water resources engineer should be able to build, run and analyze model results relatively quickly, easily and without excessive training requirements. An operations scheduler should be able to view selected data in a convenient format, make changes to the operation, rerun the model and analyze results quickly.
- Fit into existing data and model interfaces. Every water management organization has an existing framework of databases, real-time data, supporting models, reporting tools, etc. to which the model must be connected. A general modeling tool must be flexible enough to tailor the application to any existing or changing configuration.
- Be supported by an organization which provides continued maintenance, enhancements, user support and technology transfer.

Currently, the RiverWare palette contains the following objects and the main water quantity physical processes which they model in a river basin:

- *Storage Reservoir* - mass balance, evaporation, bank storage, spill;
- *Level Power Reservoir*- Storage Reservoir plus hydropower, energy, tailwater, operating head;
- *Sloped Power Reservoir* - Level Power Reservoir plus wedge storage for very long reservoirs;
- *Pumped Storage Reservoir* - Level Power Reservoir plus pumped inflow from another reservoir;
- *Reach* - routing in a river reach, diversion and return flows;
- *Aggregate Reach* - many Reach objects aggregated to save space on the workspace;
- *Confluence*- brings together two Inflows to a single Outflow as in a river confluence;
- *Canal* - bidirectional flow in a canal between two reservoirs;
- *Diversion* - diversion structure with gravity or pumped diversion;
- *Water User* - depletion and return flow from a user of water;
- *Aggregate Water User* - multiple Water Users supplied by a diversion from a Reach or Reservoir;
- *Aggregate Delivery Canal* - generates demands and models supplies to off-line water users;
- *Groundwater Storage Object* - stores water from return flows;
- *River Gage* - specified flows imposed at a river node;
- *Thermal Object* - economics of thermal power system and value of hydropower;
- *Data Object* - user specified data: expression slots or data for policy statements.

Table 1: Selected Methods in RiverWare

Object Type	User Method Category	User Methods	
Reservoirs	Evaporation & Precipitation	No Evaporation Pan and Ice Evaporation Daily Evaporation	Input Evaporation CRSS Evaporation
	Spill	Unregulated Spill Regulated Spill Unregulated Plus Regulated	Regulated Plus Bypass Unregulated Plus Regulated Plus Bypass
Power Reservoirs	Power	Plant Power Unit Generator Power	Peak Base Power LCR Power
	Tailwater	Tailwater Base Value Only Tailwater Base Value Plus Lookup Table	Tailwater Stage Flow Lookup Table Tailwater Compare Hoover Tailwater
Reaches	Routing	No Routing Time Lag Routing Variable Time Lag Routing SSARR	Muskingum Kinematic Wave Muskingum-Cunge MacCormack
Water User (on AggDiversion)	Return Flow	Fraction Return Flow Proportional Shortage	Variable Efficiency

MULINO

(after GIUPPONI et al., 2002)

Applications of the spatial decision making methods in the water management domain offer a potential means to manage the complex decision problems emerging due to the increasing complexity of sustainable spatial development. To this context, an EU RTD project called MULINO (**MUL**ti-sectoral, **IN**tegrated and **O**perational Decision Support System for Sustainable Use of Water Resources at the Catchment Scale) aims to contribute, by developing a DSS to assist water authorities in the management of water resources. Specific aims of the MULINO-DSS are improving the quality of decision making and seeking to achieve a truly integrated approach to river basin management. Through the integration of socio-economic and environmental modeling techniques with GIS functions and multi-criteria decision aids, MULINO-DSS aspires to be an operational tool which meets the needs of European water management authorities and facilitates the implementation of the EU Water Framework Directive.

The diversity of cultural, socio-economic and environmental characteristics of the case studies to be conducted in Italy, Belgium, Portugal, Romania and the United Kingdom requires that the tool is capable of a common approach to different decision cases but also to be flexible enough to adapt to the specific objectives and constraints of a given decision problem.

A common structure integrating hydrologic, environmental and socio-economic models in a multi-criteria analysis tool has been designed. Allowing the MULINO-DSS tool to cope with real problems and issues arising from variegated and conflicting water uses and demands, but also simulating alternative scenarios based on changes in external driving forces (policy changes in particular). To do this, the DSS tool deals with spatial variations of the most important social, economic and environmental parameters. Finally, MULINO enables an efficient transfer of knowledge and skills to water managers and other end users.

The DPSIR framework (Driving forces – Pressure – State – Impact – Response) has been chosen as an interactive and reporting component of MULINO-DSS and as a common denominator for the different case studies. This framework, developed by the European Environmental Agency (EEA) for environmental reporting purposes, structures the description of the environmental problems and constructs the cause-effect relationships between various sectors of human activity and the environment.

The decision making process is based here on a systematic approach that distinguishes the following phases: (1) The intelligence or problem formulation phase. The decision maker is concerned with the identification and decomposition of the problem and the organization of the objectives; (2) The design phase. This phase includes detailed analysis of the problem situation to understand the general nature of the problem and its extent by establishing the cause and effects relations. Feasible options are generated and criteria defined; (3) The choice phase. The DM needs to consider the impacts of choice alternatives along multiple dimensions in order to choose the best course of action to solve the problem.

DSS for Irrigation Water Management in the Jingtai Chuan Scheme (Gansu Province, NW-China)

(after GAO, 1999)

A computerized model was developed by the China Institute of Water Resources and Hydropower Research for an irrigated area of 547 km² (compare file www.icid.gao_1999.pdf on CD). The total design flow capacity is 28.6 m³/s. The scheme encompasses pumping plants, pipelines, aqueducts, lined canals, tunnels, etc. The water originates from the Yellow River. Without irrigation, agriculture would not be feasible in this area. The model combines water resources availability, climatic conditions, soil types, crops, crop water demand, water demand for other uses, canal and other water distribution system capacities, etc. Some parameters are results of individual models, such as a crop water requirement model, an irrigation schedule model, a canal simulation model, etc. Since these data change continuously, they are interlinked by an overall dynamic model. In practice locally acquired data from the 10 water management stations in the field are transmitted to a water management center. The water management center carries out a water supply and demand analysis which is then implemented by the local stations.

HYDRONOMEAS

(KARAVOKIROS et al., 2001)

HYDRONOMEAS has been developed by the N. T. University of Athens within the framework of the project “Modernization of the Supervision and Management of the Water Resource System of Athens”, funded by the Athens Water Supply and Sewage Company (1999-2000).

The critical questions to be answered were as follows:

• What is the maximum total withdrawal from the hydrosystem, for a given hydrologic regime and a given reliability level?

• What is the minimum failure probability in achieving a given set of operational goals, for a given hydrologic regime?

• What is the minimum cost to achieve a given set of operational goals, for a given hydrologic regime and a given reliability level?

• What are the consequences of modifications in the hydrosystem (e.g., construction of new projects), and the impacts of different management policies or hydroclimatic scenarios?

• How could the system respond to special occasions such as channel damages or an intense increase of water demand for a specific period (e.g., during the 2004 Olympic Games)?

Suitable for simulating complex multipurpose, multi-reservoir systems and for detecting the optimal water resources management policy. It applies the parametrization-simulation-optimisation methodology, keeping the number of control variables small. The results are given in probabilistic terms. The software has been developed in an Object Pascal environment (Delphi) and uses a relational database.

The steady-state simulation yields: reservoir water balance including annual mean value of water runoff, rainfall, evaporation, reservoir leakage, aqueducts inflow, outflow, losses, consumption; aqueducts flow balance; targets failure; probability; optimal reservoir operating rules.

THANNI

(source: http://www.commonwealthknowledge.net/Thanni/ltactgth.htm)

The World Bank, in conjunction with the Institute for Water Studies, Chennai has developed the THANNI (**T**ools for the **H**olistic **A**nalysis of **N**atural **N**etwork **I**nformation) decision support system as a tool for integrated water resources management. This DSS has two major components: an information system to help organize basic hydrologic, agricultural, urban and other information about the basin; and an optimization model that maximizes the benefits from water use subject to a variety of hydrological, economic, legal and policy constraints. Both the information system and the optimization model have been made in a flexible manner to allow for consideration of different scenarios, data updates, model reformulation and further analysis.

The THANNI-DSS uses a variety of popular software, such as EXCEL spreadsheets and the GAMS optimization package to create an interactive graphical interface for ease of input and output.

The optimization model helps give greater insight into the physical and conceptual interconnections in the basin and the inter-sectoral and inter-regional tradeoffs involved in the consideration of various hardware (infrastructure) and software (policy) options for basin management. Currently, the model as formulated is a monthly model for the chosen planning year. The decision variables are the inter-sectoral water allocation, cropping pattern, flows in the system, reservoir operation, etc. The objectives are to maximize water use benefits subject to constraints on area available, meeting crop water requirements, meeting in-stream water use requirements, etc. The interactive model can be optimised for each scenario considered. The results (e.g. flows, water allocation, benefits from use, hydropower generation, shadow prices, etc.) can be shown as tables schematics and graphs.

THANNI gives decision-makers an additional tool for policy and scenario analysis and gives stakeholders a focal point for discussions. These should be augmented with expert opinion, views, policies, and other tools such as geographic information systems, and simulation, water quality, stochastic models, etc. as appropriate.

The THANNI system was developed after an initial set of stakeholder meetings and interviews (involving participation from various government, NGO and private groups and individuals such as farmers, industrialists, drinking water board, pollution control board, forestry department, washer men, decision-makers, etc.) to identify and assess the issues.

An initial information system and model were then formulated using nodal and conceptual schematics to synthesize the available information. The model has been used to illustrate optimal water allocations among users, cropping patterns, water pricing, water trades, optimal canal lining to reduce losses, etc. Thus, it can keep track of multiple-objective water resources decisions in an economic framework and help answer a variety of important questions facing decision-makers and stakeholders:

- What changes in crops or area cropped are required upstream to divert increasing quantities of water for drinking purposes ?
- Can minor changes in reservoir releases or cropping patterns accommodate in-stream requirements for washing ?
- What are the benefits in each scenario - by sector, by region, by district ?
- What may be optimal allocations or flows in the system to meet urban demands in 2020 ?
- Would an additional reservoir help ?
- Does it help to increase field application efficiency by lining canals vs. basin efficiency of water use ?
- Can agricultural policy constraints (such as a minimum rice crop) be met ?
- What difference could high-yielding varieties of crops that require different temporal patterns of water supply make in this situation ?
- How much hydropower can be produced ?

The information systems can take advantage of recent advances in Geographic Information Systems (GIS) and interactive databases, spreadsheets, documents and the Internet to create useful thematic maps and overlays, perform interactive spatial analyses, and interact with models.

WASSER

(LLAMAS & CUSTODIO, 2001)

The DSS WASSER (Utilization of Groundwater Desalination and Wastewater Reuse in the Water Supply of Seasonally Stressed Regions) was developed by members of the National Observatory of Athens/Greece. The main aim was to counter saltwater intrusion problems by recharging a coastal aquifer with treated wastewater while extracting fresh or slightly brackish water (which is being desalinated) to meet demands. The task of the DSS is to coordinate and control the management of these water resources. The components of this decision tool, as depicted in *Figure 4*, are:

- groundwater demand module;
- screening module;
- groundwater module;
- pumping and recharge module;
- desalination module;
- wastewater treatment module;
- economic analysis module.

The DSS was tested in three areas: selected coastal aquifers of Israel, and the islands of Rhodes and Cyprus.

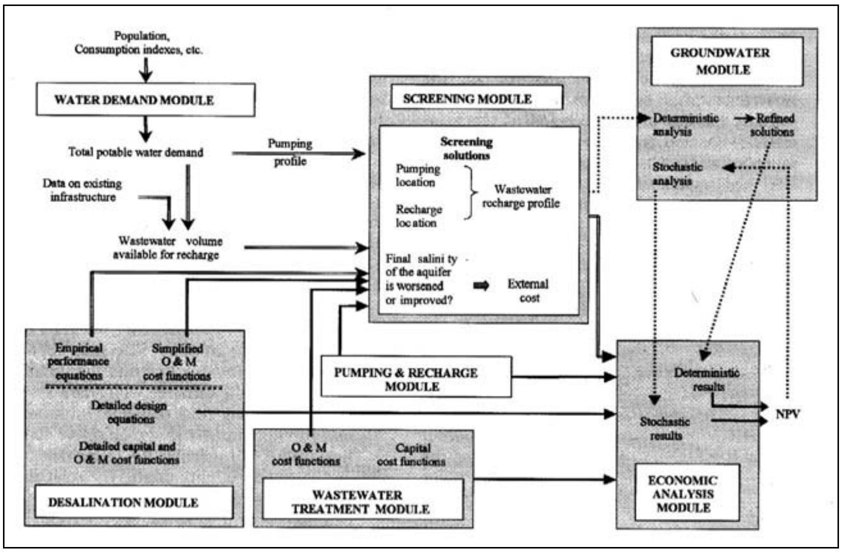


Figure 4: Modules of the Decision Support System WASSER.

Multi-criteria assessment methods, such as PROMETHEE (WASSERFORSCHUNG E.V., 2001) may be used for assistance in the decision process. PROMETHEE uses the level of achievability of certain indicators for different solution options to establish a ranking list for the best suitable options.

4.2.2 Groundwater Models

During the past several decades, computer simulation models for analyzing flow and solute transport in groundwater and surface water systems have played an increasing role in the evaluation of alternative approaches to (ground)water resources development and management.

The use of such models is limited by uncertainties due to sparse and inaccurate data, poor definition of stresses acting on the system, and errors in the concept. Although forecasts of future events that are based on model simulations are imprecise, they nevertheless may represent the best available decision-making information at a given time. However, computer models and simulations need to be updated periodically as the actual groundwater system continues to respond to the physical and chemical stresses imposed upon it and as new information on the groundwater system becomes available. Computer models commonly are used as learning tools to identify additional data that are required for a better definition and understanding of groundwater systems.

There is a vast number of models available for simulating groundwater flow, solute transport and the combination of both, such as (selected examples only):

Groundwater Flow Models

- saturated zone: e.g. MODFLOW (developed by USGS; McDONALD & HARBAUGH, 1988) and derivates such as: Visual MODFLOW (Scientific Software; www.scisoftware.com/) and Processing MODFLOW (PMWIN; developed by KINZELBACH & CHIANG; www.pmwin.net/);
- unsaturated zone: e.g. HELP (**H**ydrologic **E**valuation of **L**andfill **P**erformance), is a hydrological modeling tool for designing landfills, predicting leachate mounding and evaluating potential leachate contamination. (www.wes.army.mil/el/elmodels/helpinfo.html; www.scisoftware.com/products/help_overview/help_overview.html). It simulates leachate generation and infiltration in the unsaturated zone.

Solute Transport Models

- RT3D (A Modular Computer Code for Simulating **R**eactive Multi-species **T**ransport in **3**-**D**imensional Groundwater Systems; CLEMENT, 1997);
- FEFLOW – (**F**inite **E**lement subsurface **FLOW** system) simulates density-dependent flow (salt water intrusion), transient or steady-state flow, saturated and unsaturated flow, multiple free surfaces (perched water table) and mass and heat transport (www.ssg-int.com/html/feflow_details.html or www.feflow.com/). It can be conducted as 2D or 3D modeling;
- FEMWATER, a three-dimensional finite-element computer model for simulating density-dependent flow and transport in variably saturated media. The entire program structure is integrated into the Department of Defense Groundwater Modeling System (GMS) that contains a state-of-the-art

graphical user environment that allows efficient model setup and visualization (LIN et al., 2002);

- SUTRA (Saturated and (or) unsaturated, constant or variable-density fluid flow, and solute or energy transport); there is a 2D-version published in 1997 and a 3D-version published in 2002. SUTRA is a groundwater saturated-unsaturated transport model, a complete saltwater intrusion and energy transport model. SUTRA simulates fluid movement and transport of either energy or dissolved substances in a subsurface environment. SUTRA employs a two-dimensional hybrid finite-element and integrated finite-difference method (VOSS, 1984; SOUZA, 1987);
- MOC (**M**ethod **o**f **C**haracteristics) models 2-D solute transport and dispersion in ground water (GOODE & KONIKOW, 1991; http://water.usgs.gov/software/moc.html).

A good overview on techniques applied in groundwater modeling is documented in REILLY (2001).

5 Strategies to Achieve Sustainability in Groundwater Resources Management

There are a number of options to increase the efficiency and sustainability of water resources management. They may be divided into four main groups: the establishment of an effective decision support system (DSS), hydrological and hydrogeological measures, measures related to socio-economic aspects and such related to ecological aspects.

A prerequisite for all such measures is the formulation of an overarching national water policy. All aspects which are important to achieve sustainable water resources management must be addressed in this policy, i.e. the

- water supply: principles (e.g. ownership of resources, access, water rights); responsibilities (who does what); long-term strategies; emergency plans;
- sanitation: responsibilities (who does what concerning extension of services, sewage water collection, treatment and reuse); waste water standards (for domestic/industrial wastewater and wastewater reuse; long-term strategies;
- water utilization: principles of resource development/management (integrated water resources management); principles of water allocation (demand management); this part should cover all components of water resources, i.e. surface water, fresh groundwater, brackish groundwater, treated wastewater, desalinated water, harvested rainwater; long-term strategies;
- water quality/protection: aim and measures to maintain a good quality of the surface water and groundwater resources (e.g. groundwater protection zones); water quality standards; control and monitoring objectives and mechanisms; coordination with land use planning authorities; mechanism for clean-up operations (polluter-pays-principle, what happens in case of pollution); contingency plans; long-term strategies;
- water economics: principles for water pricing (for all water uses/users; for freshwater and water treatment); cost recovery principles; water markets (tradable water rights); subsidies/incentives for individual uses/users or water conservation measures or improved irrigation efficiency, etc; long-term strategies;
- water resources sharing: on the national level (transfer mechanisms/principles from one area to the other) and on the international level (use/allocation of transboundary water resources); long-term strategies;
- institutional framework: which authorities on which levels are responsible for which tasks; mechanism of coordination among these authorities and with other national and international authorities (e.g. concerning environmental impact assessments, land use planning, etc.); role of NGOs (private water supply companies; water user associations, etc); research/human resource development; legislative aspects; long-term strategies;

- public participation: confidence building; which information is provided to the public and by which means; mechanisms of cooperation; water user associations.

A good example for such policies are those established by the Ministry of Water and Irrigation (MWI) of Jordan in 1998 (file Jordan Water Strategy & Policies.pdf on CD).

5.1 Measures related to Data Acquisition, Resources Assessments and Decision Support Systems

Since these measures often provide the basis for a reliable assessment and establishment of a decision tool, they are listed as separate measures in this document. Often such an instrument is lacking, not sufficiently updated or incorrect in its concept. A decision support system provides the basis for meaningful decisions concerning demand management and protection.

Optimizing Data Quality

Many data concerning water are, especially in developing countries with low budgets for monitoring and data assessment/evaluation, unreliable, inconsistent, insufficient or not usable for certain assessments. This pertains to almost all parameters used in the establishment of a (ground)water resources management plan. Data insufficiency starts already at a low level. Often the very basic data for wells or springs, such as coordinates, elevation, total and screened depths are not available. Well completion reports are rare to come by so that maps showing the tops and bases of aquifer units are difficult to establish, if at all. When the quality of the input data is already poor, the result will not be much better. Even if databases are existing, the quality of these data is often poor and not sufficiently checked for errors. In many countries of the Arab region it is urgently required to establish or redesign programs and procedures for data acquisition, database input/control and for data evaluation. Measures of data quality assurance and quality control must accompany such programs.

In most countries of the Arab region the assessment of abstraction and consumption data is difficult because withdrawals and uses are not sufficiently metered, monitored or even not registered at all (illegal wells, illegal connections). The monitoring requires that flow meters are installed and maintained in operation. A monitoring program needs to be conducted, if possible on a monthly basis and the results need to be checked for plausibility. All illegal abstractions need to be curtailed.

Optimizing Data Assessments

The same principles of quality assurance and quality control count for data assessment routines. It is recommendable to prepare annual reports for all concerned data, such as meteorological data, surface water flow data, spring discharge data, abstraction, consumption, groundwater monitoring, well licensing, etc. Annual assessments of the water budget should be prepared, listing the problems encountered and countermeasures implemented to improve the situation. Guidelines for these assessments must be established describing in detail the applied methods and processes. Only when such reports are available the higher management will be able to address the problems properly.

The Establishment of a Decision Support System

As already mentioned above, the set of parameters needed for a comprehensive water resources management plan and their influence on one another is very complex. It can only be handled by a robust decision support system which manages the data input, processing and assessment as well as gives simulation results for assumed conditions in the future. A DSS must be able to deal with crisis situations such as water shortages in certain areas and redistribute the water resources according to the national policy. The output of a DSS (which describes the technical means for achieving a solution) is, among others, an integrated water resources management plan (see below). Water quality must be an integral part of a DSS, in order to recognize where interventions are needed, such as conservation, protection, clean-up or abstraction reduction measures.

The Establishment of an Integrated Water Resources Management Plan (IWRM)

Availability of renewable water resources (surface and groundwater), non-renewable water resources and water demand are highly variable throughout the year. The main objective of an IWRM-Plan is to use the renewable water resources most effectively and protect them against pollution. For this task the minimum, average and maximum available amounts of surface water, the demand for individual uses, the safe yield of groundwater resources, social parameters and the vulnerability of the aquifer system to contamination have to be known as exactly as possible in time and space. An IWRM-Plan has to indicate for longer time periods what the planned use of all available resources is, i.e. how to provide water for domestic, agricultural, industrial and commercial, touristic and ecological purposes. The aim of such a plan is not only to meet the demands but also to avoid over-exploitation in certain areas and find suitable solutions how to resolve situations of water scarcity or shortage in individual sectors in the medium and long-term range.

An integrated water resources management plan requires the integration of all kinds of demands and needs. In this respect it is necessary to take into consideration the existing and planned land uses and to provide that the planning authorities take into consideration all water related aspects, such as priority areas for (ground)water resources exploitation and protection demands, when establishing land use development plans. This especially pertains to sites and activities which may be hazardous to the groundwater resources.

5.2 Measures related to the Hydraulic Regime and Protection of the Aquifer System

The Use of Water Sources Other than Local Groundwater

In case a (ground)water resource is at risk to become depleted or deteriorated in quality, a possible measure would be to shift the source of water, either completely or in part, from groundwater to surface water and/or marginal (non-conventional) water, or to import water (usually, but not necessarily, surface water) from outside the river-basin or groundwater system boundaries.

The Change of Rates or Spatial Patterns of Groundwater Pumpage

Groundwater abstraction may lead to unwanted water level declines or hydrochemical reactions. Examples include the upward or downward leakage from aquitards that may cause highly mineralized water to intrude into a freshwater aquifer, saltwater or brackish water intrusion, land subsidence due to irreversible reduction of porosity in aquitards, and release of arsenic or other harmful substances as a result of hydrochemical reactions.

Possibilities to avert such negative impacts include an increase or decrease in pumpage at individual locations that result in a new equilibrium of the groundwater system, or a change in the spatial distribution of pumpage to minimize its existing or potential unwanted effects. In well fields where water levels begin to decline below the screened horizon for instance the spacing between wells could be increased. In areas where the release of substances, for instance gypsum from an overlying aquitard, occurs, abstraction could be shifted to areas where such release could not occur. In areas where saltwater intrusion or upcoming of brackish waters occurs, abstraction could also be shifted to places where intrusion or upconing is unlikely or intrusion/upconing could be blocked by freshwater injection (see below).

Water demands for domestic purposes and irrigation vary considerably. Demand for irrigation is often high during periods when no sufficient amounts can be provided from surface water and at times of dryness. Also, the cropping pattern, the type of crops, the cultivation methods or the irrigation methods may vary from one area to the other. Such seasonal differences can only be taken into account and properly managed using an effective management tool.

The Increase of Recharge to the Groundwater System

Common options include pumpage designed to induce infiltration from surface water bodies (e.g. recharge dams), or recharge of surface water or reused water of appropriate quality by surface spreading or injection through wells. When injecting water into groundwater, the suitability of the hydrochemical composition of the injection water is of prime importance in order to avoid the occurrence of clogging and unwanted chemical processes in the aquifer system.

Augmenting groundwater recharge may be achieved through (compare BOUWER, 2002; PYNE, 1995): ponding water on the soil surface with dams, basins, furrows, ditches, etc.; infiltration trenches, shafts or wells in the vadose zone; or direct injection into the aquifer. Such systems may be operated temporarily or continuously, depending on (excess) surface water (or marginal water) availability and quality. Artificial recharge requires adequate permeability of the soils and the underlying aquifers. Desilting and treatment measures may be necessary prior to infiltration. Recharge wells need to be backflushed periodically to avoid clogging. The time interval at which this is necessary depends on the composition of the water and the type of sediment/rock into which water is injected.

Other than augmenting groundwater recharge, artificial recharge may be used to reduce seawater intrusion, to reduce or halt land subsidence (e.g. Antelope Valley/California, Shanghai, Bangkok), to temporarily store water (e.g. as a precautionary measure against acute water shortages), and to improve the quality of the infiltrated or injected water (e.g. riverbank filtration).

Countermeasures against saltwater intrusion may comprise the use of artificial recharge of treated wastewater against advancing saltwater fronts (compare Chapter 6: Orange County).

Also high quality treated water may be stored by means of artificial recharge in areas that are not used for drinking water extraction. In times of need, this water may be abstracted for agricultural uses. However, all possible negative effects must be carefully studied prior to conducting this measure.

The advantages and disadvantages of artificial recharge methods are listed in Table 2 (adopted from ESCWA, 1999a).

Table 2: Advantages and Disadvantages of Artificial Recharge Methods

Method	**Design and Management Factors**	**Advantages**	**Disadvantages**
Spreading Basins	Frequency of flooding, drying, cleaning; pre-treatment of water; maximizing hydraulic loading, type purpose, operational rules	Low construction cost, rapid implementation, low maintenance and repair costs, customary water rights	Large land area required, soil clogging, algae blooms, insect breeding, less control of placement, land use conflicts, flood destruction
Recharge Dams	Intermittent reservoir filling; surface treatment to remove silt and fine particles, operational role released, small surface area, large depth, outlet for sediment, type, construction	Recharge to shallow aquifers, flood control, conjunctive use, continuous and high recharge volume, storage benefits	Unreliability of annual refill, high costs for installation and maintenance at all times irrespective of outcome, siltation, evaporation, contamination
Pits and Shafts	Cleaning of pit base to maintain high infiltration rate; plant and equipment to maintain, standby, simple design	Less land for spreading, large immediate storage capacity, low costs, easy access to aquifer	High maintenance costs, clogging, contamination, limited strata penetration
Recharge Wells	Well design, power requirements, pumps, pipework, air release valves, flow meters, well development, injection-recovery efficiency, well layout	Direct access to aquifer, minimum system losses, minimum land requirements, range of depths	Suspended solids, clogging, formation of organic slime, possibility o chemical precipitation, water right disputes

Extensive experience has been made in the USA, where 56 aquifer storage recovery wellfields (ASR) were operational in 2002 (PYNE, 2002), Spain (MURILLO DIAZ et al., 2002), Australia (e.g. CHARLESWORTH et al., 2002), India, and the Netherlands. A good documentation of presently used recharge methods and occurring problems is presented in DILLON (2002).

The Decrease of Discharge from the Groundwater System

Possibilities include pumpage that is designed to decrease discharges to streams, lakes, or springs, or from groundwater evapotranspiration. Both of these possibilities can have undesirable effects on surface water bodies or on existing biological resources which must therefore be carefully analyzed beforehand.

Other possibilities comprise usage of water of other sources instead of groundwater, such as the reuse of treated wastewater (in agriculture or for artificial recharge), rainwater harvesting, desalination of seawater or brackish water, etc. It is recommended to use the guidelines developed by WHO/FAO/UNEP for the use of wastewater in agriculture as a basis for preparing national guidelines, regulations and codes of practice for the application of treated wastewater in agriculture.

Wastewater irrigation can enrich the soils with organic matter and nutrients and increase its water holding capacity. It may, however, also contain toxic or hazardous substances. Long-term uncontrolled application of wastewater in agriculture may lead to a build-up of soil salinity, the accumulation of toxic substances in the soil and groundwater and a reduction of soil and rock permeabilities.

The loss of water resources caused by inefficient water use is enormous (JICA, 2002) and must be reduced. As much as 60 percent of water used for agriculture, which accounts for about 70 percent of all water use, is lost by infiltration and evaporation prior to reaching the crops. The rate of water unaccounted for, mostly caused by leakage from the supply network, in developing countries is about 40 percent. Measures for increased irrigation efficiency and reduction of water losses in the water supply system have therefore an enormous potential to decrease groundwater abstraction.

In this context it is important to mention that irrigation efficiency is difficult to assess and may vary considerably over time due to changing conditions in the water distribution system, soil, crop water requirements and climate. It is distinguished between (ROGERS et al., 1997):

- water conveyance efficiency (E_c): the percentage of source water that reaches the field;
- water application efficiency (E_a): the percentage of water delivered to the field and is used by the crop;
- irrigation efficiency (E_i): the percentage of water delivered to the field and is used beneficially (i.e. for all beneficial uses, such as salt leaching, crop cooling, pesticide or fertilizer application, frost protection, etc.);
- water distribution efficiency (E_d): the percentage of the average application depth delivered to the least-watered part of the field (indicating the degree of uniformity in the amount of water infiltrated into the soil);

- distribution uniformity (U_d): the percentage of average application amount received in the least-watered quarter of the field.

The Change in Volume of Groundwater in Storage at Different Time Scales

Possibilities include managed short-term (time scale of months and years) increases and decreases in storage in the groundwater reservoir, or a continuing long-term (possible time scales of decades and centuries) decrease in groundwater storage. Of course, complete or almost complete depletion of aquifer storage is not a strategy for sustainability, but an extreme approach that may be considered in situations of severe water scarcity. Changing rates or patterns of groundwater pumpage will lead to changes in the spatial patterns of recharge to or discharge from groundwater systems (see above).

Watershed Protection/Conservation

Even if some (ground)water resources are presently not being used, they might still be important for long-term development to meet future demands. Important aquifers or surface water resources in this sense should be declared as water priority areas, where no other land use development is allowed or at least certain restrictions are imposed.

Watershed protection or conservation measures should be implemented in all areas where important (ground)water resources are located that may presently not be used but may be of importance for future water resources development. Protection/conservation measures encompass more general issues compared to groundwater protection zones, where land use restrictions are rather strict. However, the required level of protection depends on the importance and size of the resource. Most important in watershed protection or conservation is the avoidance of new land use activities which are possibly hazardous to groundwater. Also the promotion and application of best management practices, especially those for agriculture, is recommended.

Groundwater Protection Zones

All contribution zones to points of water abstraction, either wells, springs or surface water bodies, should be protected by protection zones. Groundwater protection zones may cover large areas of up to 100 km² and more. The required measures for protection against pollution depend on the travel time from the point of infiltration to the point of discharge. Also, the protection aims are different, which is the reason that mostly groundwater protection zones are commonly divided into up to four zones (MARGANE, 2003b). The objective of protection zone 1 is to avoid any direct contamination of the well. For this purpose the perimeter around the well of at least 10 m in all directions is fenced and all human activities are prohibited inside. The aim of protection zone 2 is to avoid bacteriological infections. This zone commonly encompasses all areas from which the travel time from the point of infiltration to the point of discharge is less than the typical survival time of bacteria, viruses and other pathogens. Typically a travel time of 50 days is chosen to delineate groundwater protection zone 2. Protection zone 3 usually comprises the entire zone of contribution. The aim of this zone is to protect the water resources to be become contaminated by substances which are persistent and harmful to human beings, such as pesticides, heavy metals, etc.

The existing hazards to groundwater must be closely investigated and monitored and all future pollution hazards avoided. To decide which existing pollution hazards may endanger the water resources, so-called maps of groundwater vulnerability may be prepared (MARGANE, 2003a). They could also be used as decision tools for future land use development. Areas of low groundwater vulnerability may be considered as suitable areas for siting activities possibly hazardous to groundwater, such as waste disposal sites, sewage treatment and collection systems, industrial and commercial complexes, etc. Groundwater vulnerability maps may also be directly used to delineate groundwater protection zones, such as proposed by the Swiss authorities for karst environments (using the EPIK method; SAEFL 2000).

Introduction of Best Management Practices (e.g. for Agriculture and Industry)

Concerning Best Management Practice (BMP) guidelines, those for agriculture/crop production, for effective operation of irrigation and drainage systems (WORLD BANK, 1998c), for salinity control (WORLD BANK, 2000b; file Directions-for-managing-salinity_S-AUS.pdf on CD), for pollution prevention (EPA homepage: http://www.epa.gov/watertrain/agmodule/; compare file EPA-Agricultural Management Practices for Water Quality Protection.pdf on CD\BMP\Agriculture; CORE4 program) and for water efficiency (EPA: www.epa.gov/owm/water-efficiency/index.htm; USBR: http://www.usbr.gov/ waterconservation/publications.html) must be differentiated.

Concerning BMPs for agriculture, such guidelines are under preparation in several states of the USA and Canada. Good example are those available online from the Ontario Ministry of Agriculture and Food (OMAFRA; http://www.gov.on.ca/ OMAFRA/english/environment/bmp/series.htm#Soil). These give guidance for:

- farm forestry and habitat management;
- field crop production;
- fish and wildlife habitat management;
- horticultural crops;
- integrated pest management;
- irrigation management;
- livestock and poultry waste management;
- soil tillage;
- nutrient management;
- nutrient management planning;
- pesticide storage, handling and application;
- soil management;
- water management; and
- water wells.

Due to climatic conditions and water scarcity soils have been degraded by soil salinization in many areas of the Arab region. Therefore special emphasis should be put on measures to stop salinization processes and reduce salinization in already degraded soils.

Concerning pollution prevention in the industrial and commercial sector, the promotion of cleaner industrial/commercial production is imperative for a successful water protection policy. A prerequisite for environmental friendly production, however, is that this process is supported and also sufficiently controlled by the authorities. Standards for wastewater and regulations for the disposal of wastes have to be issued and enforced.

The establishment of an advisory service for cleaner production methods in order to improve the production process is highly recommended, because there is often no sufficient awareness about modern and environmental friendly production technologies. Ultimately, the registration of production according to ISO norms, such as the ISO 14000 family (which aim to reduce raw material/resource use, reduce energy consumption, improve process efficiency, reduce waste generation and disposal costs, and utilize recoverable resources; file ISO14000-family.pdf on CD) means not only improved environmental friendly production, but also better trading possibilities on the international market. The reduction, recycling and recovery of resources (e.g. water) as well as the appropriate treatment of sewage water and disposal of industrial wastes must be key elements of such an advisory service. Extensive BMP guidelines for commercial and industrial businesses are available, such as those from UNEP (www.uneptie.org/pc/cp/), UNIDO (www.unido.org/), US/EPA (Cleaner Production Network: www.epa.gov/international/ techasst/info/cpnetwork.html), Australian EPA (www.epa.nsw.gov.au/ cleaner_production/index.htm) and from WORLD BANK, UNEP & UNIDO (1999; file Worldbank_pollution-prevention-and-abatement-handbook.pdf on CD\BMP\Industry). They give detailed recommendations for all related activities about how to avoid contamination of water resources. Recommendations on how to properly carry out industrial waste management were documented by US EPA (files on CD\BMP\Industry\EPA_IndWasteMgmt\).

Contingency Plans/Remedial Action Plans

Contingency Planning is the development and implementation of both long and short-term drinking water supply replacement strategies for supplying safe drinking water to the consumer in the event of contamination or physical disruption.

Such a plan needs to be established and updated on a regular basis for each individual well or well field used for domestic water supply. It has to mention what alternative water sources are to be used in case of disruption of water supply due to contamination. Such alternative water sources might constitute other wells or springs which are connected to the same supply network.

A Remedial Action Plan describes what needs to be done and who is responsible for the individual actions in case the water source became polluted, for instance by an accidental spill.

Drought Prevention Plans/Inundation Prevention Plans

In case of extreme water scarcity due to extended periods of drought or in case of extreme wet climatic conditions resulting in flooding, water resources management needs to be adapted to such extreme conditions in order to avert human and natural catastrophes.

In areas where the probability of drought periods is high, countermeasures need to be implemented, such as storage of surface water, conveyor and distribution systems, or emergency groundwater wells, etc.

Prevention plans are even more important in areas where flooding frequently occurs, such as at the confluence of wadis and rivers with large catchment areas. Flooding events can occur within very short time periods after rainfall. Structures have to be robust and of large enough capacity to retain such flashfloods. Evacuation plans are an important part in Inundation Prevention Plans.

Drought Prevention and Inundation Prevention Plans must be laid down as a written procedure and the responsible staff must be trained in their implementation.

Conjunctive Use of Surface and Groundwater

Often surface and groundwater resources may be available at the same location with surface water being available at highly variable amounts. The pattern of surface water availability may be considerably different from the pattern of water demand. It may therefore be useful to exploit groundwater at times of low surface water availability and recharge surface water into groundwater or store surface water otherwise at times of high surface water availability.

5.3 Measures related to Socio-Economic Policies

Institutional and Legal Reforms

A strong institutional framework is the basis for a reliable and well accepted (ground)water resources management plan. Such institutions require good cross-institutional cooperation and exchange, sufficiently trained staff, appropriate financial funding and a strong backing from the Government.

Authority in the water sector in the Arab region is mostly fragmented and responsibilities for surface water exploitation, groundwater exploitation, water resources assessment, water resources planning, water resources protection, water resources monitoring, water law enforcement, licensing of water abstraction rights, etc., are distributed among several institutions without clear mandate. This is a major constraint for an effective water resources management and protection. Institutional reforms are urgently required to solve this problem.

Often the legal basis for the implementation of certain measures is insufficient. Therefore all implementation work has to start with the analysis of the existing legal framework and its amendment. Laws alone, however, will remain meaningless if they are not accompanied by the required by-laws, regulations/guidelines and standards and if there is no sufficient enforcement.

In the Arab region, the present legal conditions in the water sector are reflecting the influence of different common laws: the Ottoman Majalla code, the Sharia principles, and the French and British codes. In the countries of the Arabian Peninsula (Saudi Arabia, UAE, Oman, Qatar, Bahrain, Kuwait and Yemen) the water laws are based on Sharia and traditional principles. In Lebanon and Syria legislation in the water sector is a combination of the Sharia and Majalla code, whereas the water law in Oman, Jordan and Egypt contain elements of modern and customary laws (ESCWA, 1999a). The Maghreb region is largely influenced by the French legal principles.

Some countries have declared water as a public property, such as Syria, Jordan, Morocco, Oman and Yemen, whereas in others water is commonly still regarded as a private property, the latter being a major constraint for water resources not being sufficiently well managed and protected.

Many issues, such as well/abstraction licensing, water rights, water protection, water reuse, are still not appropriately regulated and standards for drinking water, bottled water, wastewater effluents from industries/commercial and domestic sewage treatment plants (STPs), or wastewater reuse in agriculture are often missing or not up to date. Such laws and regulations, however, are the main prerequisite for an effective management and protection of water resources. Also water law enforcement is often too weak as a result of unclear laws and mandates/responsibilities, insufficient manpower or training, inappropriate financial funding and institutional backing. Sanctions and penalties must be imposed against all users who do not respect water regulations, permits and licensing procedures.

A basic requirement for law enforcement is that there is acceptance among the population, that the legislation is clear and concise in the definition of regulations and consequences and the distribution of tasks and responsibilities. Acceptance will only be reached if the population can be convinced that the law is in their own interest.

Treaties for Shared Water Resources

International river and lake basins constitute about 47 percent of the world’s continental land area. Many countries depend on transboundary waters, either as surface water or as groundwater. Without bilateral or multilateral agreements these countries risk to loose part of such resources if upstream abstractions are increased.

The ‘Helsinki Convention for the Protection and Use of Transboundary Watercourses and International Lakes’ was established in 1996. It obliges the signing parties to (1) prevent, control and reduce water causing or likely to cause transboundary impact; (2) to ensure that transboundary waters are used with the aim of ecologically sound and rational water management, conservation of water resources and environmental protection; (3) to ensure that transboundary waters are used in a reasonable and equitable way, taking into particular account their transboundary character, in the case of activities which cause or are likely to cause transboundary impact; (4) to ensure conservation and, where necessary, restoration of ecosystems.

In 1997 the 'Convention on the Law of Non-Navigational Uses of International Watercourses' was adopted by the UN General Assembly but is not yet in force because it is signed by only 16 and ratified by 9 countries.

In the western part of the ACSAD region many aquifers are shared between nations (*Figure 5*).

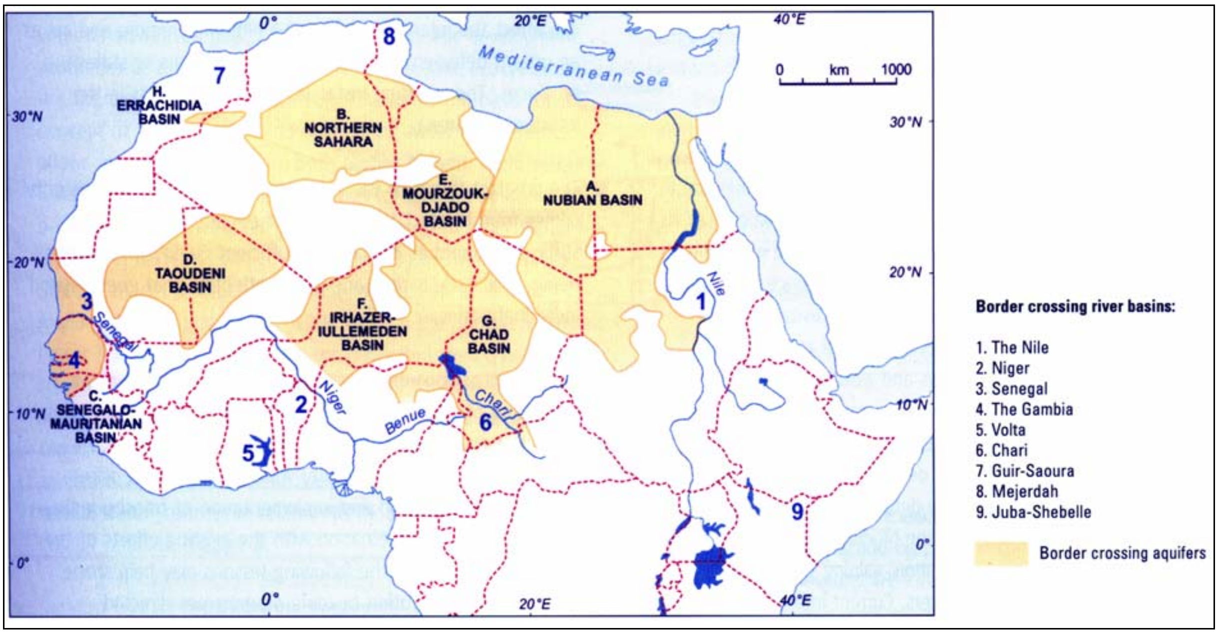


Figure 5: Transboundary Aquifers in Northern and Western Africa
(from UNESCO, 2003)

There are still very few cases where the allocation of surface and groundwater resources between countries is regulated by bilateral or multilateral treaties. Especially transboundary groundwater resources are often neglected in this respect but are sometimes much more important than surface water resources. The mining of groundwater resources in a country located in the upstream direction of a groundwater resource may cause severe depletion of the resource in a country in the downstream direction.

Cost Recovery

In the long term, the only sound mechanism for financial sustainability in the water sector is cost recovery. Costs must be covered for all incurred costs, i.e. for maintenance and operation of all activities related to water supply, sewage water collection and treatment, as well as for all other measures related to water resources management (e.g. resources assessments, exploration investigations, etc.), protection (protection zone delineation, general water quality conservation measures) and clean-up operations.

Decentralization

One of the Dublin conference (1992) principles states that decisions like water markets and privatization, or river basin management should be made at the lowest appropriate level. The basic idea is that the people affected should also be centrally involved in the decision processes concerning the allocation of water resources. However, determination of the appropriate decision level for water management issues is not an easy task and mainly depends on the availability of suitable local authorities, their financial resources, knowledge/capability and backing from the higher institutional levels. Often these prerequisites are not guaranteed at lower institutional levels. Also inter-agency cooperation may often be easier at higher institutional levels. However, participation of local user groups should be ensured because decisions related to the natural resources exploitation and land use in their area directly affects them. Commonly extensive training and capacity building programs have to be conducted when lower level administration units are involved.

Formation of Water User Associations

It may be useful to promote the formation of water user associations for assisting in the decision process on how the demand in a certain watershed is managed and protection measures are implemented. This way the users are directly involved in decisions which largely affect them. The stronger the active participation of such user groups, the better will be the acceptance of protection measures or measures to decrease abstraction.

Water user association may even be allowed to operate local water supply utilities for domestic and/or agricultural uses under their own control. The clear advantage is that such groups have to work under conditions of financial self-sufficiency and therefore need to implement appropriate pricing schemes. Such user associations have for instance successfully been formed in Morocco, Tunisia, Egypt, Mexico, Argentina, Indonesia and the Philippines (ESCWA, 1999a).

Restricting Abstraction Licenses

To manage a groundwater resource effectively, the right to abstract water should be limited in amount and time. The total amount of abstraction in a hydrologic or hydrogeological basin should not exceed natural replenishment and other inflows into the regarded aquifer system. For this purpose a groundwater resources management plan should be established taking into account the maximum allowable abstraction amounts of all abstraction licenses. When issuing a license, the abstraction amounts of individual wells should be distributed evenly and spaced sufficiently, in accordance with the availability and quality of renewable resources in the aquifer system. The total amount and time period for which a water abstraction right is granted should be limited in order to be able to readjust a management plan at later times.

In many developing countries this is the most difficult issue, because it is often not accepted that water is a national property. Often water rights were issued previously without any restriction of the abstractable amount or the validity period of the license. In this case a reformation of the water law may be unavoidable.

Promotion of Private Water Supply Companies

In developing countries it can often be observed that the number of wells to meet the needs for a certain purpose, especially in irrigation, is much higher than required. In most cases it would be less costly to supply water from a central well field via a distribution system, instead of each farmer having his own well(s). This would also be a measure to more effectively control the used amounts and to appropriately price abstractions.

However, privatizations need enormous capital investments and private companies will have to cover their costs from the water fees collected. The competition of private companies in the same area is often not justified because it would create excess capacities and would therefore be counterproductive to sustainable water resources management. On the other hand it has to be prevented that a water supply monopolist abuses his role by charging unreasonable fees and reducing services beyond acceptable conditions. Therefore mechanisms have to be found, how contracts for private water supply companies are awarded, how they are controlled and how the water price has to be fixed. In the initial phase of privatization, state subsidies to maintenance and operation costs may be unavoidable in order to prevent excessive increases of the water tariffs.

A good indicator for the efficiency of a water utility company is the share of unaccounted-for-water (UFW), i.e. the amount of water which is serviced but where no charges are being collected for. It consists of water losses through leaking pipes, illegal connections and unpaid water bills. An efficient company loses only 10-20% of its water as UFW, whereas inefficient companies, mostly state owned, may loose up to 70%. In many countries of the Arab region UFW is still above 50%.

Creation of Water Markets

Private water rights are commonly not used throughout the entire concession period. The complete sale of water rights or of certain amounts of the maximum allowable (ground)water abstraction may be allowed in order to avoid the licensing of too many wells (or surface water abstraction rights) in one area. By this measure costs for drilling, operation and maintenance, well licensing, etc., could be reduced. On the other hand an appropriate infrastructure needs to exist that allows the transfer of water.

Water markets should follow three basic principles:

- Security: the allocation of a certain amount of water should be guaranteed over a longer time period in order to guarantee economic safety for agricultural operations; a transfer of water rights may not cause damage to another party, therefore disputes about water rights need to be addressed appropriately;
- Sustainability: water abstraction/use needs to be less than the renewable amount; adequate protection of the environment must be ensured;
- Flexibility: the transfer of rights from one owner to another should be as flexible as possible; this way the economic return of water uses is optimized.

The concept of water markets was developed for the conditions in the western part of the USA, where it is applied since the late 19th century. It is also applied in some areas of the eastern part of the USA, in Australia (e.g. in New South Wales: http://www.dlwc.nsw.gov.au/care/water/sharing/index.html; DSNR, 2003), India, Pakistan, Chile (since 1981), Mexico (since 1992), Peru, and South Africa (since 1998 with the passing of the new Water Act; NIEUWOUDT, 2003) but may be applicable in other areas too. Most of these concepts are designed for surface water allocation. Especially here, public allocation schemes have often resulted in costly and inefficient systems. In water scarce areas like the Arab region, which are much more dependent on groundwater, water markets may however, also be developed for groundwater.

A successful water market approach requires the participation of a large number of users as buyers and sellers, sufficient water supplies and infrastructures to meet demands, and the presence of authorities to control the transfer of rights and settle disputes. In the case of water markets the maximum allowable amount to be abstracted from surface water or a well and the time duration of a license need to be specifically fixed, based on the criteria of sustainability, i.e. the abstraction must be less than the renewable amount. The transfer of non-user (sleeper) rights may be restricted in times of water shortage. Generally, water rights would move from lower to higher economic values/returns.

The water market system depends on the type of water rights. There are three systems: public allocation (distribution is administered by a public authority), prior (appropriative) rights (Western USA) and riparian rights (Eastern USA, Australia and South Africa). In the Western USA it is distinguished between senior and junior appropriative rights, the former needing to be fulfilled before the latter. Riparian rights link the ownership/use of water to ownership or use of adjacent land.

In South Africa it is distinguished between water rights in areas where water is scarce and where it is abundant. In the former, the acquisition of a license is obligatory. In these areas it is possible that water rights are withdrawn if in the public interest. Water rights are issued for a time period not exceeding 40 years.

In New South Wales/Australia, so-called water sharing plans are established for 10-year time periods by a local water management committee. These plans are established following an 8-step approach:

1. setting up flow classes;
2. providing water for the environment;
3. providing water for basic landholder rights;
4. determining requirements for water extraction;
5. setting limits on water for extraction and share that between different water users;
6. provide flexibility for access license holders;
7. provide clear licensed rights;
8. monitoring and reviewing of the plan.

As the experience shows, the approach of water markets may not be leading to a reduction in water consumption. However, this depends on the general regulatory framework. If water abstraction is not adequately priced, water markets may result in operations under the principle “use it or loose it”, i.e. water may be consumed in amounts well above the actual need. This is observed in parts of the Western USA, especially California, where the agricultural water sector is heavily subsidized, while some municipalities have to build desalination plants in order to meet domestic water demands (WORLD BANK, 1996).

In many countries of the Arab region some form of water market is already in place in some countries, e.g. in the form of water sales by tankers to areas of water shortage (often to urban areas with insufficient water supply; e.g. Amman: 2 JD/m³). However, these sales are mostly not controlled based on the above-mentioned criteria so that the misuse of such mechanisms is commonplace.

An effective water market system should ensure that the following points are addressed (modified after WORD BANK, 1996):

- Stakeholder participation must be ensured;
- Rules for allocation of water resources for existing and new rights have to be found;
- A public registry and an authority that supervises water allocations and solves disputes have to be established;
- The establishment of water user associations should be promoted;
- The development of potential monopolies has to be prevented;
- Infringements of trades on other user's rights have to be prevented;
- Water allocations need to follow the principle of sustainability with respect to water resources management, social equity, economic viability and environmental safety.

Promotion of and Incentives for Water Saving / Increasing Water Efficiency

When water tariffs are low, there is mostly no initiative or "need" to save water from the point of view of the consumer. In case water tariffs cannot be increased to reduce water spending, water saving methods should be supported by public awareness campaigns and incentives. Awareness campaigns may encompass water saving at home, for individual commercial businesses and industries and, most importantly, for irrigation efficiency. Incentives may encompass all sectors: domestic, industrial and agricultural water uses.

In the domestic sector, the most effective water saving method is the installation of water saving toilet flushes and the use of machines (washing machines, dish washers, etc.) which use less water. Public awareness campaigns are needed to convince the public that reducing the water spending is in the public interest because it helps to decrease the risk of resources depletion and pollution. A water-loss management program should also be envisaged to reduce losses from the distribution system and the sewage water collection system. Water could also be saved by using reclaimed wastewater for non-potable water uses for instance in certain industries.

In agriculture, the irrigation efficiency is mostly low in the Arab region, especially when no fees have to be paid for water. By investing into methods to increase irrigation efficiency large amounts of water could be saved or used to meet other water demands. If a reduction of water spending is not possible by other means, such as introducing a water tariff for irrigation water, a reduction could be achieved by incentives for increasing irrigation efficiency. OWEIS (2001) lists a number of measures for increasing irrigation efficiency (file ICARDA_Irrigation-Efficiency.doc on CD).

On-farm water management measures may encompass:

- Ditch lining;
- Development of water reuse systems;
- Installation of surge valves and gate pipes;
- Sprinkler systems;
- Field leveling; and
- Soil treatment.

A good description of methods for water use efficiency and conservation is documented in diverse documents of US EPA and US Bureau of Reclamation (http://www.usbr.gov/waterconservation/; http://www.epa.gov/owm/water-efficiency/; compare CD\Water conservation & efficiency).

Extensive water conservation programs are in place for instance in the USA, especially in water scarce areas, such as e.g. Colorado (http://www.usbr.gov/lc/region/wtrconsv/). The US Bureau of Reclamation supports the preparation of water conservation plans (USBR, 2000; file USBR-Lower-Colorado_AG-Guidebook.pdf on CD). It suggests that a standard outline for such programs should be used:

Water Management Plan Document

1. Description of District
2. Inventory of Water Resources and Water Budget
3. Problems, Opportunities and Goals
4. Existing Water Management Measures and Programs
5. Evaluation of Fundamental Water Management Measures
6. Evaluation of Additional Water Management Measures
7. Selected Measures and Projected Results
8. Environmental Review
9. Implementation Schedule and Budget

Subsidies for Water Resources Augmentation

Measures to augment water resources, such as rainwater harvesting, artificial groundwater recharge or (ground)water desalination are costly. In case that water supply operations are conducted by private companies in areas of acute water shortage, the available water resources could be augmented by providing subsidies for the realization of such resource increasing measures.

Managing Demand through Water Pricing

Efforts to recover costs of water utility operation and maintenance should focus on those consumers who use the most water. The most effective measure to regulate water spending is the adoption of a suitable water pricing system. Water tariffs must be governed by certain principles:

- Water must be affordable by poor people, i.e. the low tariffs must be adjusted to the minimum income;
- The more water is spent, the higher the tariff must be, i.e. the higher domestic water tariffs must be adjusted to the income of the more wealthy population. This effectively reduces overuse;
- Water tariffs must take into account all costs, i.e. also the costs for sewage water collection and treatment as well as those for quality control and protection.

Irrigation and industrial/commercial water tariffs must follow the same principles.

In the Arab region the formulation and implementation of appropriate water tariffs is a major challenge (ESCWA, 1997b). In this process economic, political, social and religious circumstances have to be considered.

Stakeholder Participation

Measures will only be effective when all groups possibly affected actively participate in the decision and implementation process. This could be reached either through special seminars, workshops, awareness campaigns or other public relations measures. The formation of water user associations (see above) may facilitate this process. Public awareness for the need to save and protect the water resources should encompass all social groups, especially the younger population.

Temporary Restrictions for Water Consumption

In times of critical water supply shortages it may be necessary to impose restrictions for individual uses or users during certain time periods and in certain areas. This applies especially for irrigation water uses at times of severe water shortages.

5.4 Measures related to Ecological Policies

Collecting Fees for Water Quality Conservation

In order to protect water resources more effectively, several countries have started to collect fees from the industry and agriculture for activities which are possibly polluting (MARGANE, 2003b). For instance in France, the Water Agencies (Agences de l' Eau) collect a 'nitrate fee' for the amount of nitrogen applied by fertilizers and a 'pesticide fee' for the amount of pesticides applied on cultivated land. These fees should be used to finance other protection measures, such as the establishment of protection zones (which are in the public interest and therefore mostly paid for by the public) or watershed protection (preventive groundwater protection in upstream areas of groundwater protection zones or in catchment areas which may be important for groundwater development in the future).

A similar water pricing system is now in place in Morocco, following the enactment of the 1995 water law.

In Germany several states introduced the payment of the so-called 'Wasserpfennig' in the late 1980s. The aim of this fee was to compensate farmers in groundwater protection zones for not using fertilizers and pesticides or leaving their land fallow. In Baden-Wurttemberg for instance the charge is 5.1 ct/m³. Many states have stated in their water law that this fee is to be used for measures related to improving or conserving the quality of groundwater. Some, however, like Baden-Wurttemberg have not, so that this regulation has in practice often not achieved its goal.

Reduction of Water Discharges into or Abstraction from Ecological Valuable Habitats

Especially in areas where the local flora and fauna is endangered by depletion or pollution of the water resources, such as wildlife or forest protection areas or wetlands, additional water saving and protection efforts are required. Negative effects on the environment can be avoided implementing strict land use and water abstraction and discharge restrictions. The best solution would be to maintain or reattain a flow regime that is close to the natural pre-development conditions. Often, however, the water levels in such areas (e.g. Azraq oasis/Jordan, Palmyra oasis/Syria) have declined dramatically eradicating the natural vegetation and thus the floral and faunal habitat. In such cases, reforestation is only possible involving continuous irrigation throughout the dry period. Evapotranspiration may be reduced by planting less water consuming plants. There is, however, no example where this rehabilitation process has been implemented successfully.

6 Examples for Sustainable Groundwater Resources Management

Japan: Drought Conciliation Councils to Counter Water Shortages

(source: UNESCO, 2003: 298)

Due to climatic conditions and topography, river flow varies considerably in Japan. Surface water is the main water source. Its availability thus is a major constraint to development. Droughts pose an increasingly serious problem with increasing demands, especially in the large urban areas. In such areas where demand cannot be completely satisfied, new water abstractions are permitted only when river flow exceeds existing abstraction rights, giving priority to public drinking water supply.

Drought conciliation councils have been established in drought affected basins. In principle, the conciliation process is conducted among the stakeholders themselves. However, in reality an official river administrator is usually needed as mediator.

France: Establishment of Basin-wide Water Management Plans

With the enactment of the 1992 water law an operational framework for water management has been introduced in France. So-called water management plans (Schémas d’ aménagement et de gestion des eaux, SAGE) have to be established for each basin by a basin committee, the so-called local water commission (Commission Locale de l’ Eau, CLE), a group of representatives from the Ministry of Environment, the regional directorate for environment (Direction Régional de l’ Environnement, DIREN) of the basin, water agency, and the Superior Fishery Council. Altogether this basin committee consists of between 60 and 110 persons. The management plans have to integrate all water related aspects for groundwater, surface water, brackish water and sea water. These plans are established for 15 year time periods and are based on a balance between the ecological needs (needs for protection) and the economic needs (water demands). Action plans are established every 5 years, especially with the aim to improve water quality.

The basin committee annually makes recommendations for water charges to be collected by the water agencies. These are divided into extraction charges, to finance the management of a resource from the quantitative point of view, and pollution charges, designed to help improve the water quality. The water price covers water supply costs (approx. 1/2), wastewater treatment (approx. 1/3) and protection and conservation measures (1/6).

The SAGE plans contain an evaluation of the current status of water resources, concerning quality, quantity and ecological functions, an analysis of the pressures on the water systems, and the evaluation of possible measures to bring into balance the demands and the needs. For this purpose all costs, also possible future costs or ‘intrinsic costs’, such as for the value of clean water, at present and in the future for different stakeholders are estimated. Based on a participatory process an action plan is then developed.

Table 3: Total Economic Value of Water

	value of use		value for non-use (‘intrinsic value’: idealistic value attached to the existence of the resource)
	for stakeholder A	for the other stakeholders	
at present	real value	value for other individuals	
in the future	value of optional use (for a resource that may be used in the future)	value for future generations	

Nile River Basin: A Shared Water Resource

The Nile River basin (3,038,100 km²; *Figure 6*) is shared between 10 countries (sorted by size of land area within the basin): Sudan, Ethiopia, Egypt, Uganda, Tanzania, Kenya, Congo, Rwanda, Burundi and Eritrea. The Nile River Basin Action Plan was established in 1992 and in 1999 the Nile Basin Initiative was launched by the Council of Ministers of Water Resources (NILE-COM; www.nilebasin.org/) in cooperation with the World Bank (www.worldbank.org/afr/nilebasin/), UNDP, GTZ (www.gtz.de/transwater/english/) and CIDA.

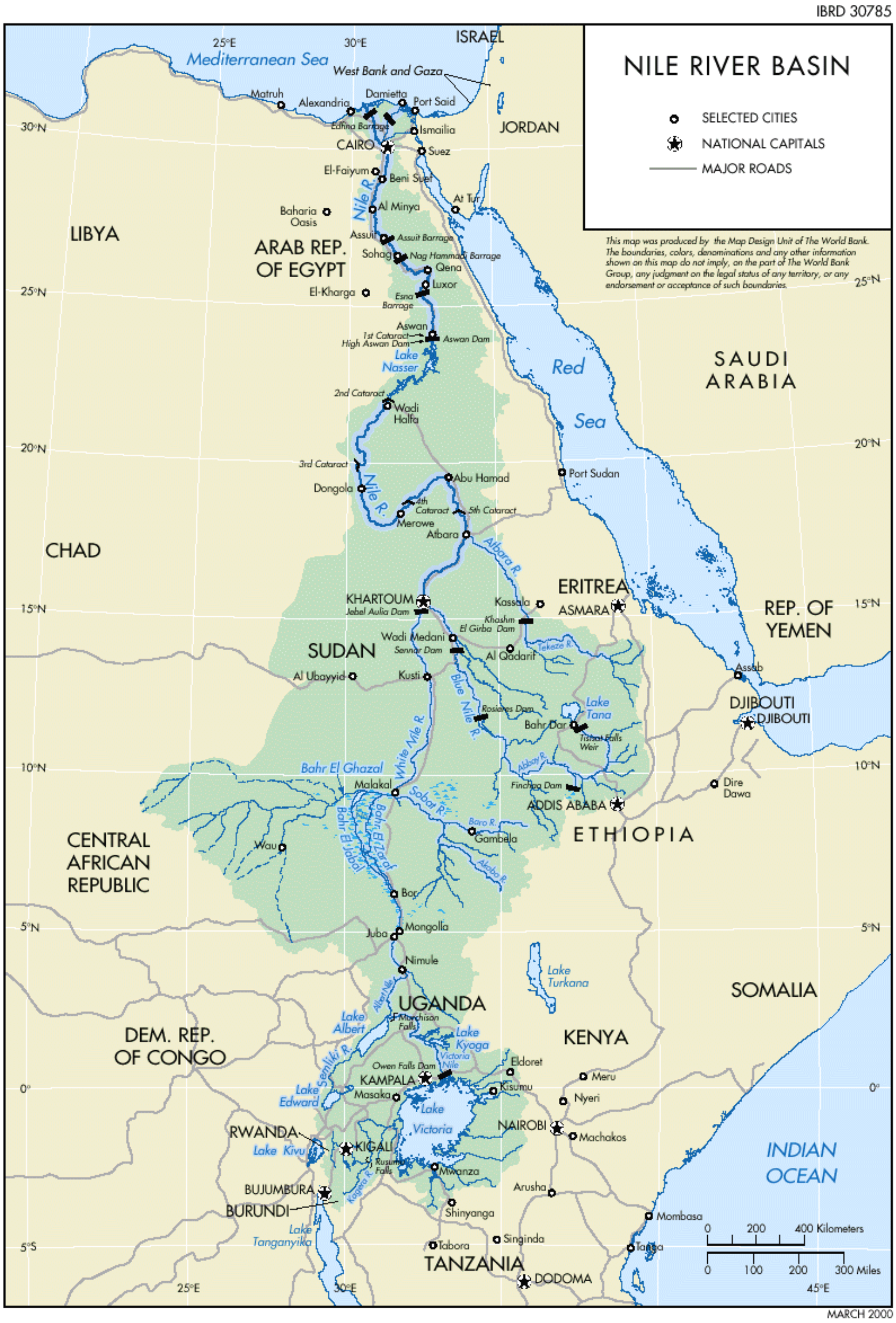


Figure 6: The Nile River Basin, a Shared Water Resource

Several projects have been initiated following the Nile-COM meeting in February 2002 in Cairo:

<u>Shared Vision Program</u>

The main task of the shared-vision program will be the creation of an *enabling environment* for investments and action on the ground, within a basin-wide framework. This program will promote the shared vision through a limited, but effective, set of basin-wide activities and projects.

The "Shared Vision Program" comprises 5 broad themes, as follows:

- Co-operative Framework
- Confidence building and stakeholder involvement
- Socio-economic, environmental and sectoral analyses
- Development and investment planning
- Applied training

Subsidiary Action Programs

Within the basin-wide framework, subsidiary action programs will comprise actual development projects at sub-basin level, involving two or more countries. This will allow the move from planning to action. While local and national governments will address what needs to be done at the local and national levels, the challenge of regional co-operation is to address development opportunities with transboundary implications.

I. GENERIC WATER RESOURCES MANAGEMENT PROJECT POSSIBILITIES

- Water Supply & Sanitation
- Irrigation & Drainage Development
- Fisheries Development
- Hydropower Development & Pooling
- Watershed Management
- Sustainable Management of Wetlands & Biodiversity Conservation
- Sustainable Management of Lakes & linked Wetland Systems
- River Regulation
- Flood Management
- Desertification Control
- Water Hyacinth & Weeds Control
- Pollution Control & Water Quality Management
- Water Use Efficiency Improvements

II. OTHER RELATED JOINT DEVELOPMENT PROJECT POSSIBILITIES

Infrastructure:

- Regional energy networks, including power interconnection and gas pipelines
- Telecommunication development
- Regional transport, including: railway and road networks; river and marine navigation; aviation

Trade and Industry:

- Promotion of trade (including border trade)
- Industrial development
- Regional tourism development
- Promotion of private investment and joint ventures
- Marketing and storage of agricultural products
- Forest crop harvesting

Health, environment, other:

- Malaria and other endemic diseases control
- Protection of wildlife
- Environmental management
- Disaster forecasting and management

Though no formal treaty has yet been signed which would formally recognize certain water rights for individual countries, it is hoped that this initiative leads to a better cooperation in the management of the common water resource.

As important as the regulation of water sharing concerning surface water is the issue of transboundary groundwater resources in this framework (*Figure 7*).

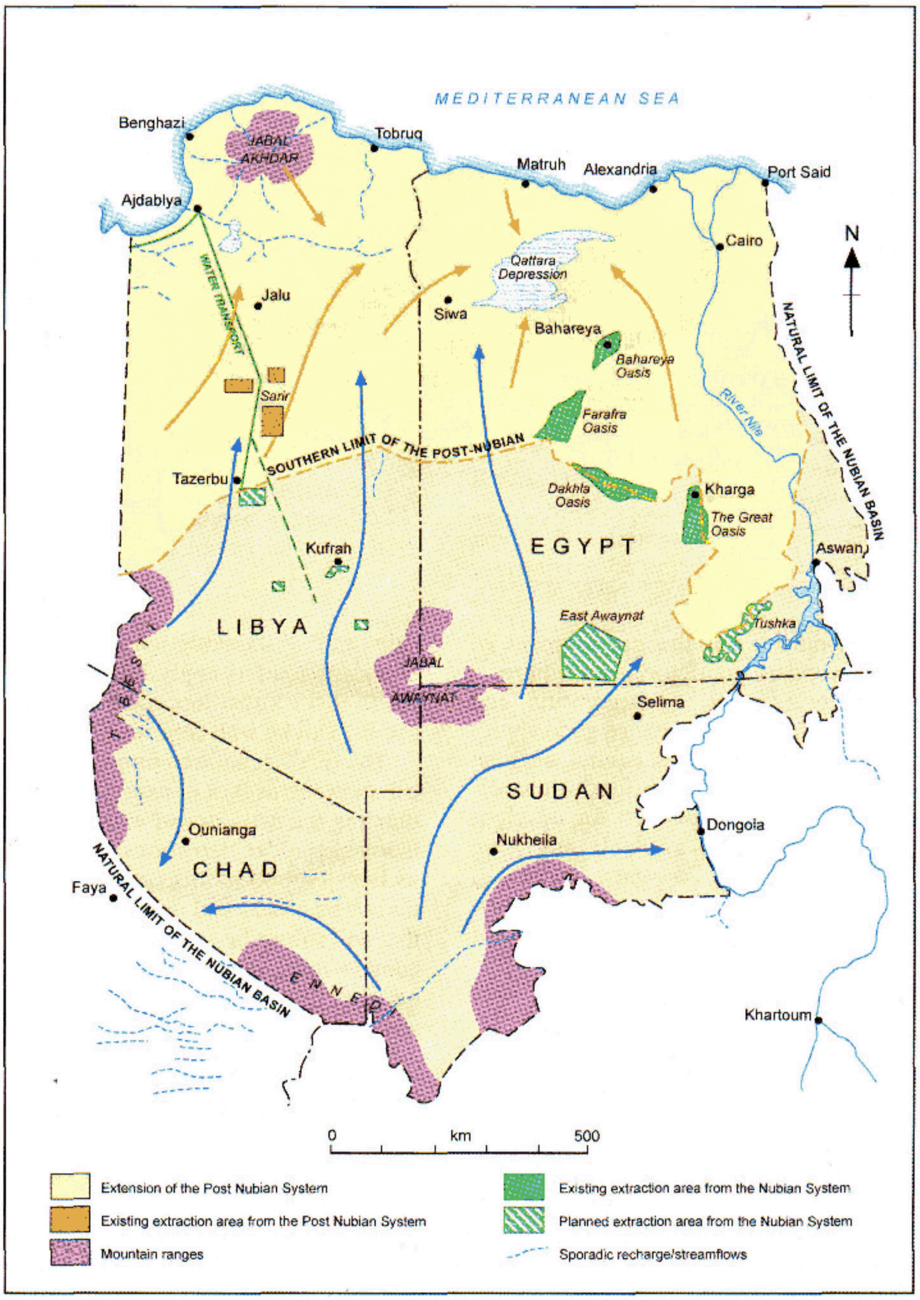


Figure 7: The Nubian Aquifer System a Shared Groundwater Resource
(adopted from LLAMAS & CUSTODIO, 2001)

Similar initiatives or commissions have been established in several larger shared surface water basins during the past decade, such as the Okavango River Basin Water Commission (OKACOM; 1994; Angola, Botswana, Namibia) and the Mekong River Commission (Cambodia, Laos, Thailand, Vietnam; 1995). So far these bilateral or multilateral initiatives focus mainly on surface water resources. However, in the future it will be important to integrate groundwater resources into such management plans.

Mexico: Deregulation of Water Market

(source: WORLD BANK: file on CD: WB_Sust-Development-Mexico-Aquifers.pdf)

In Mexico water resources are very unevenly distributed. Whereas the southern part can be regarded as tropical, much of the northern part receives less than 400 mm/yr rainfall and faces high evaporation. However, much of the agricultural activity is concentrated in the dry northern part. The irrigated area (5 million ha, i.e. the fifth largest in the world) is about one third of the cultivated area but is more than three times more productive than traditional rainfed agriculture. Irrigation highly depends on groundwater, as do domestic and industrial water supply, and groundwater abstraction has increased by around 50% over the past 5 years. Presently around 40% of the renewable groundwater resources are being used on the country-wide level. Groundwater over-exploitation occurs especially in the north, in areas of high economic activity.

The reasons that have led to this overexploitation of the water resources are:

- Subsidies on water, energy, agricultural products and fertilizers;
- High taxes on imports;
- Promotion of individualism and encouragement of exploitation by government authorities;
- Ignorance of environmental impacts (e.g. saltwater intrusion, land subsidence) and long-term costs.

In recent years a number of changes took place to correct this imbalance and have led to a deregulation of the market, especially concerning the payment of subsidies. Incentives are more and more directed to support a technification of the agriculture (irrigation efficiency, fert-irrigation). With the 1997 National Water Law, a deregulation of the water market took place which allows for tradable water rights, independent of land rights. This led to investments in crops with higher economic return and the abandoning of low value crops. An extensive information and education policy for farmers about water saving technologies has led to less water consumption and higher income and employment in areas where a consensus was reached among all stakeholders, such as in the Costa de Hermosillo area.

USA: Water Management Plans

(source: USBR: file on CD: USBR_Achieving Efficient Water Management.pdf)

In several parts of the USA, especially where water is scarce, water management plans have been developed in recent years to cope with scarcity problems. As an example the Springfield Irrigation District Management Plan is presented.

The main hydrological feature is the Spring Mountain reservoir with the Springfield canal which serves as distribution system for the Springfield Irrigation District. For preparation of the management plan the following evaluations were made: inventory of water resources; establishment of a water budget containing diversion, loss and delivery data in order to identify timing problems and opportunities; analysis of the existing management structure; analysis of the legal, institutional and environmental situation; identification of issues and goals to be reached.

As one of the main problems the diversion of too much water in the early season to the irrigated area was identified. Second, there are significant unexplained losses in the early season.

Together with irrigators and district representatives the key issues were discussed and seven operational goals were identified. A technical evaluation of the costs was conducted and the possible measures were ranked in a list based on indicators such as water supply amount, efficiency and equity. The finally adopted plan was developed balancing between the benefits and the involved costs.

Orange County/USA: Freshwater Injection countering Saltwater Intrusion

(source: MILLS, 2002; USGS, 2001; LLAMEAS & CUSTODIO, 2001; KONIKOW & REILLY, 1999; Orange County Water district online: www.ocwd.com)

Like in many other areas of the world, industrial development and urban growth in the USA has been concentrated in coastal areas having access to ports. Though groundwater resources were mostly abundant, saltwater intrusion soon became a problem in many such areas. Orange County is a district of California, located south of Los Angeles. The coastal aquifer consists of highly permeable unconsolidated sediments and forms the main aquifer for the supply of the metropolis. The system is made up of up to 11 aquifers, each consisting of a distinct layer of sand and gravel, separated by layers of low permeable clay and silt units. The hydrogeological setting is complicated by the vertical tectonic movements along the Newport-Inglewood structural zone which accompanies the coastline at a distance of between 2 and 5 km. The near coastal zone was uplifted along this zone and the sediments in this mesas area have generally a lower permeability. The fault zone itself constitutes a barrier to groundwater flow of low permeability in many places. However, due to erosion, so-called ‘gaps’ were formed that were filled with more permeable alluvial deposits so that these gaps act as principal conduits for groundwater discharge under natural conditions. With increasing groundwater exploitation these gaps became the main pathways for saltwater intrusion.

Due to massive water withdrawals, seawater intrusion occurred already in the late 1940s. In large parts of the coastal plain the water level was below sea level in the early 1950s (*Figure 8*). Even though artificial recharge was applied already since 1948, saltwater intrusion progressively continued, reaching some 8 km by the mid

1970s. In the late 1960s it was decided to adopt a conjunctive-use policy that tried to optimize the use of imported water, surface water and groundwater. Artificial recharge was used at times when excessive amounts of surface water were available. It was also decided to halt intrusion by establishing a hydraulic barrier using injection of treated wastewater, the so-called 'underground water dam'. The idea was that injection would cause the hydraulic head to build up and create a sufficiently high local groundwater divide ensuring that the hydraulic gradient would force groundwater to flow from the injection area to the coast. Presently around 40 MCM of a mixture of treated wastewater (2/3) and freshwater (1/3) are injected annually. The advanced wastewater treatment plant that was built to allocate water of sufficient quality and amount for injection (Water Factory 21; high lime pre-treatment, with subsequent reverse-osmosis or activated carbon filtration) produces water that meets drinking water standards. Since clogging of the injection wells typically occurs after some time, the wells have to be routinely maintained and redeveloped, usually at 5-year intervals.

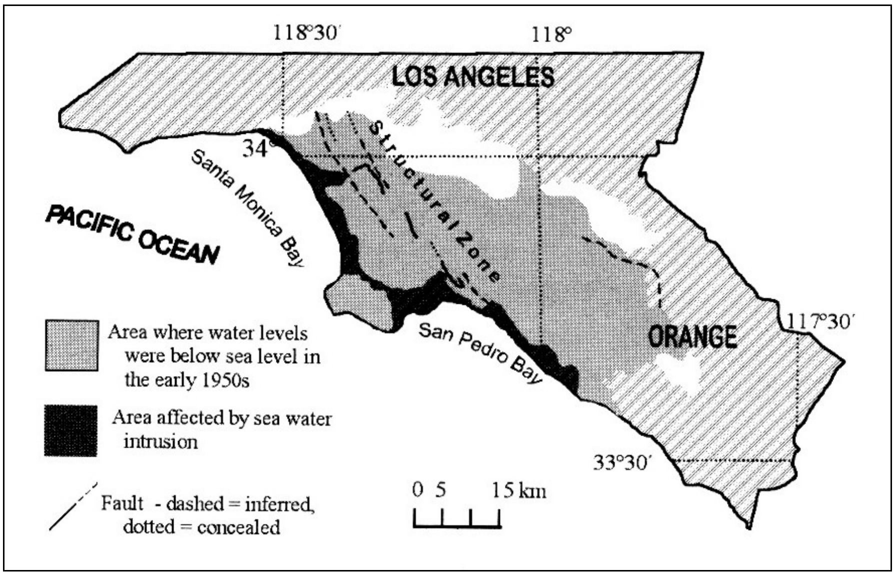


Figure 8: Salt Water Intrusion in the Orange and Los Angeles Counties of the Southwestern USA

(adopted from LLAMEAS & CUSTODIO, 2001)

Altogether around 470 CM are presently being abstracted in the area. In addition to injection, Orange County uses artificial recharge of surface water, such as that from the Santa Anna River, through recharge ponds (Santa Ana River spreading facilities; this water would otherwise run off unused to the sea through the Santa Ana gap), of imported water (60-120 MCM/yr from the Colorado River) and removal of brackish water by scavenger wells, located seaward of the injection wells. Altogether the total recharge capacity presently is around 370 MCM/yr, and actual total recharge averaged around 300 MCM/yr (1992-2001). Each of the deep artificial recharge ponds are periodically emptied, and the clogging layer is removed by scrapers or by a sand-washing device. Clogging affects only the upper two to three inches of soil. A twice-yearly cleaning cycle, which has replaced single annual cleaning, increases infiltration by as much as 40 percent.

Presently a flocculation system is being considered which could coagulate suspended solid particles so that they will settle out of the water as it passes through a series of desilting ponds, which help to reduce the sediment load in water that is diverted to the recharge basins. The flocculation system will slow the formation of a clogging layer and thereby helps to maintain efficient infiltration.

In the area between the injection wells and the coast, where seawater had already intruded, a well field was constructed with the purpose to extract the seawater and return it directly to the sea but was later abandoned because it was recognized that it would only accelerate saltwater intrusion.

Although saltwater intrusion has long been recognized and monitored in the USA and the basic concepts and processes are well understood, the appropriate management of groundwater resources in areas affected by saltwater intrusion is still a difficult task. One reason is that the modeling of seawater intrusion is often imprecise due to the non-linear coupling of the governing equations and the difficulty of accurately defining the required aquifer properties (KONIKOW & REILLY, 1999). In most cases there is a strong lack of data because the monitoring of such data over time is extremely costly in this type of environment and the data may vary considerably over time and space.

A system similar to that presented above for artificial recharge countering saltwater intrusion is in place in the Netherlands (STAKELBEEK, 1999), where since 1990 5 MCM/yr of pre-treated surface water are being injected through a series of injection wells into a sandy aquifer in the area northwest of Amsterdam to block intrusion from the North Sea.

Balouchistan/Pakistan: Community-based Cooperation

(source: LLAMEAS & CUSTODIO, 2001)

Groundwater development has relied on the traditional system of karezes (called qanats in neighboring Iran) throughout large parts of the Middle East and western and central Asia (*Figure 9*). They consist of a string of shafts connected by a tunnel. The tunnel picks up water from groundwater and, with a very shallow gradient, conveys it over several hundred meters to the demand area, commonly an irrigation area. In the past, these systems were typically constructed and maintained by a group of farmers, which shared costs. When dug wells and drilled wells became popular in the 1960s and groundwater development by such means was even subsidized by the Government (support for equipment and low electricity tariffs), groundwater was increasingly developed and many of the karezes were abandoned and started to collapse. Groundwater levels declined below the level where it could be collected by the karezes. With falling water levels, however, also tubewells and dug wells had to be continuously deepened. This has increased the costs for water immensely and in some areas only larger, wealthier farmers could survive, whereas the poorer could not afford such costs. Until 1978, when the Groundwater Rights Administration Ordinance was issued, the Government did not have any mandate to control groundwater abstraction. This ordinance provides a procedure for well licensing that is to be based on the agreement of the District Water Committee and area specific guidelines. Unfortunately, these were mostly never formulated, with the exception of two valleys. In the Mastung Valley, west of Quetta, conflicts between kareze shareholders and dugwell developers became frequent in the 1960s and in an effort to resolve these conflicts, groundwater use rules were formulated by a local committee. A dugwell free zone was declared and at the same time the construction of new karezes was banned. Outside this zone, minimum distances were specified and permit procedures were laid down. A permanent committee was established to oversee the implementation of this agreement and solve disputes. Unfortunately the rules were not enforced strictly enough so that water development increased and finally most of the karezes were abandoned. In the Panjgur Valley the control of groundwater abstraction was more successful due to the different local socio-economic conditions, characterized by the inflow of money from family members working in the Gulf States. This changed the previous feudal system into a system of social equity. Water development and use was therefore an issue of common interest and a rule was established that banned the development of dugwells and tubewells, with the exemption of drinking water wells. The main difference between these two areas is that in the latter area the groundwater rule has become an accepted social rule mainly because of social equity.

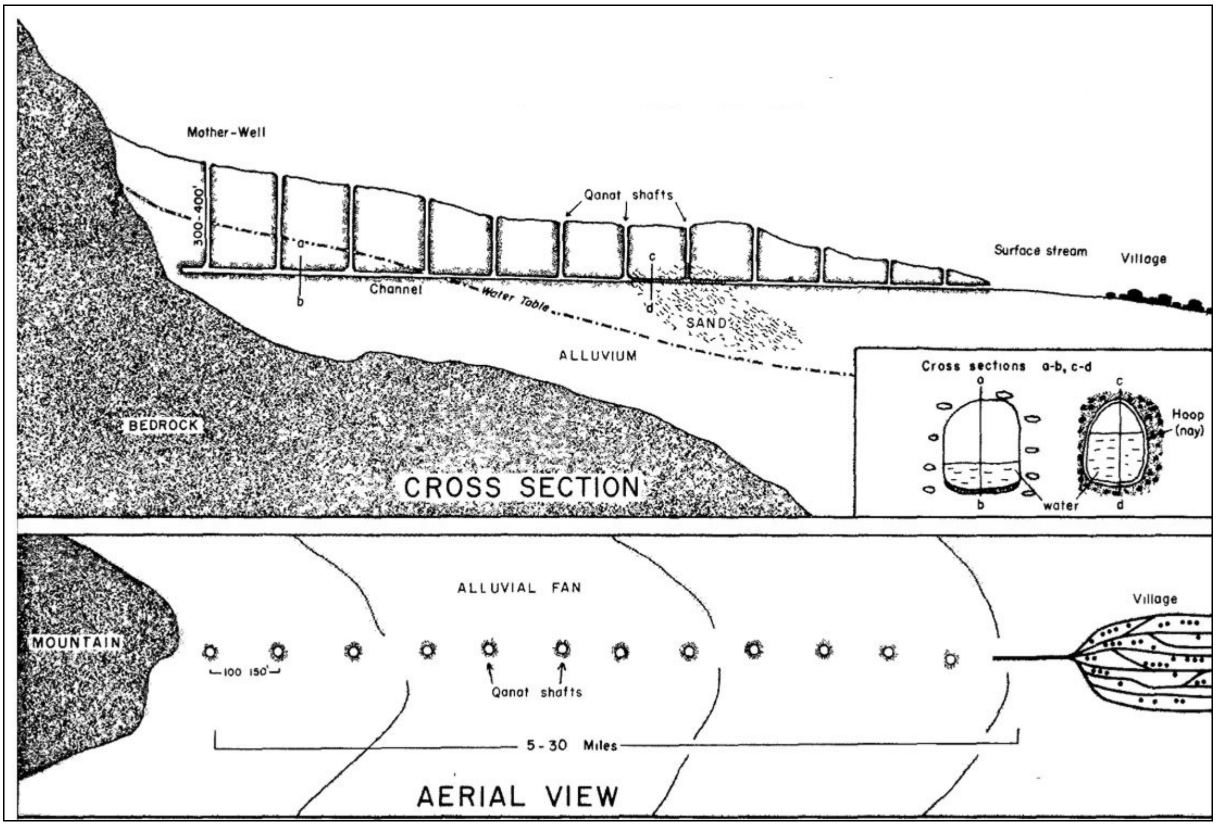


Figure 9: Schematic View of a Kareze System

Lower Indus Valley/Pakistan: Groundwater Salinization Problems

(source: MORRIS et al., 2003: 89; WORLD BANK, 1994a)

The Lower Indus Valley, an arid region receiving less than 200 mm rainfall per year, has been gradually developed into an agricultural zone over a period of some 60 to 70 years until the middle of the 20th century by establishing a widespread irrigation system that comprises 3 major reservoirs, 21 barrages and 43 main canals. The irrigated area encompasses around 14 million ha. Current mean annual canal diversions to the Indus command area total 126.4 billion m³ (BCM). The annual groundwater pumpage has increased from 4 BCM in 1959 to 59 BCM in 1996 - 1997.

Under natural conditions the groundwater table was around 30 m below land surface with a very low gradient. Due to the enormous losses from the irrigation network, water levels rose by the mid 1950s to 1 to 2 m below land surface, resulting in water logging and soil and groundwater salinization. Earlier studies revealed that conveyance losses in canals varied between 15 to 30 percent. Around 2 million ha were severely and 4.6 million ha moderately affected by salinization. Much of this area had to be abandoned causing enormous economic losses.

In the late 1950s the Salinity Control and Reclamation Project (SCARP) was initiated making use of the following measures: groundwater abstraction, surface drains, conjunctive use of surface and groundwater. To this end 25,000 boreholes were drilled. Groundwater of low salinity is used directly for irrigation, whereas saline water is conveyed via a network of collector drains to the sea.

In the late 1980s SCARP transition projects were aimed at reducing public involvement in the groundwater sector by closing down or transferring public tubewells to the water users. However, many communities refused to take over responsibility for deep tubewells because of high operation and maintenance costs.

Table 4: Irrigation system losses corresponding to canal supplies to IBIS

Description of Losses	Annual System Losses (BCM)			
	1975-80	1980-85	1985-90	1990-95
Canal Conveyance losses	27.4	27.3	26.9	27.0
Watercourse Conveyance Losses	41.3	41.1	40.4	40.7
Field Application Losses	15.5	15.4	15.2	15.3
Total Losses	84.2	83.8	82.5	83.0
Total Canal Diversions	130.7	130.0	128.0	128.8
Overall Irrigation Efficiency (%)	36	36	36	36

Table 5: Indus plain provincial trends of water table depths

Province	Total Area (mha)	Percent Area under Water Table Depth in meters					Total <3 m
		<1	1 - 2	2 - 3	>3	Misc.	
Punjab	10.17	7	11	17	63	2	35
Sindh	5.57	6	24	27	40	3	57
Balochistan	0.35	1	6	9	84	0	16
NWFP	0.62	6	12	6	66	10	24
Total	16.71	7	15	20	55	3	42

NOTE: mha=million hectares

Although investments in drainage have been significant in Pakistan during the last two decades, waterlogging still affects large tracts of land and salinity constrains agricultural production. These problems are further exacerbated by the use of poor quality groundwater. Therefore on the whole, the situation has not much improved with the introduction of the SCARP project.

Guadiana Basin/Spain: The Role of Groundwater User Groups

(source: LLAMAS et al., 1992; LLAMEAS & CUSTODIO, 2001; MORRIS et al., 2003)

The western La Mancha area in the Central Spanish Plateau has been intensively exploited over the past three decades for irrigation. Abstraction increased sevenfold between the mid 1960s and the late 1980s (from 0.2 BCM/yr in 1974 to 0.6 BCM/yr in 1987), resulting in a severe decline of water levels of 20 to 30 m until the mid 1980s, the disappearance of springs, which fed the Guadiana River, and the drying up of the Tablas de Daimiel wetland at the confluence of the Guadiana and Giguela Rivers. The western La Mancha area is characterized by calcareous aquifers with high transmissivity. In 1981 the Guadiana River disappeared. In 1987 the Mancha aquifer was officially declared over-exploited. According to the 1985 water law, the declaration of over-exploitation requires the preparation of a groundwater management plan which must be established in joint cooperation between the basin water authority and groundwater user groups. These groups did previously not exist and had first to be formed. A three year action plan was established in 1988 that had the objective to revive the wetland area mainly by transferring water from other areas to the wetland. However, for different reasons the amount of water actually transferred was by far insufficient so that by the late 1980s the wetland had become an ‘ecological desert’. The abstraction exceeded natural recharge by around 200 – 300 MCM/yr and the transferred amount barely covered 10% of this water deficit. By the water imports the Las Tablas wetland has been restored. However, the overall problem of over-exploitation has not been reduced due to the lack of cooperation of the farmers. After 1994 even 9,000 new illegal wells have been drilled. A positive development started in 1992 with the introduction of the Agrarian Income Compensation Program, supported by the EU in the framework of its agricultural reform program. The program offers the farmers compensation in exchange for a reduction in the amount of water used per hectare of irrigated land, as well as a reduction in the use of chemical fertilizers, pesticides and herbicides. The success of this program, however, is questionable since abstractions were not metered in the first phase of the program and there are still many illegal abstractions. Nonetheless, it has helped to establish user associations and created some level of awareness for the problems.

Figure 10: The Guadiana Basin, a Depleted Groundwater Resource in Central Spain (adopted from LLAMEAS & CUSTODIO, 2001)

After the declaration of over-exploitation, the Guadiana River Basin Agency supported the creation of the General Groundwater User Community that was constituted in 1996. However, some farmers feeling themselves not sufficiently represented in this body established the Castilla-La Mancha Groundwater User Association. The conflict between those two organizations hindered the formulation of common management goals. The recognition of water rights has been the main source for conflicts between the user associations and the government authorities.

This example shows that the formation of user associations is not an easy task and must be actively supported by government authorities. All user groups must be appropriately represented in them so that all water related aspects can sufficiently be addressed. The government can only reach a consensus with such groups if their problems are sufficiently recognized and addressed.

The loss or significant reduction of the wetlands has caused a considerable decrease of evapotranspiration from around 175 MCM/yr in the mid 1970s to about 50 MCM during the 1990s. This in turn results in an increase in available renewable resources of almost 50%, a side-effect which must be considered when establishing a water resources management plan.

Cologne/Germany: Cooperation of Water Utility Companies with Farmers for Groundwater Protection

(source: UBA, 2001; www.rgw.de/drueberunddrunter/)

The elevated nitrate contents in groundwater used for the water supply of Cologne and surrounding communities led to the idea of founding a protection association for soil and groundwater "Drüber & Drunter" (upstream & downstream) in 1985. The main aim of this association was to combine the needs of the farmers for an efficient and profitable agricultural production with the needs of the water utility companies for groundwater protection. The work is funded by money the water utility companies previously paid as compensation to the farmers for leaving their land fallow.

The work consists of several components: part of the already heavily contaminated groundwater was removed, the sewage collection system was rehabilitated, the land with highly permeable soil was bought and remains fallow, and an agricultural extension service was established that gives advice to the farmers. Soil samples were analyzed at regular intervals in order to adapt fertilization to the required level.

Previously the farmers were applying excessive amounts of fertilizers. The protection association provides advice to the farmers how to more efficiently fertilize their land so that no or little nitrogen infiltrates into the groundwater. Crucial in this respect is the selection of crops and the amount and timing of fertilization.

The cooperation has resulted in decreasing nitrate contents and higher agricultural production.

Similar cooperation agreements are now in place in many well field areas for domestic water supply throughout Germany.

Tunisia: Participatory Demand Management

(source: World Bank, 2001a)

The Government of Tunisia recently endorsed a new Water Sector Strategy whose main objective is participatory demand management. This strategy forms the basis for the new World Bank supported Water Sector Investment Project (WSIP) and all future investments in the sector. The strategy specifically addresses the integrated management and conservation of water resources economic efficiency of irrigation water use, and institutional restructuring and capacity building. Under the WSIP, reforms include (1) delegating progressively overall responsibility for the management of irrigation perimeters, including public perimeters, to Water User Associations (WUAs); (2) extending modern cost and income accounting practices to all governorates with a view to introducing transparent contracting and billing between Government and WUAs, and reduce the cost of water delivery in irrigation; (3) implementation of a binomial irrigation tariff structure with a 15% nominal increase for irrigation water per year; (4) establishing a socio-economic unit for water resources management to facilitate future inter-sectoral water allocation decisions; and (5) formulation of a communication strategy for water conservation.

7 Conclusion and Recommendations

In the Arab region the water stresses are among the highest in the world. Between 70 and 90% of the water resources consumed are used for irrigation. Population growth rates of between 2 and 4% per year may lead to a dramatic increase in water scarcity over the next 10 years.

Therefore there is an urgent need for reforms in the water sector. Such reforms are not an easy task and depend on the socio-economic conditions and political willingness. Often water and electricity are highly subsidized in order to maintain political stability. This, however, has often led to the wasting and inefficient use of water, especially in the agricultural sector.

Political reforms implemented in many developing countries in recent years have shown that successful reforms have to strike a careful balance between the demands (for water) and the needs (socio-economic and ecological). A participatory approach instead of a directed approach is needed to come to solutions that meet those demands and needs.

The above listed measures show examples of what could be achieved by which action. However, the hydro(geo)logical, political and socio-economic conditions vary largely from country to country and the management of water resources depends on laws and regulations in many other sectors. Therefore an appropriate concept has to be developed for each individual case and condition. In some cases individual measures may be very effective for achieving a more sustainable management of water resources, in others, however, they may not be applicable or yield negative results. The suggestion of a general concept is thus not possible. The list of measures presented in this report only intends to document how individual countries have tried to overcome their water management problems under their specific conditions.

Generally, an accurate assessment of all available water resources has first to be made. This should be done in the form of a (countrywide) Integrated Water Resources Management Plan (previously often called Water Master Plan). Only when the resources are known they could be distributed according to the national policy. In this plan, water quality problems, water conservation and protection areas have to be integrated, in order not to overestimate the available amounts. In a next step, the demands of all users, the present supply and its infrastructure, and the main problems in water allocation have to be analyzed (compare *Annex A-1*). Proposals and alternatives have to be developed how to increase available amounts and quality of water, how to minimize demands, how to provide an appropriate infrastructure for water allocation, and how to price water resources. The final choice of appropriate measures is commonly supported by a cost-benefit analysis. In this context the existence of a National Water Policy is a key prerequisite because it defines the general conditions for water resources management in a country.

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ZAGONA, E.A., FULP, T.J., GORANFLO, H.M. & SHANE, R.M. (1998): RiverWare: A General River and Reservoir Modeling Environment. – Proceedings of the First Federal Interagency Hydrologic Modeling Conference, 113-120; Las Vegas/USA.

9 Internet Links

(sorted by subject)

Best management practice guides:

Agriculture: *Ontario Ministry of Agriculture and Food (OMAFRA)*: www.gov.on.ca/OMAFRA/english/environment/bmp/series.htm#Soil;

Soil Salinity: *FAO: Land and Water Development Division*: http://www.fao.org/ag/agl/aglw/default.stm; *US Bureau of Reclamation (USBR)*, National Irrigation Water Quality Program - *NIWQP*: http://www.usbr.gov/niwqp/;

Pesticide Management: *FAO, Pesticide Management Unit*: http://www.fao.org/ag/AGP/AGPP/Pesticid/Default.htm;

Pollution prevention: *US EPA* : http://www.epa.gov/watertrain/agmodule/; http://www.epa.gov/ebtpages/pollutionprevention.html or http://www.epa.gov/ebtpages/pollbestmanagementpractices.html

UNIDO (Cleaner Production Program): http://www.unido.org/en/doc/4460 or http://www.unido.org/cp;

World Bank (Pollution Management): www.worldbank.org/pollutionmanagement/ (e.g. pollution prevention handbook: http://lnweb18.worldbank.org/ESSD/envext.nsf/51ByDocName/PollutionPreventionandAbatementHandbook)

Water efficiency: *EPA Water Use Efficiency Program*: www.epa.gov/owm/water-efficiency/index.htm (e.g. Water Conservation Plans); *US Bureau of Reclamation (USBR),* Water Conservation Field Services Program: http://www.usbr.gov/waterconservation/

Rainwater harvesting: www.rainwaterharvesting.org/

Resources: *World Resources Institute (WRI)*: http://www.wri.org/, World Resources Report 2000-2001

Surface water resources: *World Commission on Dams (WCD)*: www.dams.org/ [disbanded in Oct 2001, activities now taken over by UNEP's *Dams and Development Project (DDP)*: www.unep-dams.org.

Water resources (surface and groundwater): *World Water Assessment Program (WWAP)* of UNESCO: www.unesco.org/water/wwap/description/ index.shtml; *World Bank (WB)*: www.worldbank.org/ (country profiles, country sector papers, etc.); *Food and Agriculture Organization (FAO)*: www.fao.org/ (especially the database AQUASTAT: www.fao.org/ag/agl/aglw/aquastat/main/); *International Water Management Institute (IWMI)*: www.cgiar.org/iwmi/

Water quality: *Global Environment Monitoring System (GEMS)* of UNEP: www.cciw.ca/gems/

Shared water resources: UNECE Environment and Human Settlements Division: www.unece.org/env/water/partnership/part.htm

10 Glossary

(partly adopted and modified from FAO, 2003)

Actual/natural: The adjective qualifies the variable and indicates whether it corresponds to a natural situation, i.e. a measure of the water balance without human influence, or an actual situation, i.e. the conditions at a given time taking into account human influence either through uptake abstraction of water or through agreements or treaties. Natural conditions are considered stable over time while actual situations may vary with time and refer to a given period.

Average precipitation (mm/year and km^3/year): Double average over space and time of the precipitation falling on the country in a year.

Average actual evapotranspiration (mm/year and km^3/year): Double average over space and time of evaporation from water bodies, rivers and plants.

Dependency ratio (percent): That part of the total renewable water resources originating outside the country.

External renewable water resources (ERWR; km^3/year): That part of the country's renewable water resources which are not generated in the country. The ERWR include inflows from upstream countries (groundwater and surface water), and part of the water of border lakes or rivers.

Exploitable water resources (km^3/year) (also called manageable water resources or *water development potential*: The water resources considered to be available for development under specific economic and environmental conditions. The computation of exploitable water resources considers factors such as dependability of the flow, extractable groundwater, and minimum flow required for non-consumptive use.

Exploitation index (percent): Withdrawals of conventional freshwater resources (surface and groundwater) in relation to total renewable resources.

Internal renewable water resources (IRWR; km^3/year): Average annual flow of rivers and recharge of aquifers generated from endogenous precipitation.

Natural flow (km3/year): The amount of water that would flow in natural conditions, i.e. without human influence. It contrasts with actual flow, which takes into account upstream abstraction of water and treaties or agreement.

Non-conventional water resources: Total volume of water obtained through the development of new technologies. They are water generations (productions) that come either from desalination of sea and brackish waters, from wastewater regeneration for reuse or rainwater harvesting methods.

Renewable resources: Total resources that are offered by the average annual natural inflow and runoff that feed each hydrosystem (catchment area or aquifer).

Total actual renewable water resources (TARWR; km^3/year): The sum of internal renewable water resources and incoming flow originating outside the country. The computation of TARWR takes into account upstream abstraction and quantity of flows reserved to upstream and downstream countries through formal or informal agreements or treaties. It is a measure of the maximum theoretical amount of water actually available for the country.

Total natural renewable water resources (km^3/year): The sum of internal renewable water resources and natural incoming flow originating outside the country. It does not vary with time.

Total natural outflow (km^3/year): Annual natural outflow of surface and groundwater from a country into the sea or a neighboring country. The Aquastat calculation sheet considers only the outflow into the neighboring countries (natural in general; actual where there is consumption in the country or reservation for downstream countries).

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/
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 A-1: Problem Analysis (Examples)

Issue	Problems	Impacts	Solutions	Actions	Responsibilities	Monitoring/Verification (Indicator)
Groundwater Pollution	Widespread overuse/inefficient use of N-fertilizers	Elevated nitrate contents in water supply wells/springs detected in area xyz	a) Relocate water supply wells (if possible) b) Reduce nitrogen release into groundwater	a) Relocating water supply to area abc b) Ban to use fertilizers during certain time periods, limiting amounts of N-fertilizer to be applied c) Establish and enforce groundwater protection zones d) Establish water conservation/protection program	a) xyz Authority b) Ministry of xyz c) Ministry of xyz d) Ministry of xyz	a) Water supply well(s) for village xyz contain less than x mg/l NO_3 b) Surveys conducted on xx.xx.xx, … showed no fertilizer application on farms in xyz area c) groundwater protection zones established for wells/springs abc, xyz, … , fences erected, … d1) water conservation plan for xyz area issued d2) watershed protection program established and in force in xyz area
	Uncontrolled sewage water infiltration into groundwater from cesspits	Biological contamination of springs in area xyz, …	a) construct sewage water collection system for xyz village, b) enforce regular cleaning and emptying of cesspits, …	…	…	…
	Inefficient treatment of industrial sewage water	Contamination by heavy metals detected in wells xyz, …	a) close down factories b) enforce sewage water	…	…	…

Issue	**Problems**	**Impacts**	**Solutions**	**Actions**	**Responsibilities**	**Monitoring/Verification (Indicator)**
			treatment at factories			
	…	…	…	…	…	...
Surface Water Pollution	...					
Water Level Decline	…					
…	…					
…	…					

Part B - 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 the renewable water resources are very scarce, even though they are distributed fairly uneven (*Figure 11*). In the northern part of some countries of the Maghreb region rainfall is relatively high 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 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 (fossil groundwater).

In sharp contrast to the renewable water resources stands the water withdrawal, especially that for agricultural uses (*Figure 12*), which constitutes often more than 70% of the total water use. In many countries of the Arab region, the water withdrawal for irrigation is responsible for the large deficit in the water budget.

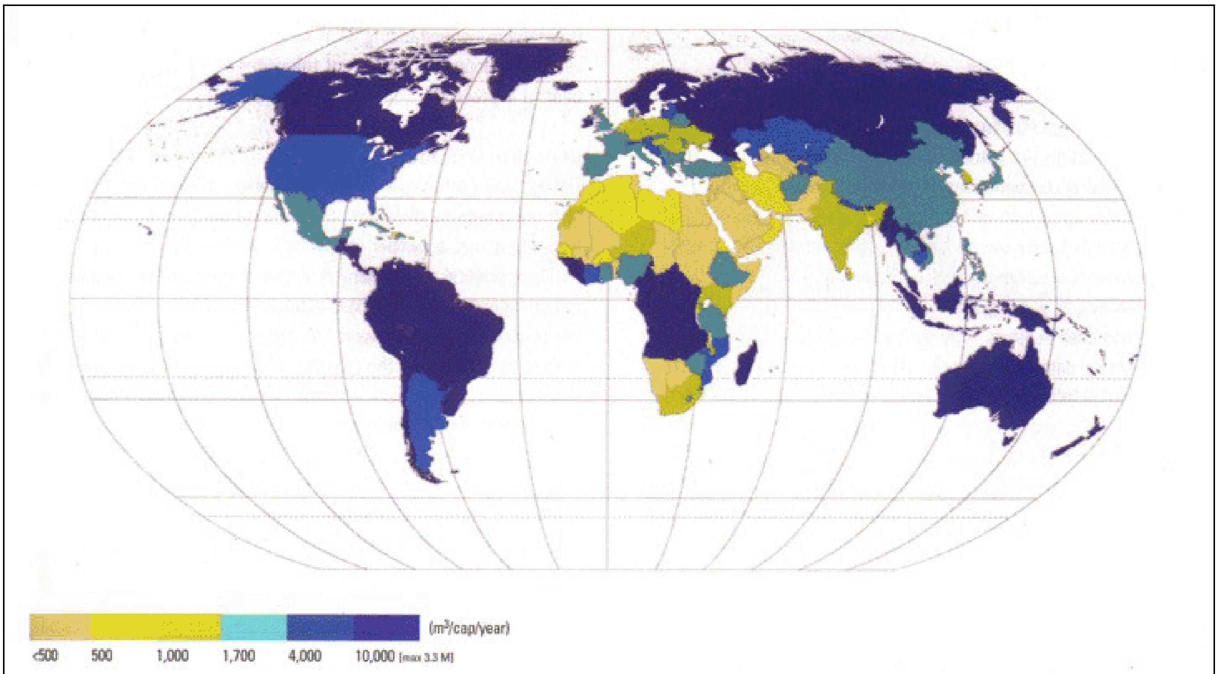

Figure 11: Per capita Internal Renewable Water Resources Generated within a Country (1995) (adapted from UNESCO, 2003)

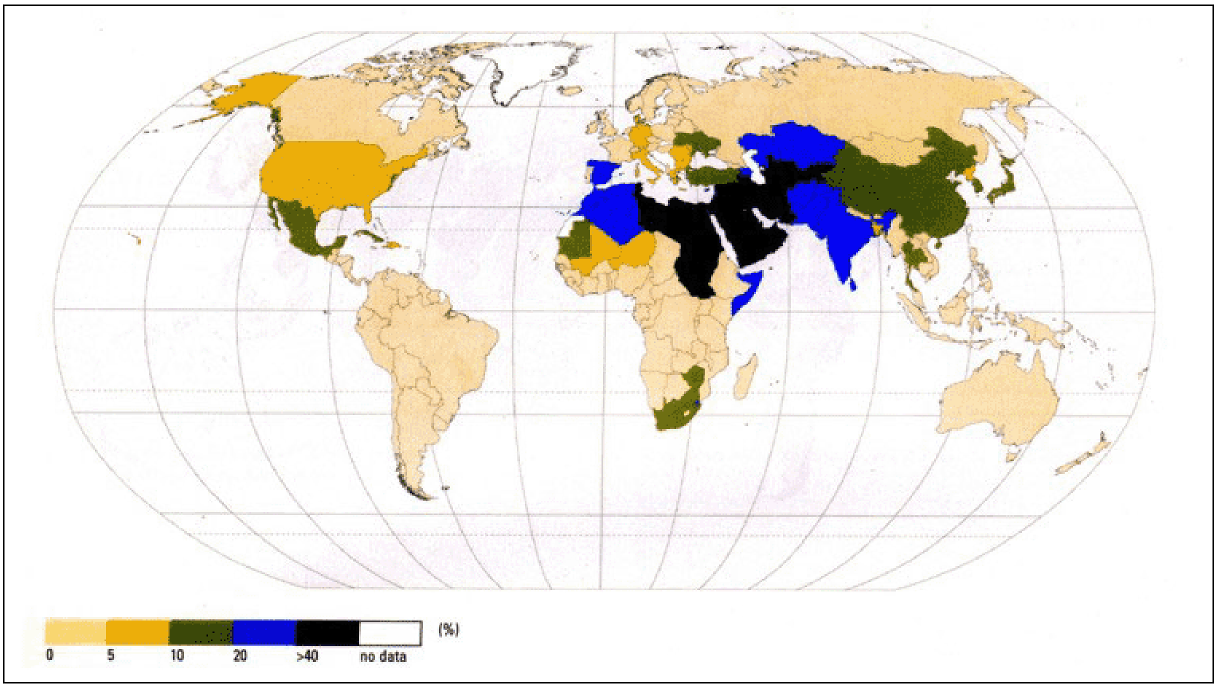

Figure 12: Agricultural Water Withdrawals as Percentage of Renewable Water Resources Generated within a Country (1998)

(adapted from UNESCO, 2003)

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

Country	Renewable Water Resources : Ground-water (km³/yr)	Renewable Water Resources : Surface Water (km³/yr)	Total Renewable Water Resources (km³/yr)	Land Area (km²)	Population in 2000 (1000)	Water Resources Availability per Capita in 1997 (m³/ca/yr)	Ground-water Use (km³/yr)	Desalina-tion (km³/yr)	Waste-water & Drainage reuse (km³/yr)	Water Consump-tion (km³/yr)	Sustaina-bility Index/ Utilization (%)	Water Resources Consump-tion per Capita (m³/ca/yr)
Algeria	*13.00*	*2.00*	*15.00*	2,381,740	*32,362*	*464*	*7.18*	*0.0746*	*0.4*	*7.65*	*51*	*236*
Bahrain	0.10	0.0002	0.1002	690	613	173	0.258	0.286[1]	0.0175	0.31	**309**	506
Djibouti	*0.20*	*0.05*	*0.25*	23,180	*991*	*252*	*0.52*	*0.00015*		*0.52*	***207***	*522*
Egypt	4.10	55.50	59.60	995,450	68,523	925	4.85	0.0066	4.92	65.76	**102**	960
Eritrea			6.30	101,000	3,659	1722						
Iraq	2.00	70.37	72.37	437,370	23,280	2963	0.513	0.0074	1.5	49.1	78	2109
Jordan	0.277	0.475	0.752	88,930	5,003	168	0.486	0.0025	0.061	0.76	**121**	152
Kuwait	0.16	0.0001	0.1601	17,820	2,165	89	0.405	0.603[1]	0.025[1]	0.701	**439**	324
Lebanon	0.60	2.50	3.10	10,230	3,281	995	0.24	0.0017	0.002	1.225	40	373
Libya	*0.40*	*0.65*	*1.047*	1,759,540	*6,562*	*160*	*7.18*	*0.21*	*0.11*	*7.50*	***716***	*1142*
Mauritania	*5.80*	*1.50*	*7.30*	1,025,220	*2,327*	*3137*	*1.03*	*0.0017*	*0.0676*	*1.10*	*15*	*471*
Morocco	*22.50*	*7.50*	*30.00*	446,300	*28,781*	*1042*	*12.85*	*0.0012*	*0.35*	*13.20*	*44*	*459*
Oman	0.55	0.918	1.468	212,460	2,518	613	1.644	0.051	>0.04[1]	1.721	**117**	683
Qatar	0.085	0.0014	0.0864	11,000	579	98	0.185	0.300[1]	>0.04[1]	0.298	**345**	515
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
Somalia	*3.30*	*8.16*	*11.46*	627,340	*10,916*	*1050*	*1.95*	*0.0001*		*1.95*	*17*	*178*
Sudan	*1.00*	*26.00*	*27.00*	2,376,000	*33,064*	*817*	*22.95*	*0.0006*		*22.95*	*85*	*694*
Syria	5.10	16.375	21.475	183,780	16,125	1438	3.5	0.002	1.447	9.81	46	608
Tunisia	*2.70*	*1.94*	*4.64*	155,360	*9,480*	*489*	*2.91*	*0.0087*	*0.006*	*2.92*	*63*	*308*
UAE	0.13	0.185	0.315	83,600	2,441	137	0.9	1.874[1]	0.108	1.223	**388**	501
West Bank & Gaza	0.185	0.03	0.215	5,800	*2,859*	*262*	0.2	0.0005	0.002	0.44	***205***	154
Yemen	1.40	2.25	3.65	527,970	18,654	303	2.2	0.009	0.052	2.9	**779**	155

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

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

Country	Total Internal Renewable Water Resources (km³/yr)	Groundwater: Produced Internally (km³/yr)	Surface Water: Produced Internally (km³/yr)	Overlap: Surface – Groundwater (km³/yr)	Total Renewable Water Resources (km³/yr)	Land Area (km²)	Population in 2000 (1000)	Water Resources Availability per Capita (m³/ca/yr)
Algeria	13.90	1.70	13.20	1.00	14.49	2,381,740	30,291	478
Bahrain	0.004	0.00	0.004	0.00	0.12	690	640	181
Djibouti	0.30	0.02	0.30	0.02	0.30	23,180	632	475
Egypt	1.80	1.30	0.50	0.00	58.30	995,450	67,884	859
Eritrea	2.80					101,000	3,659	1,722
Iran	128.50	49.30	97.30	18.10	137.51	1,622,000	70,330	1,955
Iraq	35.20	1.20	34.00	0.00	75.42	437,370	22,946	3,287
Jordan	0.68	0.50	0.40	0.22	0.88	88,930	4,913	179
Kuwait	0.00	0.00	0.00	0.00	0.02	17,820	1,914	10
Lebanon	4.80	3.20	4.10	2.50	4.41	10,230	3,496	1,261
Libya	0.60	0.50	0.20	0.10	0.60	1,759,540	5,290	113
Mauritania	0.40	0.30	0.10	0.00	11.40	1,025,220	2,665	4,278
Morocco	29.00	10.00	22.00	3.00	29.00	446,300	29,878	971
Oman	0.99	0.96	0.93	0.90	0.99	212,460	2,538	388
Qatar	0.05	0.05	0.001	0.00	0.05	11,000	565	94
Saudi Arabia	2.40	2.20	2.20	2.00	2.40	2,149,690	20,346	118
Somalia	6.00	3.30	5.70	3.00	13.50	627,340	8,778	1,538
Sudan	30.00	7.00	28.00	5.00	64.50	2,376,000	31,095	2,074
Syria	7.00	4.20	4.80	2.00	26.26	183,780	16,189	1,622
Tunisia	4.15	1.45	3.10	0.40	4.56	155,360	9,459	482
UAE	0.15	0.12	0.15	0.12	0.15	83,600	2,606	58
West Bank & Gaza	0.75	0.68	0.07	0.00	0.75	5,800	2,859	-
Yemen	4.10	1.50	4.00	1.40	4.10	527,970	18,349	223

source: UNESCO (2003)

Table B-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 Resources Management in Morocco

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

General Aspects

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.

Water Resources

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 reuse for agricultural 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, similar to the system applied in France (compare *Part A, Chapter 6*).

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.

<u>Trends in water resources management</u>

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 increase 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 the 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.

Four big cities (Casablanca, Rabat, Tangier and Tetouan) are already under the management of private sector companies for water supply, sanitation and electricity. In Casablanca, LYDEC, consisting of a consortium of Suez Lyonnaise des Eaux (35%), ELYO (24%), EDF Int. (18%), ENDESA (18%) and AGBAR (5%), was awarded a 30-years delegated management contract in 1997. In 2001 a 25-years concession was given to AMENDIS, a consortium lead by the French company Vivendi Env. (51%).

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Questionnaire was not returned.

1. How is ‘sustainable yield’ defined ?

No information.

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).

No information.

3. What is the share of groundwater in the different sectors of water supply ?

No information.

4. What are the main factors influencing groundwater resources management decisions (demand driven economical considerations sociological considerations etc.) ?

No information.

5. What are the main problems in groundwater resources management ?

No information.

6. Is domestic water supply in the hand of governmental institutions or privatized/semi-privatized ?

No information.

7. Do the water tariffs cover the costs of installation/operation/ maintenance ? List the water tariffs for domestic/agricultural/industrial uses.

No information.

8. Which measures are being used for the augmentation of water resources (artificial recharge wastewater reuse watershed/rainwater harvesting etc.) ?

No information.

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 ?

No information.

10. Which water management policies (institutional regulatory and resources management measures) have been implemented to achieve a status of sustainable groundwater resources management ?

No information.

3 Groundwater Resources Management in Tunisia

(modified after El BATTI, 2003; various World Bank reports and FAO Aquastat)

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.

Trends in Water Resources Management

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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Questionnaire was not returned.

1. How is ‘sustainable yield’ defined ?

No information.

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).

No information.

3. What is the share of groundwater in the different sectors of water supply ?

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4. What are the main factors influencing the groundwater resources management decisions (demand driven economical considerations sociological considerations etc.) ?

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5. What are the main problems in groundwater resources management ?

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6. Is domestic water supply in the hand of governmental institutions or privatized/semi-privatized ?

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7. Do the water tariffs cover the costs of installation/operation/ maintenance ? List the water tariffs for domestic/agricultural/industrial uses.

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8. Which measures are being used for the augmentation of water resources (artificial recharge wastewater reuse watershed/rainwater harvesting etc.) ?

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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 ?

No information.

10. Which water management policies (institutional regulatory and resources management measures) have been implemented to achieve a status of sustainable groundwater resources management ?

No information.

4 Groundwater Resources Management in Egypt

(modified after KHATER, 2003, NWRC homepage and FAO Aquastat)

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 (ESCWA, 2003: 4.1 BCM). 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 B-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 B-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 B-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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Questionnaire was not returned.

1. How is ‘sustainable yield’ defined ?

Not specified.

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).

See *Table B-4*.

3. What is the share of groundwater in the different sectors of water supply ?

No data.

4. What are the main factors influencing the groundwater resources management decisions (demand driven economical considerations sociological considerations etc.) ?

Not specified,

5. What are the main problems in groundwater resources management ?

See *Table B-6*.

6. Is domestic water supply in the hand of governmental institutions or privatized/semi-privatized ?

In recent years, private participation focused mainly on the irrigation sector. The legal framework has been amended to liberalize the agricultural sector, decentralize the water sector, including the participation of the private sector, and promote cost recovery. So far, private sector has had limited involvements in terms of water users associations and water board projects. Cost recovery in the country is now possible for irrigation projects, sub-surface drainage, new lands, and mega projects like the Toshka. Since the operation and maintenance activities of irrigation projects are expensive, it is necessary to encourage the farmers to pay at least part of these costs. The cost-recovery based on consumption of water for different crops has been accepted more easily. However, achieving cost recovery based on the volumetric uses of water has proved to be difficult, mainly due to its economic and social impacts on the users.

Concerning private sector participation and groundwater used, there is no information.

7. Do the water tariffs cover the costs of installation/operation/ maintenance ? List the water tariffs for domestic/agricultural/industrial uses.

No information.

8. Which measures are being used for the augmentation of water resources (artificial recharge wastewater reuse watershed/rainwater harvesting etc.) ?

No information.

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 ?

No information.

10. Which water management policies (institutional regulatory and resources management measures) have been implemented to achieve a status of sustainable groundwater resources management ?

No information.

5 Groundwater Resources Management in Jordan

(source: MARGANE et al., 2002; MARGANE & ALMOMANI, 2002 ; MARGANE & SUNNA, 2002 ; FAO Aquastat)

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 B-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.

<u>Institutional Aspects</u>

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 m³/ha per year, which is much less than in the highlands where it reaches on average 16,000 m³/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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1. How is ‘sustainable yield’ defined ?

Safe yield is considered to be equal to the total internally produced renewable groundwater resources. However, recently the exploitation of the fossil groundwater resource in the Disi (Ram Group) aquifer in southern Jordan has also been included in the safe yield, even though this resource is under present climatic conditions not replenished.

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).

Based on the abstraction data collected by the Ministry, the total groundwater abstraction from wells was (1591 production wells in 2001) :

BASIN	2001	2000	1999	1,998	1997	1996	1995
AB	34,407,329	37,230,266	36,487,885	38,283,756	36,380,476	38,115,783	40,961,799
AD	46,973,648	44,941,518	41,950,591	39,230,796	36,805,955	43,408,182	40,621,123
AE	13,807,225	13,837,817	14,805,836	16,087,776	16,588,230	17,362,310	18,971,368
AF	1,431,228	1,542,890	1,858,658	1,773,552	1,541,295	1,632,315	1,632,290
AH							17,287
AK	321,660	248,038	186,068	215,712	229,310	380,704	387,876
AL	130,766,916	131,003,013	137,811,083	139,238,484	137,435,867	151,653,540	141,946,510
AM	1,459,932	1,718,746	1,911,847	2,397,252	2,063,366	2,415,007	1,591,328
AN	3,929,123	4,562,917	4,846,911	6,132,840	6,092,715	5,903,233	2,974,715
AP	806,856	837,504	815,988	1,114,440	1,318,000	1,131,500	624,000
CA	7,560,173	6,929,241	5,613,027	6,634,044	6,726,810	6,087,198	3,048,570
CC	742,764	588,864	609,120	621,312	444,248	477,299	411,173
CD	58,481,426	64,291,021	66,262,142	67,217,724	68,050,626	68,170,578	76,425,182
CE		45,996	56,004	47,004	45,650	13,000	132,100
CF	7,932,164	10,278,706	10,305,894	10,547,832	11,024,504	11,074,325	10,769,202
DA	3,983,047	3,156,386	3,243,685	3,547,800	4,264,767	4,939,234	5,608,338
DE	584,496	116,808	50,004	69,804	147,580	179,530	35,100
DF	1,011,791	453,090	332,992	193,692	155,717	133,100	86,753
DG	3,996	4,200	4,500	4,704	4,900	4,800	
EA	814,983	769,517	520,502	328,008	484,871	703,508	496,565
ED	36,635,068	44,148,516	44,376,109	42,795,672	40,805,234	52,128,337	53,439,349
F	58,227,570	56,748,483	56,449,885	55,672,740	53,900,535	53,049,441	52,484,998
G	21,924,946	24,685,325	23,549,893	23,270,568	20,220,852	21,333,981	17,502,802
H	1,063,966	1,249,953	1,147,383	1,298,964	1,251,102	1,020,049	892,046
J	1,955,580	2,029,500	1,820,496	1,469,808	1,526,800	2,471,000	2,698,860
K	22,814,296	22,408,638	26,380,028	26,889,516	36,696,152	24,973,380	23,049,850
Grand Total	457,640,183	473,826,953	481,396,531	485,083,800	484,205,562	508,761,334	496,809,184

Figure B-1: Groundwater Abstraction between 1995 and 2001 by Surface Water Basins (MWI data)

At least around 40 % of the groundwater comes from the A7/B2 aquifer. Around 14 % are abstracted from the Ram Group aquifer. In 1996, almost 80 % of the total annual groundwater withdrawal in Jordan originated from the northern and central part of the country.

In 2001 about 58 % of the consumption was provided from groundwater resources and approximately 70 % of the total amount of water was used for irrigation.

The safe yield is estimated at 277 MCM/yr.

3. What is the share of groundwater in the different sectors of water supply ?

In 1993, the share of water uses was as follows: irrigation: 73.4%, municipal: 22.1%, industrial & desertic: 4.5%. The average annual increment in water consumption between 1985 and 1993 was 7%.

4. What are the main factors influencing the groundwater resources management decisions (demand driven economical considerations sociological considerations etc.) ?

In the past, until the mid 1990s, water resources management was only supply oriented. With increasing deficits in the water budget and resulting severe water level declines in many areas of up to 2 m/yr and more, the Ministry of Water and Irrigation

(MWI) in 1998 introduced a water strategy and water policies for the four sectors: groundwater management, water utilities, irrigation water and wastewater management, containing measures on monitoring; resource protection, sustainability, and quality control; resource development; priority of allocation; regulation and control; legislation and institutional arrangements; research, development and technology transfer; shared groundwater resources; public awareness; private sector participation; etc.

5. What are the main problems in groundwater resources management ?

1) Water demand for irrigation is still very high and until now is met mainly by groundwater exploitation (70%). Wastewater reuse is still comparatively low, mainly due to the low efficiency of waste water treatment plants.

2) Water is not used efficiently in the agricultural sector. Most farmers still apply furrow irrigation instead of water saving technologies. Soil salinization is occurring in many areas (e.g. Dhuleil-Hallabat, NE-desert, Azraq).

3) The share of UFW is in many areas still around 50%, due to high physical water losses and numerous illegal connections.

4) Altogether, 55% of the households are served by wastewater sewers. Many villages in the highlands are not connected to STPs. The traditionally used cesspits allow for large scale infiltration into the groundwater. The sewage collection network in cities like Salt and Irbid is still from Ottoman times and thus considerable leakage to the groundwater resources occur. As a result, many springs in the highlands are affected by bacteriological contamination and had to be closed down for public water suppy.

6. Is domestic water supply in the hand of governmental institutions or privatized/semi-privatized ?

Water supply is almost entirely in the hand of the Government through Water Supply Corporations (WSCs) owned by the municipalities. Since 1999 the water supply for Amman is managed for a duration of 51 months by a consortium led by the French company Lyonnaise des Eaux (LEMA; water and wastewater management contract financed by a 55 Million USD loan of the World Bank for investments to rehabilitate the existing water plants and networks and to restructure the water services.).

7. Do the water tariffs cover the costs of installation/operation/ maintenance ? List the water tariffs for domestic/agricultural/industrial uses.

(source: TAHA & BATAINEH, 2002)

The current pricing structure for municipal water was introduced in October 1997.

Table B-8: Tariffs for municipal water and wastewater in Jordan

Amount (m^3)/month	***Charge (JD/m³)***	***Total bill value of water (JD)***	***Total bill value of wastewater (JD)***
Amman Water & Wastewater Tariff Residential (Bill Calculation)			
0 - 20	0.3	2.0	0.6
21 - 40	0.3	0.14(q)-0.8	0.04 (q) - 0.2
41 -130	0.3	0.006556(q^2)-0.12224(q)	0.002889(q^2)-0.07556(q)
131 - more	0.3	0.85(q)	0.35(q)
Other Governorates & Jordan Valley Tariff Residential (Bill Calculation)			
0 - 20	0.3	1.3	0.6
21 - 40	0.3	0.075(q)-0.2	0.035(q) - 0.1
41 - 185	0.3	0.004517(q^2)-0.10568(q)	0.001828(q^2) - 0.038103(q)
> 185	0.3	0.85(q)	0.35(q)
Commercial Rates			
6 – more	0.3	1 (q)	0.5(q)
Water for Agricultural Use			
Treated Wastewater			0.01/ m^3
Freshwater:			
0 - 2500			0.08/ m^3
2500 - 3500			15 fils / m^3
3500 - 4500			20 fils / m^3
> 4500			35 fils / m^3

Source: Water Authority of Jordan, 2002. q = Quantity, 1 JD = 1,000 Fils = $ 1.412

These tariffs show a fixed tariff for a 0-20m^3 block, with a minimum of 20m^3 and an increasing price for each additional consumed cubic meter of municipal water.

The current pricing structure for municipal water was devised on the base of cost recovery of the maintenance and operation costs. However, the water tariffs in Jordan were structured in such a way as to guarantee the minimum needed consumption at a subsidized fixed price per m^3 and to recover these subsidies from customers with higher consumption assuming the more consumptive customers to be wealthier. It is designed to possibly cover the service costs while keeping lifeline use affordable to the poor. The progressive pricing is at the same time a controlling mechanism to water wastage.

The charges for water and wastewater are primarily based on the amount of water consumed.

Water meter are read once each quarter of a year. The volume of water and wastewater for which the customer is invoiced is based on the total of measured consumption between two readings and estimated consumption from the last reading to the due date of the invoice.

The sale price of treated wastewater, only for irrigation, is 0.01 JD/m^3 and is to cover at least the operation and maintenance costs of the treated wastewater.

Presently, the price of water does not cover the costs in Jordan. Subsidies during the time period 1993-2000 varied between 40 and 60 % of total expenses.

8. Which measures are being used for the augmentation of water resources (artificial recharge wastewater reuse watershed/rainwater harvesting etc.) ?

1) Pilot projects for artificial recharge have been conducted in the desertic areas using small dams and at Qatrana dam.

2) Pilot projects for rainwater harvesting using small cisterns and other methods have been conducted in the Kerak and other areas of the highlands.

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 ?

1) The entire eastern part of the A7/B2 aquifer, the main exploited aquifer in Jordan, is brackish, containing water with a TDS exceeding the national standard for drinking water of 1,500 mg/l (JISM standard 286/2001). This portion constitutes approximately 40% of the aquifer storage.

2) Large parts of the A7/B2 aquifer in the most heavily cultivated areas of the NE-desert and the area south of Amman are affected by contamination with nitrate.

3) Parts of the A7/B2 and other aquifers in the highlands are affected by bacteriological contamination due to infiltration of sewage water. Because of this, a number of springs and wells had to be closed down for domestic water supply (e.g. in Ajloun, Jerash, Wadi as Sir, and the Wadi Shuayb catchment area).

10. Which water management policies (institutional regulatory and resources management measures) have been implemented to achieve a status of sustainable groundwater resources management ?

The MWI in 1998 introduced policies for groundwater resources management, water utility management, irrigation management and wastewater management.

The issuance of abstraction licenses for irrigation has been restricted and water tariffs for irrigation water were introduced.

Although there is no law yet to allow for a stricter protection of the groundwater resources, the MWI intends to introduce the implementation of groundwater protection zones in the coming few years.

A new environmental law was passed by the Parliament but not yet ratified by the King. After enactment of this law an Environment Ministry will be formed which will also be in charge of protection of water resources.

6 Groundwater Resources Management in Syria

(modified after MISKI & SHAWAF, 2003; KHOURI, 2000; FAO Aquastat; UNDP & WORLD BANK, 2000; WORLD BANK, 2001a)

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 B-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 B-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 B-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 B-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 B-13 summarizes the total water uses in Syria for 1997.

Table B-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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1. How is ‘sustainable yield’ defined ?

Sustainable yield is defined as the total abstraction from groundwater that does not cause depletion of the groundwater reserves. Sustainable yield is not exceeded when the renewable amount of groundwater in each basin does not surmount abstraction.

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).

Table B-13 shows the renewable water resources originating inside Syria, amounting in total to 9,929 MCM/yr. The share of Syria from the Euphrates River is on average 6,627MCM/yr, that of the Tigris River 1,250 MCM/yr. Therefore the total available water resources are 17,806 MCM/yr.

Table B-14: Water Uses in Syria for the year 2002

Water Use	Volume in MCM
Domestic	1,070
Irrigation	13,973
Industrial	561
Other (including evaporation from water bodies)	1,962
Total	17,566

source: Ministry of Irrigation, Eng. S.A. Shawaf

Table B-14 illustrates that in 2002 the available water resources were used to 98,7%.

3. What is the share of groundwater in the different sectors of water supply ?

Table B-15: Share of Groundwater in the different Sectors in Syria in 2002

Water Use	Volume in MCM	Percentage
Domestic	761	71
Irrigation	8,048	58
Industrial	325	58
Total	9,134	52

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.) ?

1) The availability of good groundwater in all the Syrian basins at reasonable depths leads to the relying on groundwater as main source for drinking water in rural areas. Individual farmers rely on groundwater as well in case of no adequate surface water irrigation network being available.

2) 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 economic factors, many farmed areas exceed the defined limits and farmers rely on groundwater for irrigation.

3) In dry years, when the quantities of surface water impounded in lakes fail to cover the demands, more pumping of groundwater becomes the sole solution despite drastic water level drawdowns.

5. What are the main problems in groundwater resources management ?

1) Inadequate coordination between Ministry of Irrigation who licenses water wells and the Ministry of Interior (police) who should close illegal wells.

2) Inadequate groundwater monitoring networks.

3) The technicians who are in charge of groundwater management and monitoring need continuous education and training.

4) Pollution of groundwater by nitrate due to the use of nitrogen fertilizers or treated sewage water in irrigation. Some wells in the Dera'a and Idlib governorates have shown high nitrate contents, and the Ministry of Housing and Utilities was obliged to abandon these wells and look for other sources of drinking water.

5) Salinization of groundwater caused by excessive irrigation and poor drainage, such as in the Raqqa governorate.

6) Excessive pumping of groundwater in the coastal plains between Jablah and Banias has caused sea water encroachment and groundwater quality deterioration.

7) The deep groundwater in the Badia basin has generally high salinity and is not suitable for drinking and irrigation. The Ministry of Housing and Utility and the Ministry of Irrigation in 2003 will start to build pilot desalination plants.

8) The lack of appropriate water legislation. The draft water law, now still under discussion in the parliament, will enable the Ministry of Irrigation to set up standards for all waters and control all water uses.

6. Is domestic water supply in the hand of governmental institutions or privatized/semi-privatized ?

The domestic water supply is in the hand of governmental institutions. In each 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 drinking water supply to 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 that are equally applied all over Syria, one for irrigation water, the other for drinking water. For irrigation water annual fees are collected at the rate of 3,500 SP (1USD = 50 SP) per irrigated hectare. The drinking water tariff, effective since 2001, is:

Table B-16: Tariffs for Drinking Water in Syria since 2001

Consumption for 3 months (m^3)	**Tariff (SP/ m^3)**
1-60	3.00
61-90	4.50

Consumption for 3 months (m³)	**Tariff (SP/ m³)**
91-180	13.50
≥ 181	19.00
Commercial, Touristic, Industrial	22.00
Government Buildings	8.50

Upon billing, 20% is added is added to the bill of household consumption to cover sewerage services, while about 40% is added for commercial, touristic and industrial users and 55% for government buildings.

8. Which measures are being used for the augmentation of water resources (artificial recharge wastewater reuse watershed/rainwater harvesting etc.) ?

1) Use of treated sewage water:

In the Barada and Awaj basin 18,000 ha are irrigated by treated sewage water transferred from the Adra STP mainly to the Ghouta area east of Damascus.

In the Assi basin 100 ha are irrigated treated sewage water from the Salamiyeh STP.

Upon the completion of another 10 STPs in Syria, there will be in total around 400 MCM/yr of treated sewage water for irrigation.

2) Use of industrial drainage water:

In the Assi basin 229 MCM/yr are used for industrial purposes. Of this amount, 29 MCM are lost, while 200 MCM are returned to the Assi River and used for irrigation after treatment.

3) Use of irrigation drainage water:

The reuse of irrigation drainage water implies less health and environmental hazards than treated sewage water. In the Ghab Development Project in the Assi basin, 17,400 ha are irrigated by irrigation drainage water. Here, water demand is estimated at 124MCM/yr.

4) Artificial groundwater recharge:

The Damascus Water Supply and Sewerage Authority (DAWSSA), in cooperation with the Ministry of Irrigation has started in 2001 to recharge the aquifer in Damascus city by excess water from the Figheh spring during the wet season using large diameter wells. In 2002, 2 MCM were recharged.

5) Rainwater harvesting:

In the Badia basin, hafirs have been used since 1995 for rainwater harvesting. By the year 2000 there were 34 hafirs with a total storage capacity of 2.9 MCM. Water spreading has also been practiced since 1993 in Badia to increase soil humidity. This method was applied on 655 ha in 1997.

6) Cloud seeding:

The Ministry of Agriculture and Agrarian Reform started in 1992 a project for cloud seeding. Various methods have been used during the feasibility phase.

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 ?

This share differs from one basin to the other. In general it is considered to be around 10-15%.

1) The deep aquifers in the Badia basin have high salinity, rendering the groundwater unsuitable fro drinking purposes.

2) In the Coastal basin, excessive pumping has caused sea water intrusion to the aquifers and obliged the Ministry of Housing and Utilities to rely on the water of the Sinn spring to provide domestic water supply to all the cities and towns of the coastal strip.

3) In Damascus some wells have penetrated gypsum lenses in the Mezze area and were abandoned as water supply wells.

4) The main constituents responsible for rendering groundwater wells unusable for drinking purposes are nitrates and ammonia, resulting from excessive use of organic and chemical fertilizers. Some domestic water wells in the southern part of Damascus city with high nitrate content have been abandoned, at others water is mixed with Figheh spring water to lower nitrate contents below maximum allowable limits. The drinking water wells for Idlib city in the Omk plain (Assi basin) were rendered unusable because the surrounding area that previously had been a marsh area dried up after groundwater development. This area became irrigation area and, due to excessive use of fertilizers became polluted by nitrate. The Ministry of Housing and Utilities now provides water to Idlib from Ain Zarqa spring in Assi basin.

10. Which water management policies (institutional regulatory and resources management measures) have been implemented to achieve a status of sustainable groundwater resources management ?

1) Water resources are considered as public property, owned by the Government. The Ministry of Irrigation has the right to issue water extraction licenses to government bodies, groups of people, or individuals to exploit water resources based on the according regulations.

2) Water structures like dams, irrigation canals, drinking water distribution networks, or aqueducts are constructed and owned by the Government, who also supervises their exploitation and maintenance. Water structures in the private sector are mainly wells which need licensing from the Ministry of Irrigation, provided that aquifer conditions permit so.

3) Water use is managed by the Ministry of Irrigation who is authorized to allocate water for all users, giving priority to drinking water supply, then to industrial, touristic and irrigation uses. The Ministry of Irrigation imposes regulations for rationalizing the water use for irrigation encouraging modern irrigation methods.

4) In each of the seven hydrologic basins of Syria, the responsible General Directorate of Irrigation conducts the necessary studies for water resources development and land reclamation projects in that basin, taking into account the preservation of valuable environmental habitats.

5) The Syrian Government has implemented several projects to develop the main springs, like Sinn, Figheh, Barada, Banias, Ain Tannour and to regulate their discharge and use.

6) The Ministry of Irrigation conducts deep aquifer exploration studies.

7) A draft water law has been prepared by the Ministry of Irrigation and is under discussion in the Parliament. This law updates and replaces all existing water legislation and aims to provide the basis for the sustainable use of surface water and groundwater resources.

8) Capacity building of personnel working in the groundwater domain takes place through on-the-job training and cooperation with foreign experts as well as through training abroad.

7 Groundwater Resources Management in Yemen

(source: FAO Aquastat and diverse WORLD BANK documents)

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 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.

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 levelling 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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Questionnaire was not returned.

1. How is ‘sustainable yield’ defined ?

No information.

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).

No up-to-date information.

3. What is the share of groundwater in the different sectors of water supply ?

No information.

4. What are the main factors influencing the groundwater resources management decisions (demand driven economical considerations sociological considerations etc.) ?

No information.

5. What are the main problems in groundwater resources management ?

No information.

6. Is domestic water supply in the hand of governmental institutions or privatized/semi-privatized ?

No information.

7. Do the water tariffs cover the costs of installation/operation/ maintenance ? List the water tariffs for domestic/agricultural/industrial uses.

No information.

8. Which measures are being used for the augmentation of water resources (artificial recharge wastewater reuse watershed/rainwater harvesting etc.) ?

No information.

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 ?

No information.

10. Which water management policies (institutional regulatory and resources management measures) have been implemented to achieve a status of sustainable groundwater resources management ?

No information.

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Annex B-1: Information requested for Guideline on Sustainable Groundwater Resources Management

1) Which criteria are used to define 'sustainable yield' (resource replenishment, political factors, social factors, economical factors, ecological factors) ? Are fossil groundwater resources included in the sustainable manageable resources ? What are the main factors influencing groundwater resources management decisions (demand driven, economical considerations, sociological considerations, etc.) ?

e.g.: sustainable yield = groundwater recharge
e.g.: sustainable yield = groundwater recharge + temporary demand
e.g.: agricultural self-reliance is a key political issue, more important than sustainable water resources management

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) for the entire country.

Abstraction (MCM/yr)

	domestic	industrial	agricultural	total
surface water				
groundwater				

for year with latest complete set of records

Safe Yield/Sustainable Yield (MCM/yr)

Groundwater Recharge (MCM/yr)

3) What are the main problems in groundwater resources management ?

Problem/Area	*Reason*
e.g.: bacteriological pollution of springs in the xx area/basin	e.g.: missing sewage water collection/treatment systems
e.g.: increasing groundwater salinity in xx area/basin	e.g.: inappropriate soil drainage

4) Is domestic water supply in the hand of governmental institutions or privatized/semi-privatized ?

5) List the water tariffs for domestic/agricultural/industrial uses. Does the domestic tariff cover sewage water collection/treatment ? Do the water tariffs cover the costs of installation/operation/ maintenance ?

Domestic Sector

Consumption (m³/month)	Charge per m³ (local currency)

1USD = xx

The same for the other sectors

8) Which measures are being used for the augmentation of water resources (artificial recharge, wastewater reuse, watershed/rainwater harvesting, etc.) ?

Measure/Name/Area	*Date/Year*	*Capacity (MCM/yr)*
e.g.: Artificial recharge dam xxx		

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 ?

Aquifer or Basin Name	*Reason*	*Share (%)/Amount (MCM)*
e.g.: xx aquifer (countrywide)	e.g.: salinity exceeding maximum allowable limit of xx mg/l TDS (mainly in xx area/basin), limited use for irrigation possible	xx % of safe yield

10) Which water management policies (institutional, regulatory and resources management measures) have been implemented to achieve a status of sustainable groundwater resources management ?

Strategy	*Rationale*
Integrated Water Resources Management Plan	
Use of water resources other than local (import)	
Increase of recharge to groundwater systems	
Rainwater harvesting	
Desalination	
Decrease of discharge from groundwater systems	
Water shed protection	
Groundwater protection zones	
Introduction of Best Management Practice (in domestic/industrial/agricultural sector)	
Institutional & legal reforms	
Treaties on shared water resources (transboundary)	
Cost recovery	
Decentralization	
Water user associations	
Restricting abstraction licenses	
Promotion of private water supply companies (for all sectors)	
Creation of water markets (tradable water rights)	
Promotion of and incentives for water saving/increasing efficiency	
Subsidies for water resources augmentation	
Managing demand through water pricing	
Stakeholder participation	
Temporary restrictions for water consumption/use	
Collecting fees for water quality conservation	
Reduction of water discharges into or abstraction from ecological valuable habitats	
Drought/inundation prevention	

Please attach the relevant laws/by-laws/guidelines/standards concerning groundwater resources management (if possible in English/French).

Annex B-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

A. F. Miski & S. Shawaf

for

ACSAD-German Technical Cooperation Project

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

Damascus
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Table of Contents

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

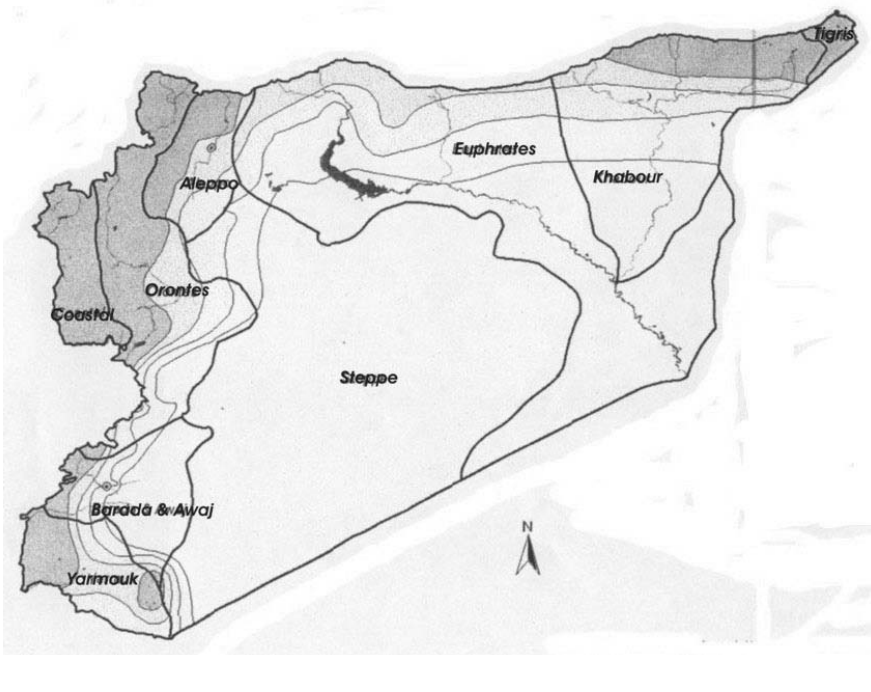

Figure 2: Hydrological Basins of Syria

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 B-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
Arab Centre for the Study of
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Contents

List of Tables

List of Figures

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).

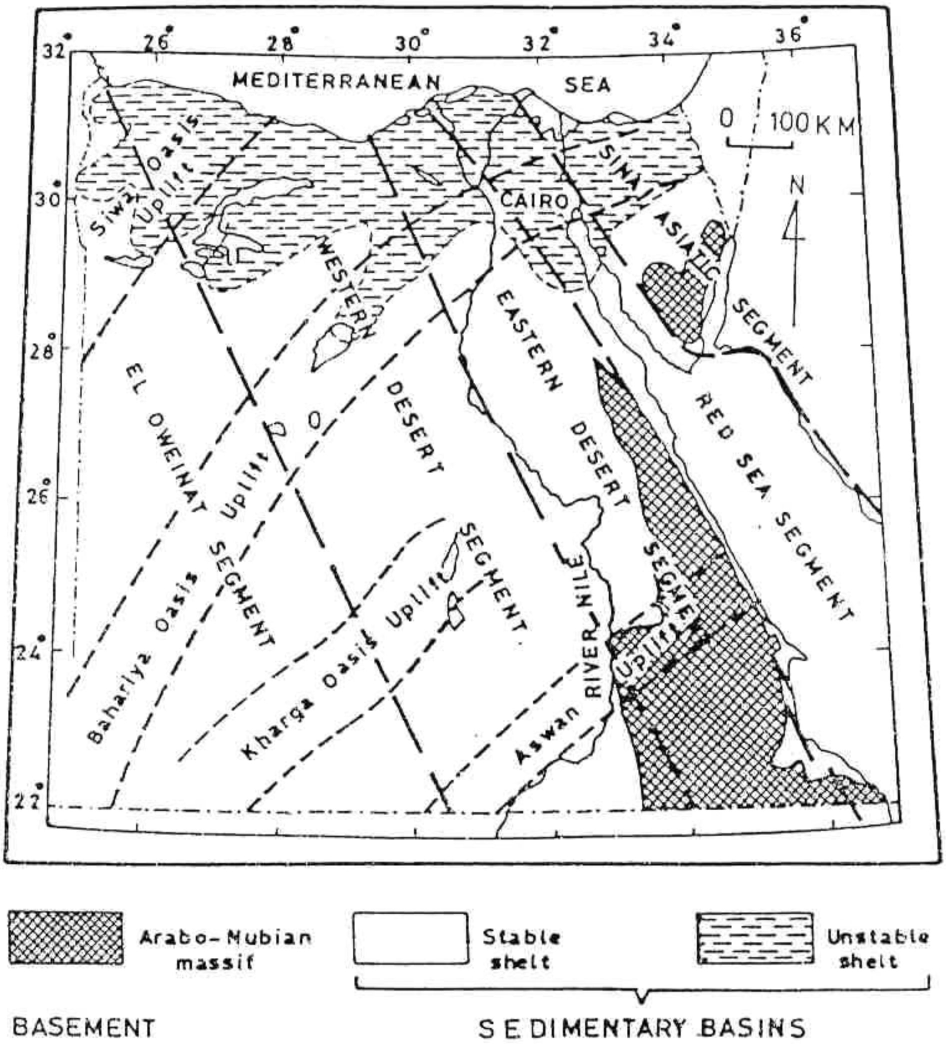

Figure 2. Tectonic Map of Egypt

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).

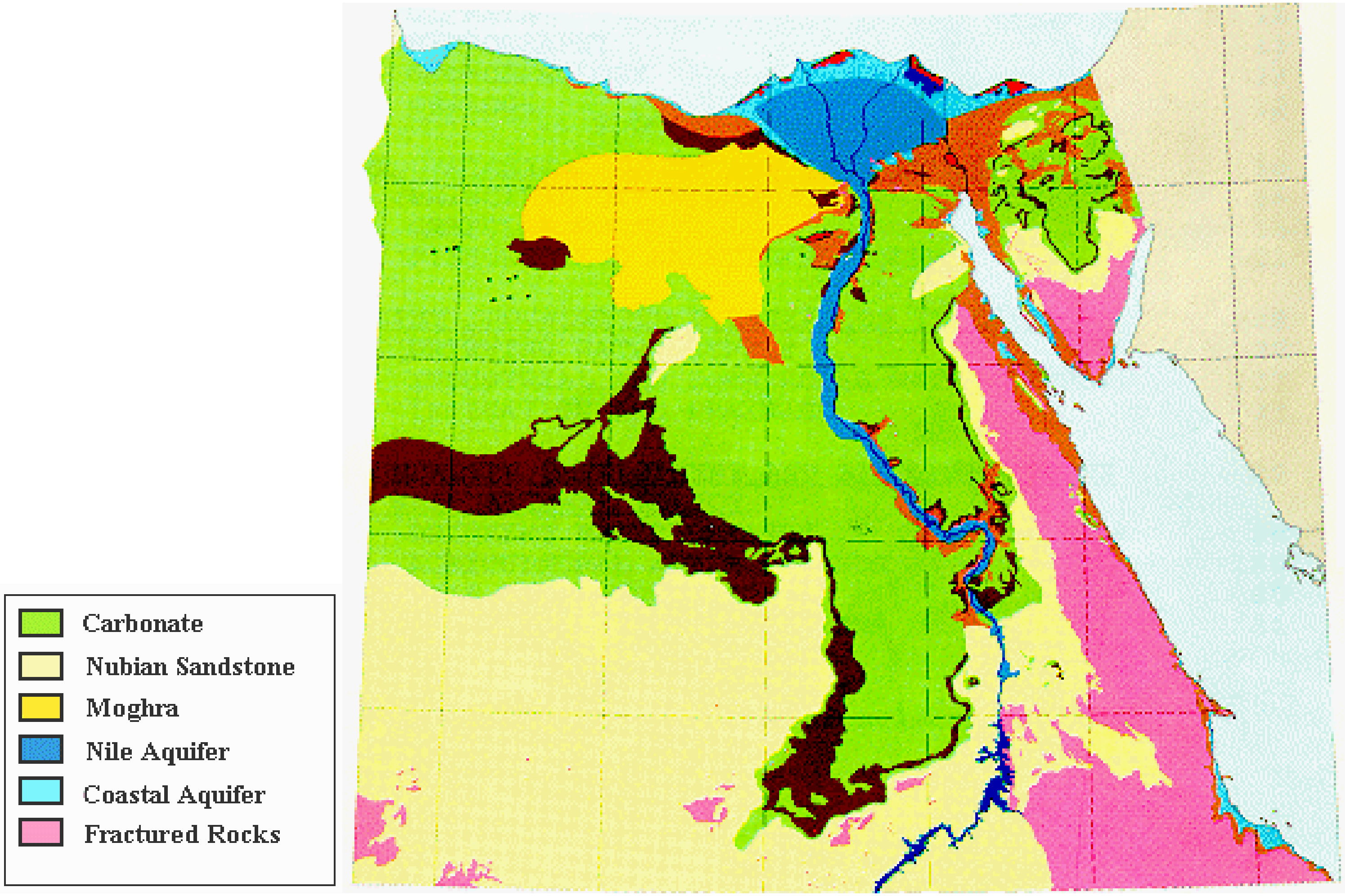

Figure 3. The Hydrogeological Map of Egypt

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

<u>*Potential*</u>

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.

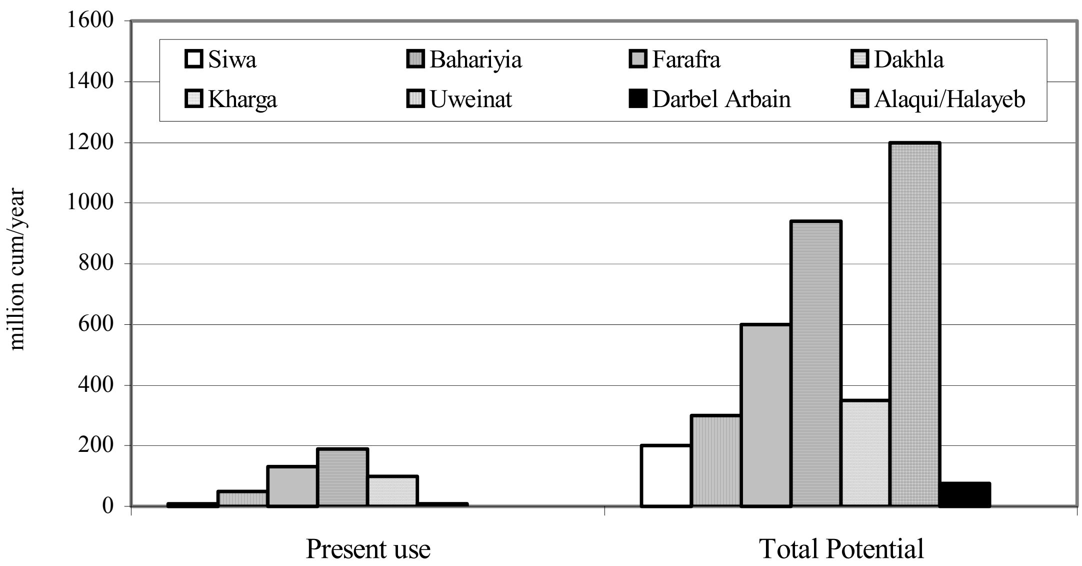

Figure 4. Groundwater in the Deserts

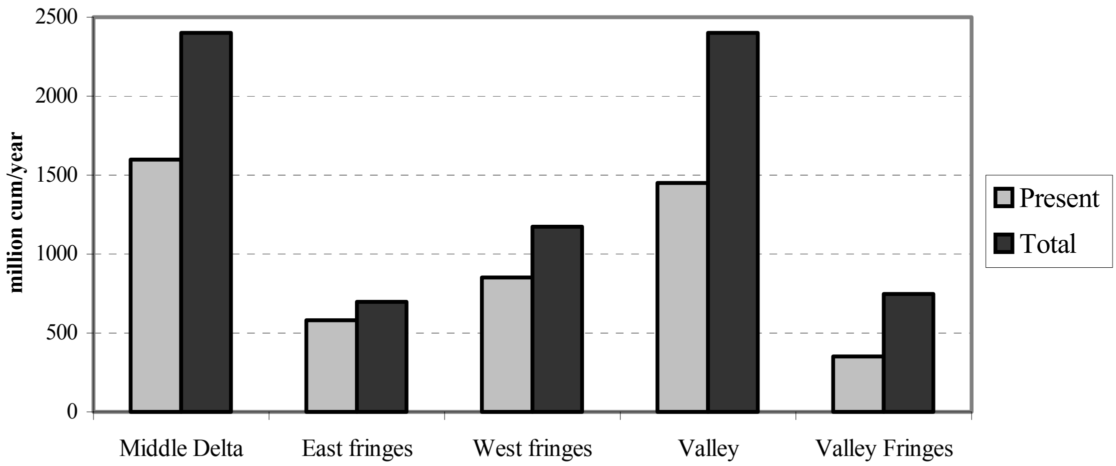

Figure 5. Groundwater in the Nile System

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.

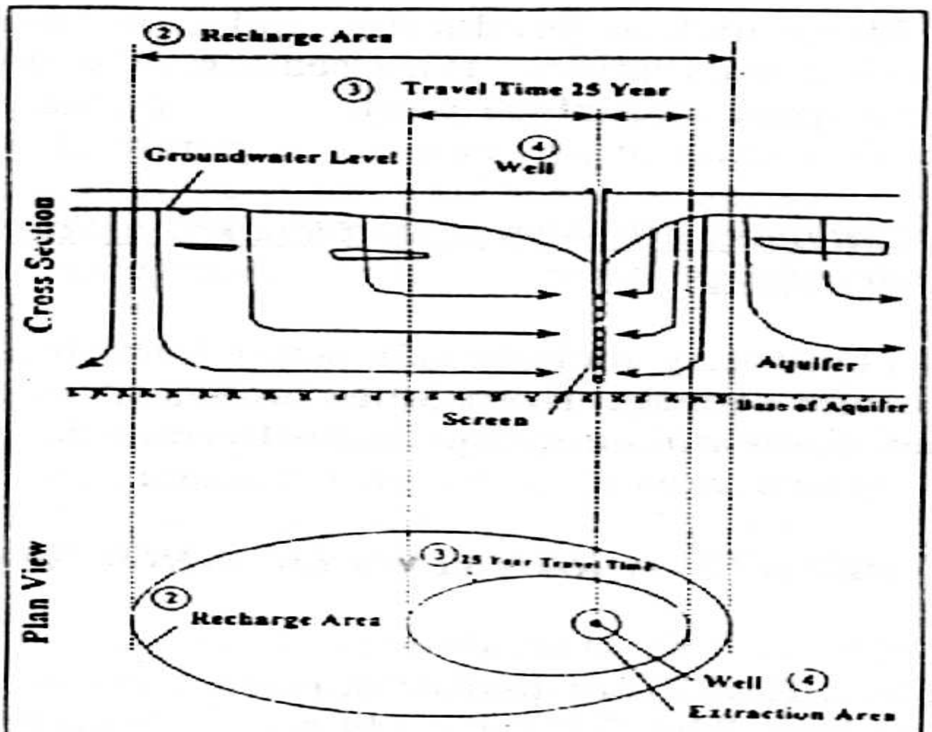

Figure 6. Illustration of Well Protection Area

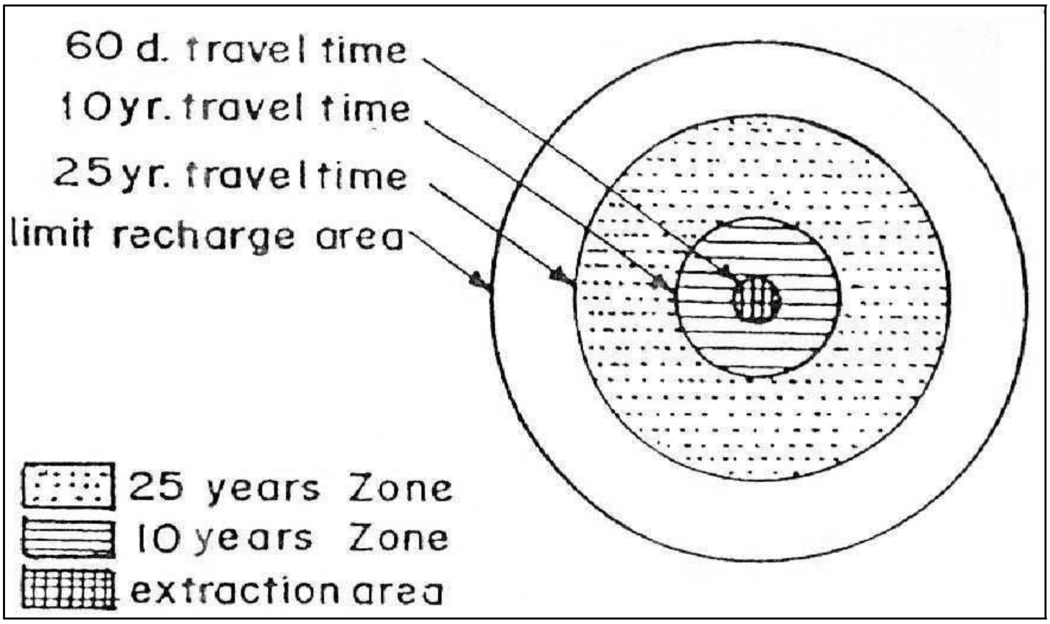

Figure 7. Zonation of Protection Areas

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.

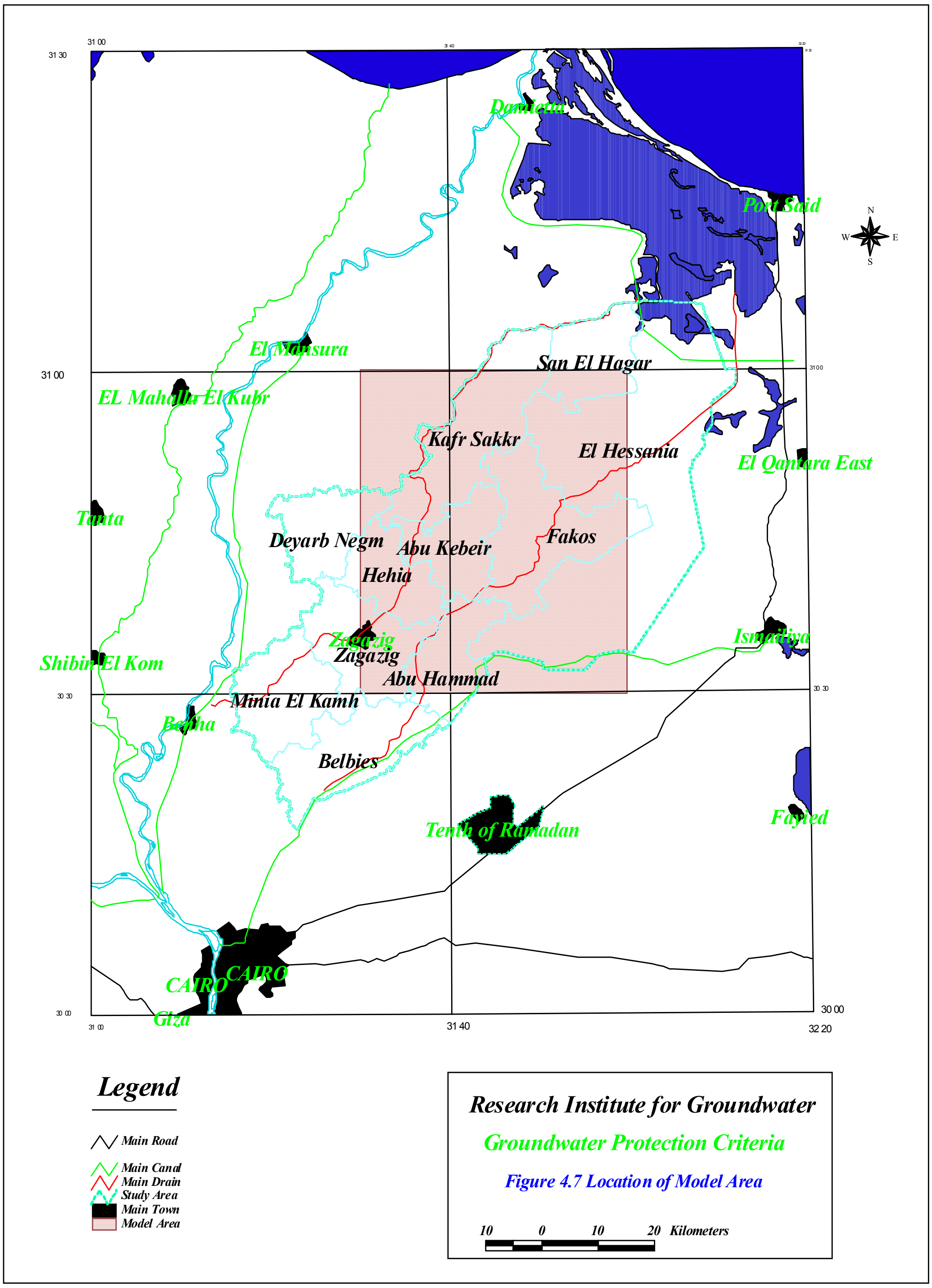

Figure 8. Location of the Study Area

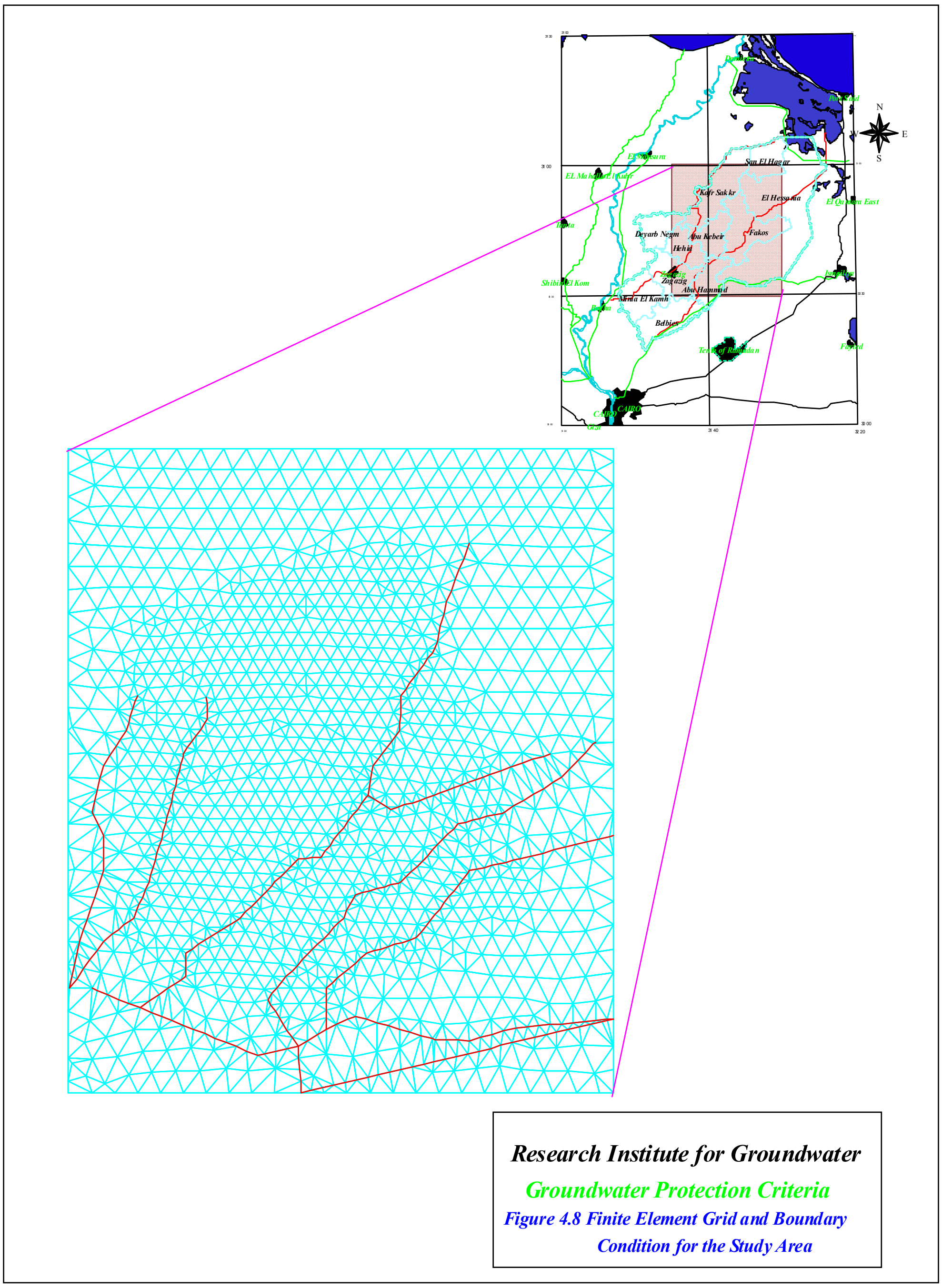

Figure 9. Finite Element Grid and Boundary Conditions for the Study Area

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.

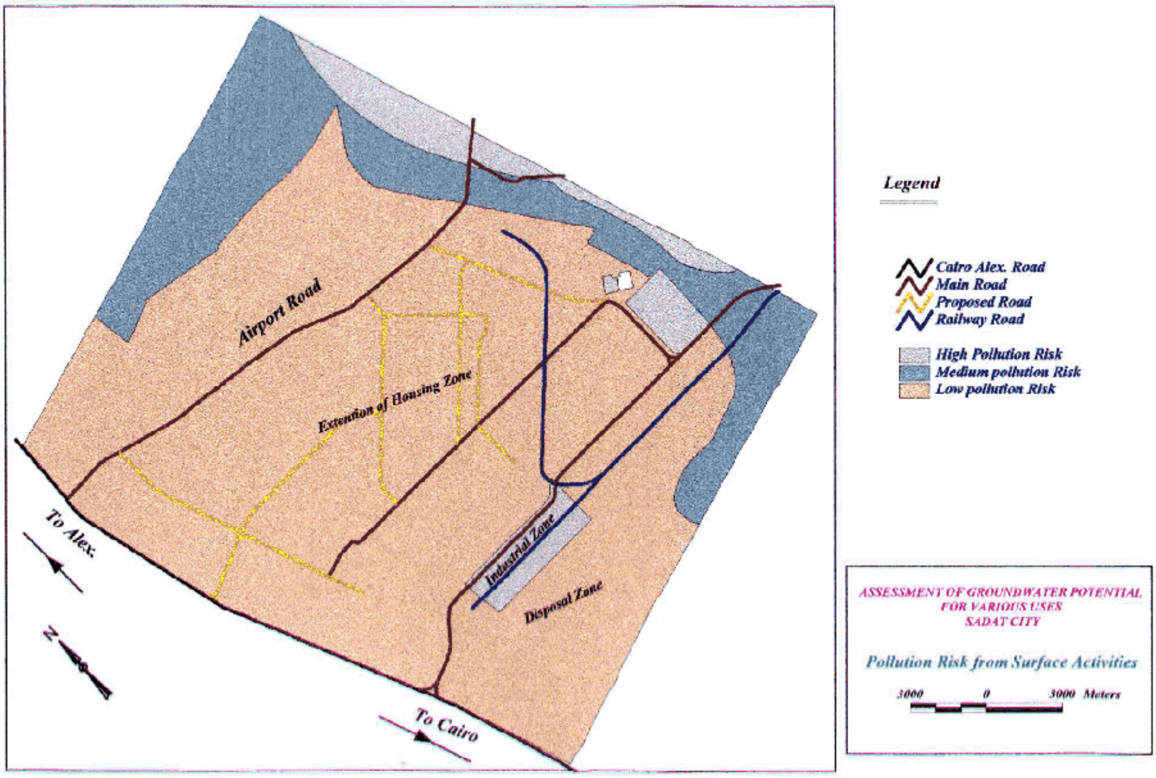

Figure 10. Pollution Risk Map of Sadat City

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.

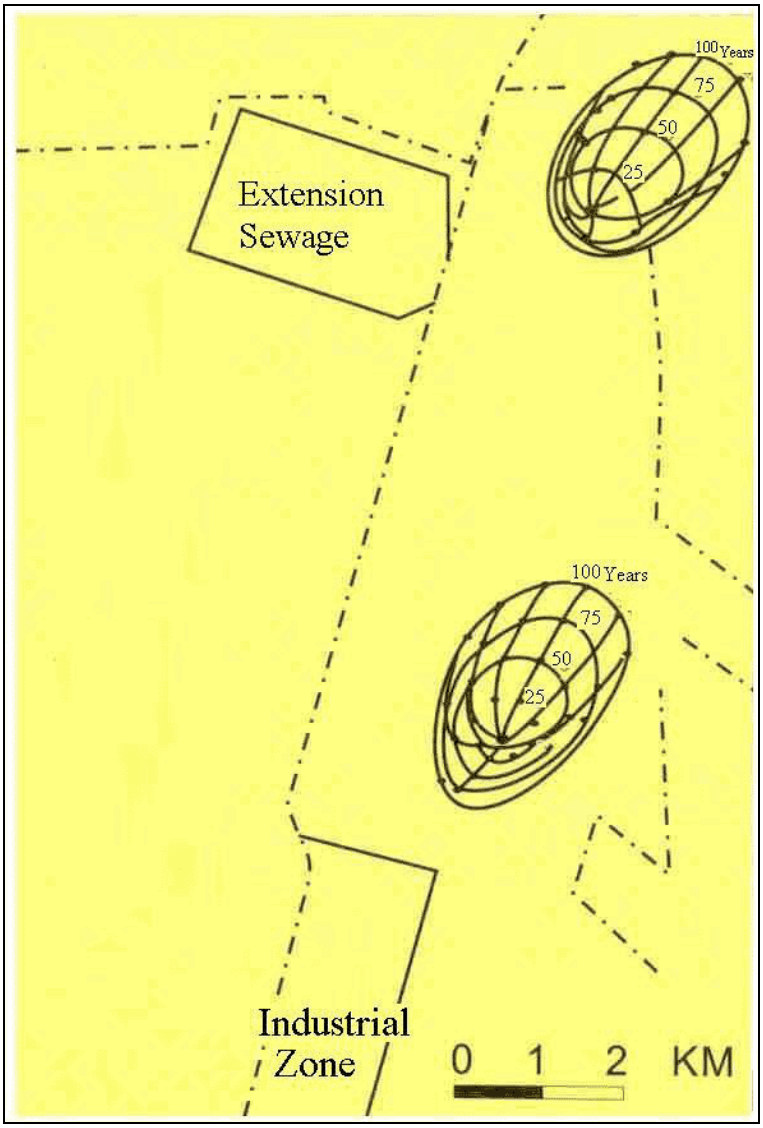

Figure 11. Design of groundwater protection zones in Sadat City

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).

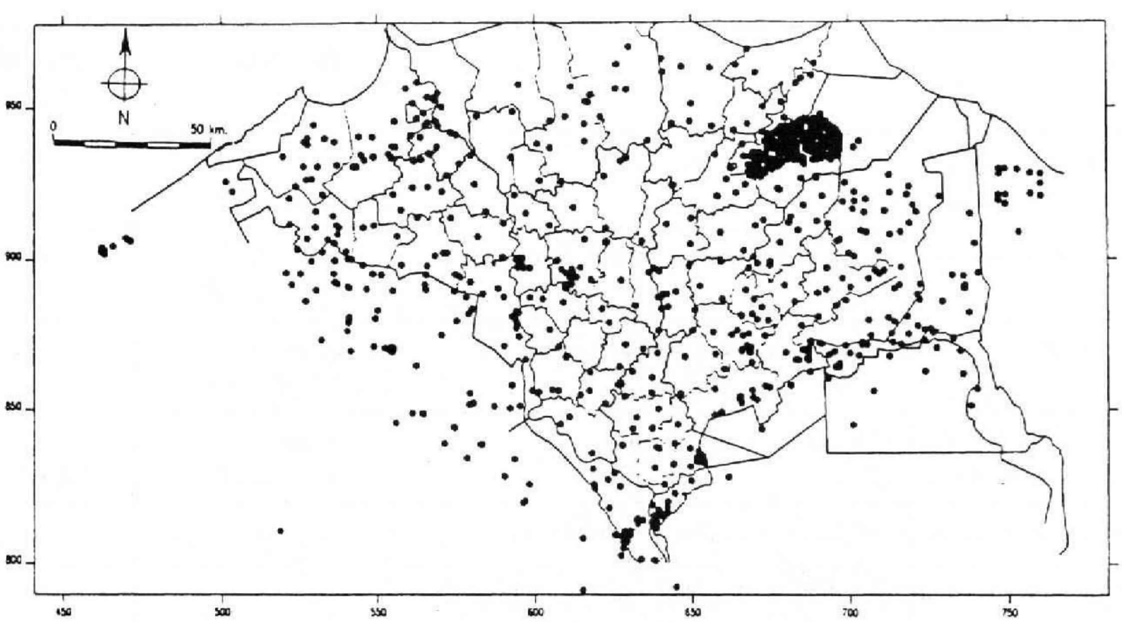

Figure 12. National groundwater level monitoring network (Nile Delta Region)

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.

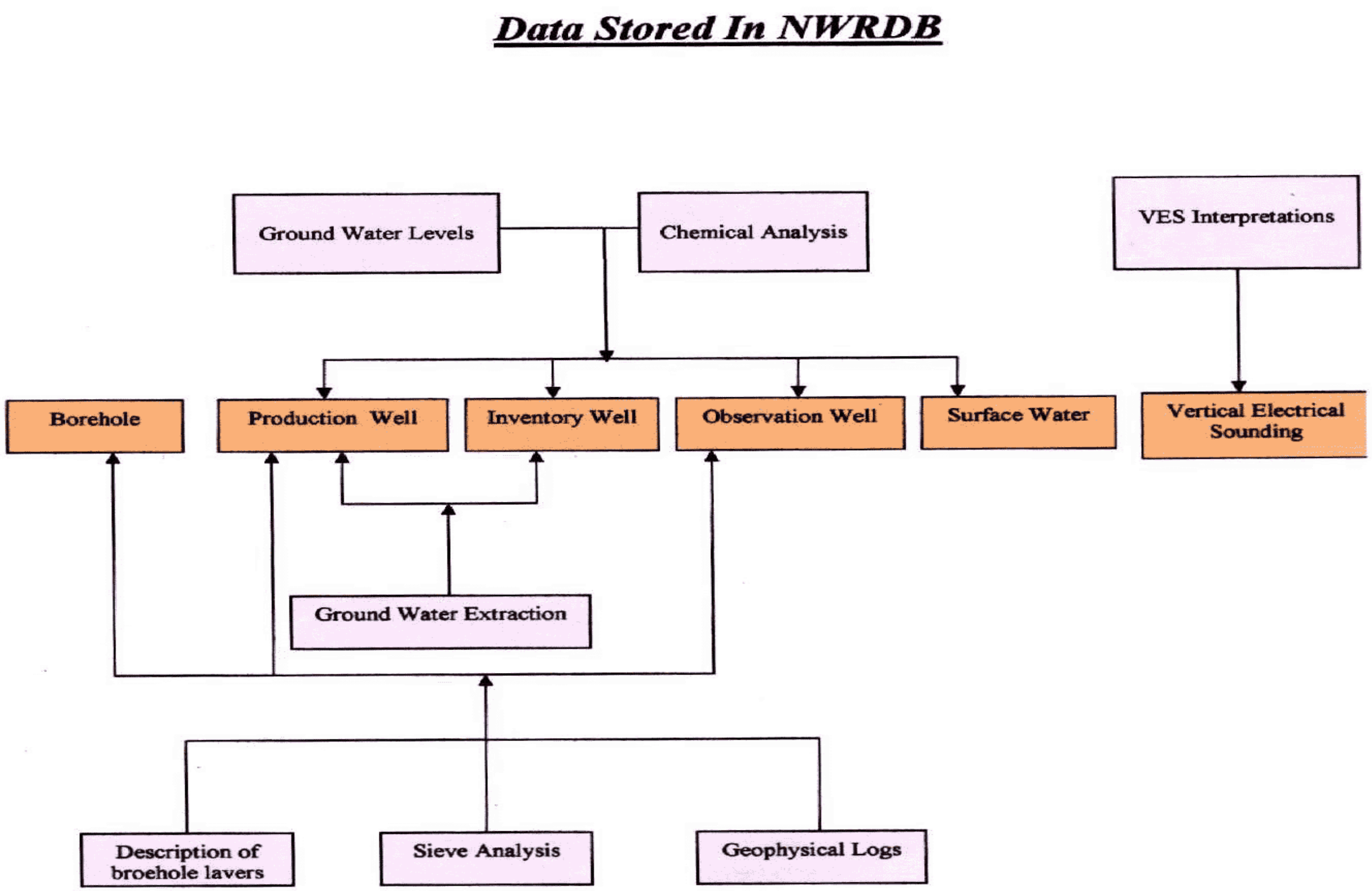

Figure 13. The Types of Data Stored in the National Water Resources Data Base

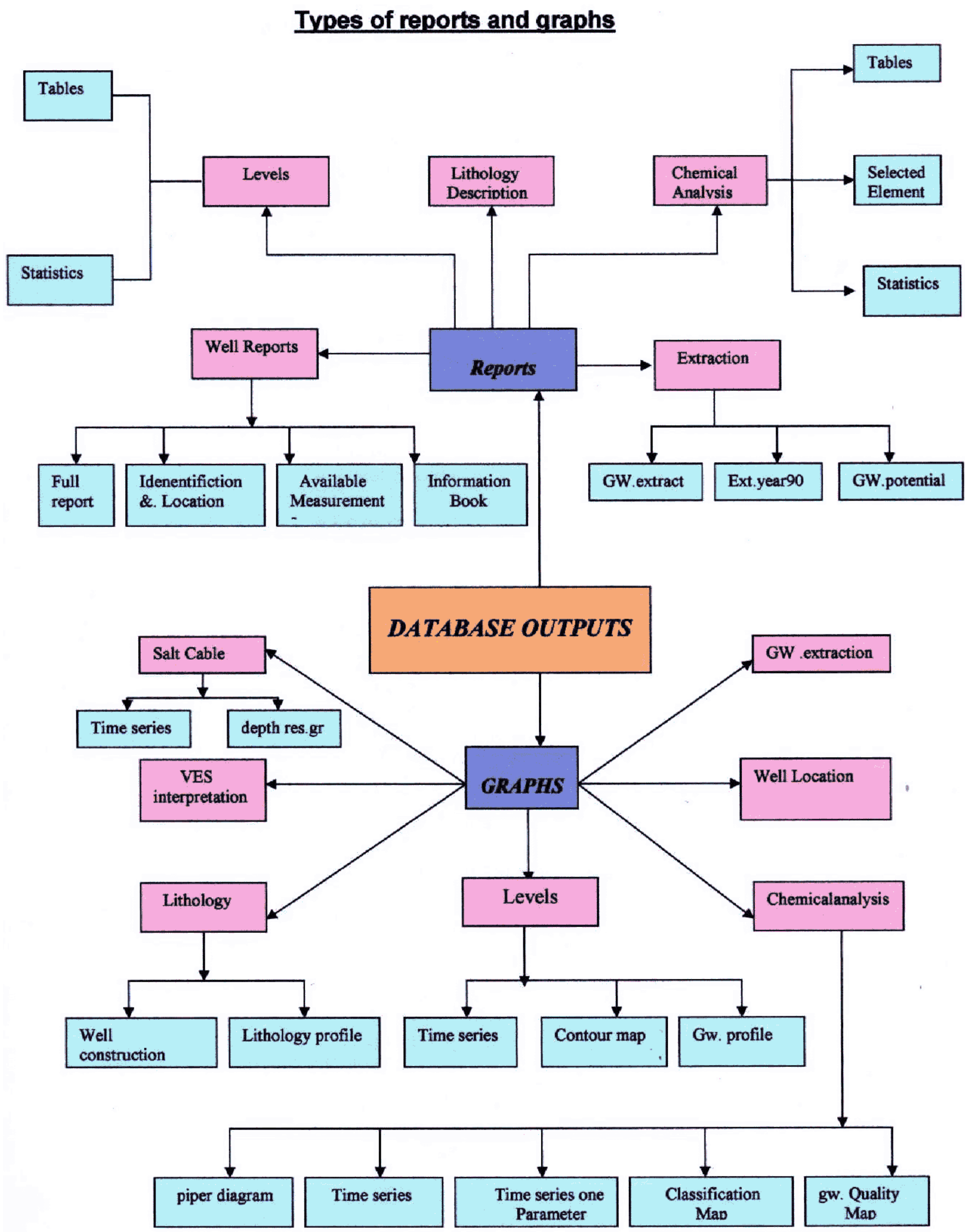

Figure 14. Types of the Outputs of the National Water Resources Data Base (Graphs and Reports)

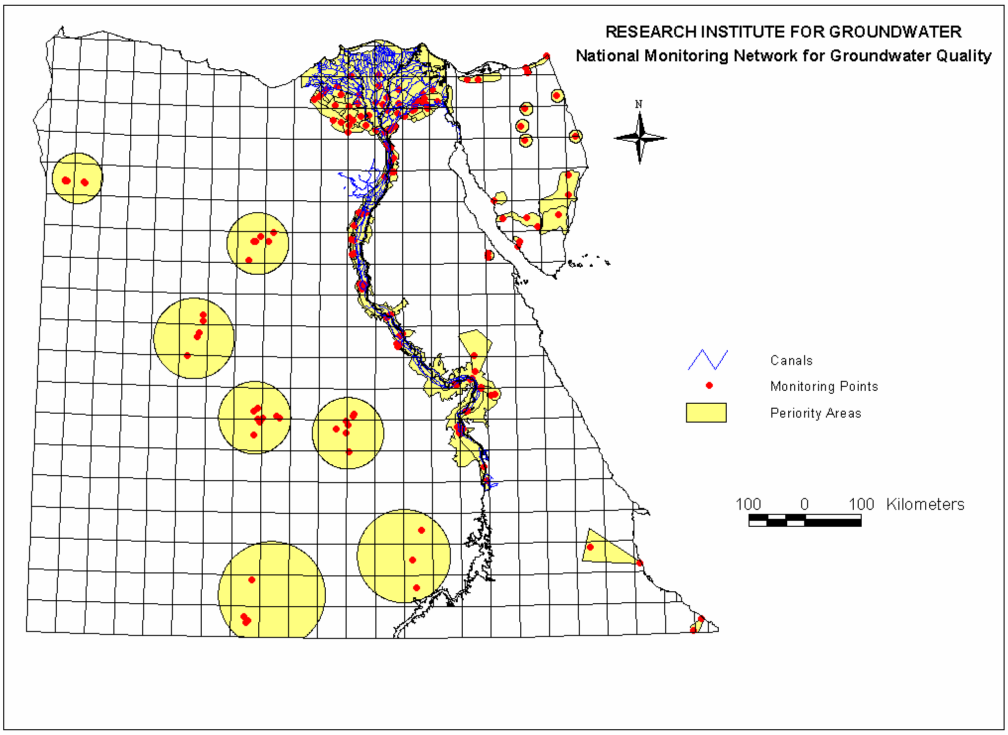

Figure 15. National monitoring network for groundwater quality

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.

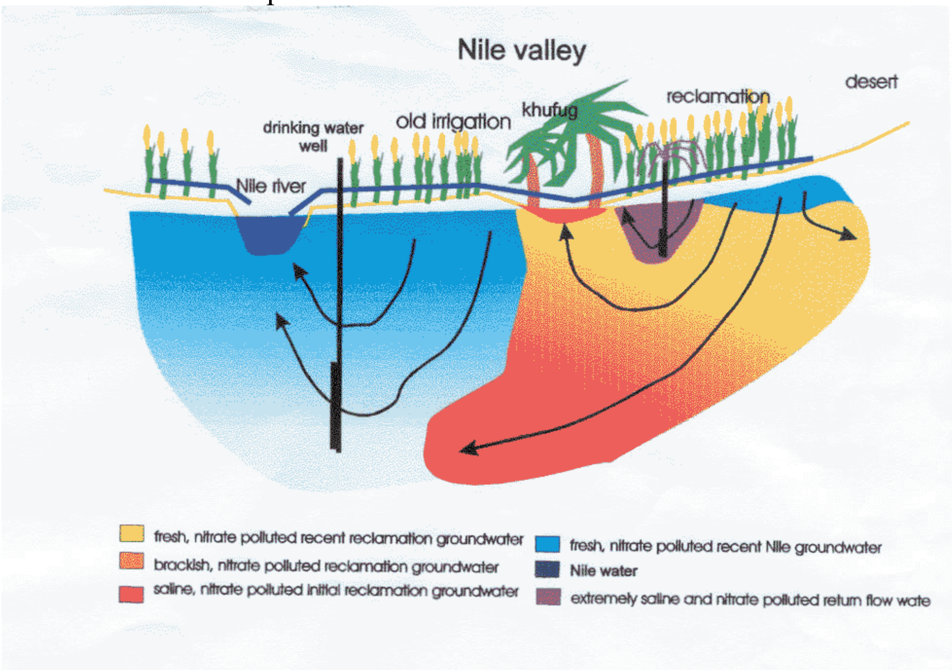

Figure 16. The main hydrochemical process in the reclamation areas

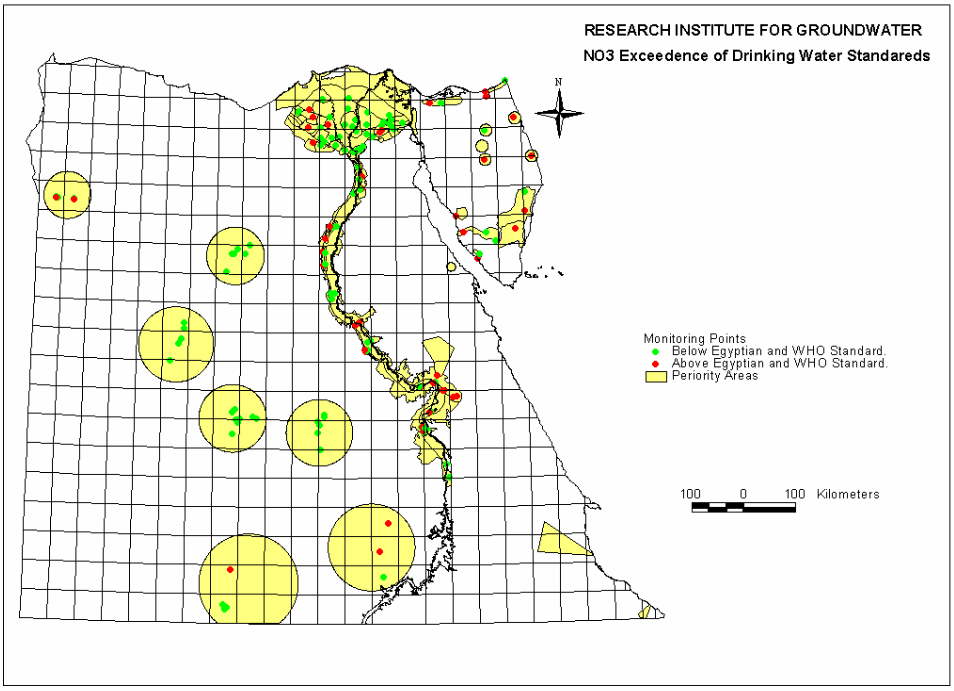

Figure 17. Nitrate concentration in the monitoring wells.

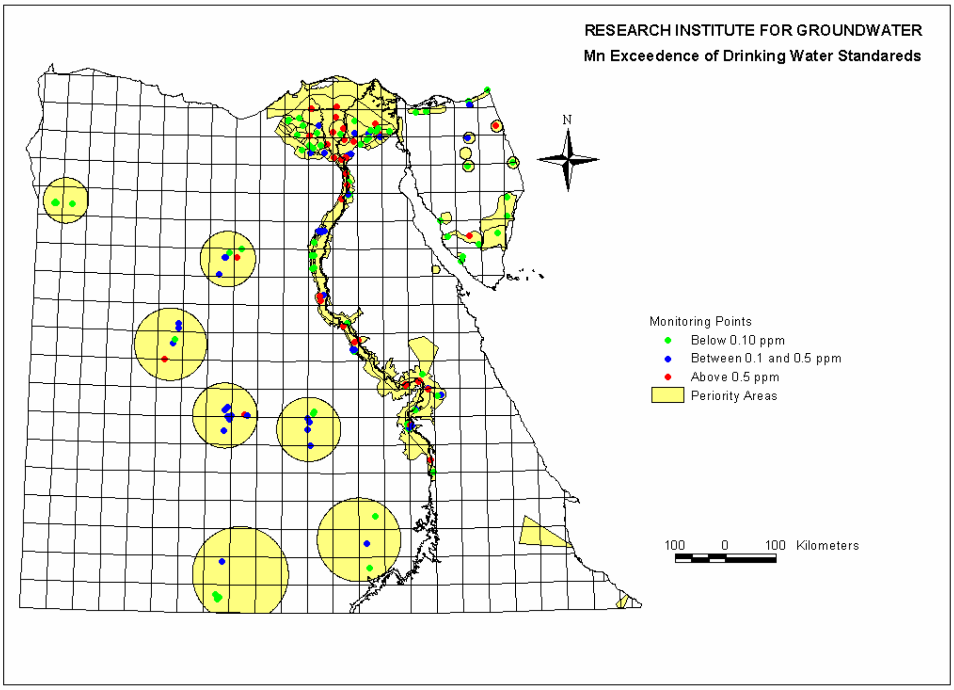

Figure 18. Manganese concentration in the monitoring wells.

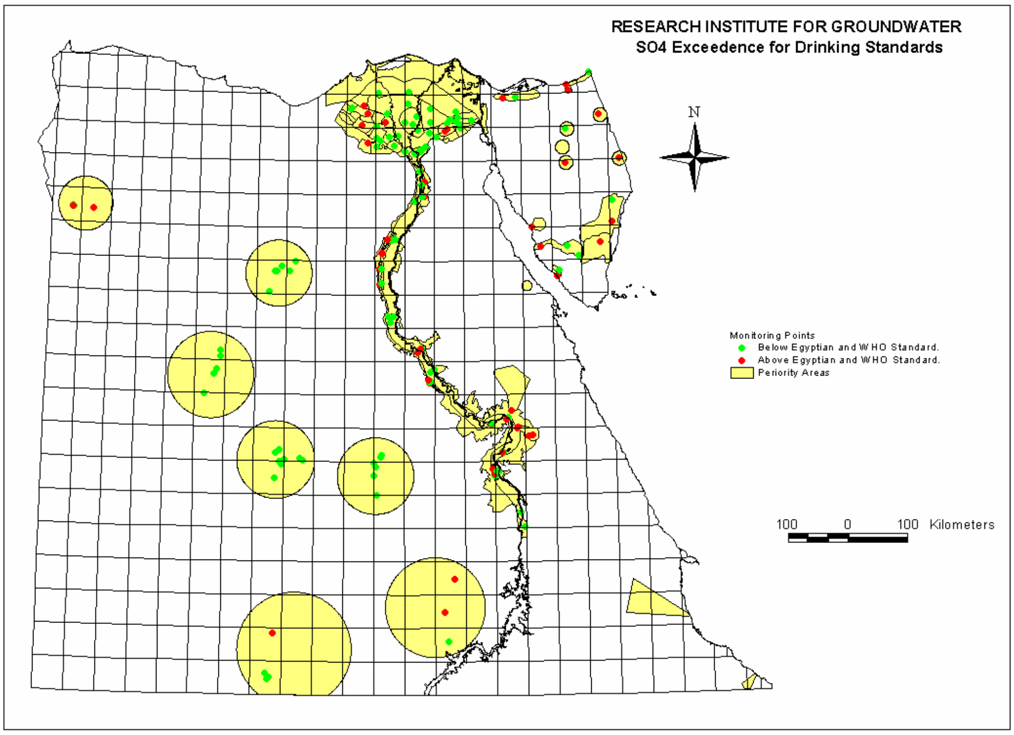

Figure 19. Sulphate concentration in the monitoring wells.

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.

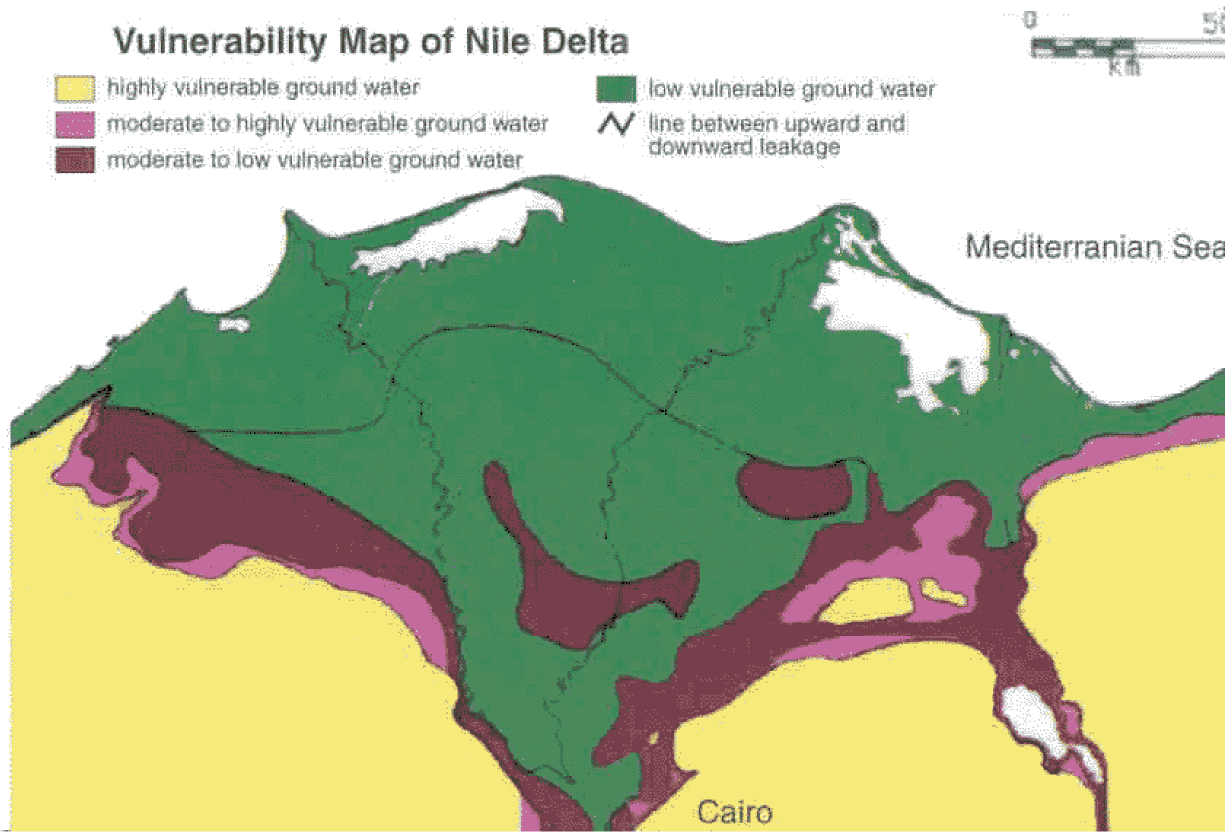

Figure 20. Groundwater Vulnerability Map for the Nile Delta

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 10th 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 10th 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.

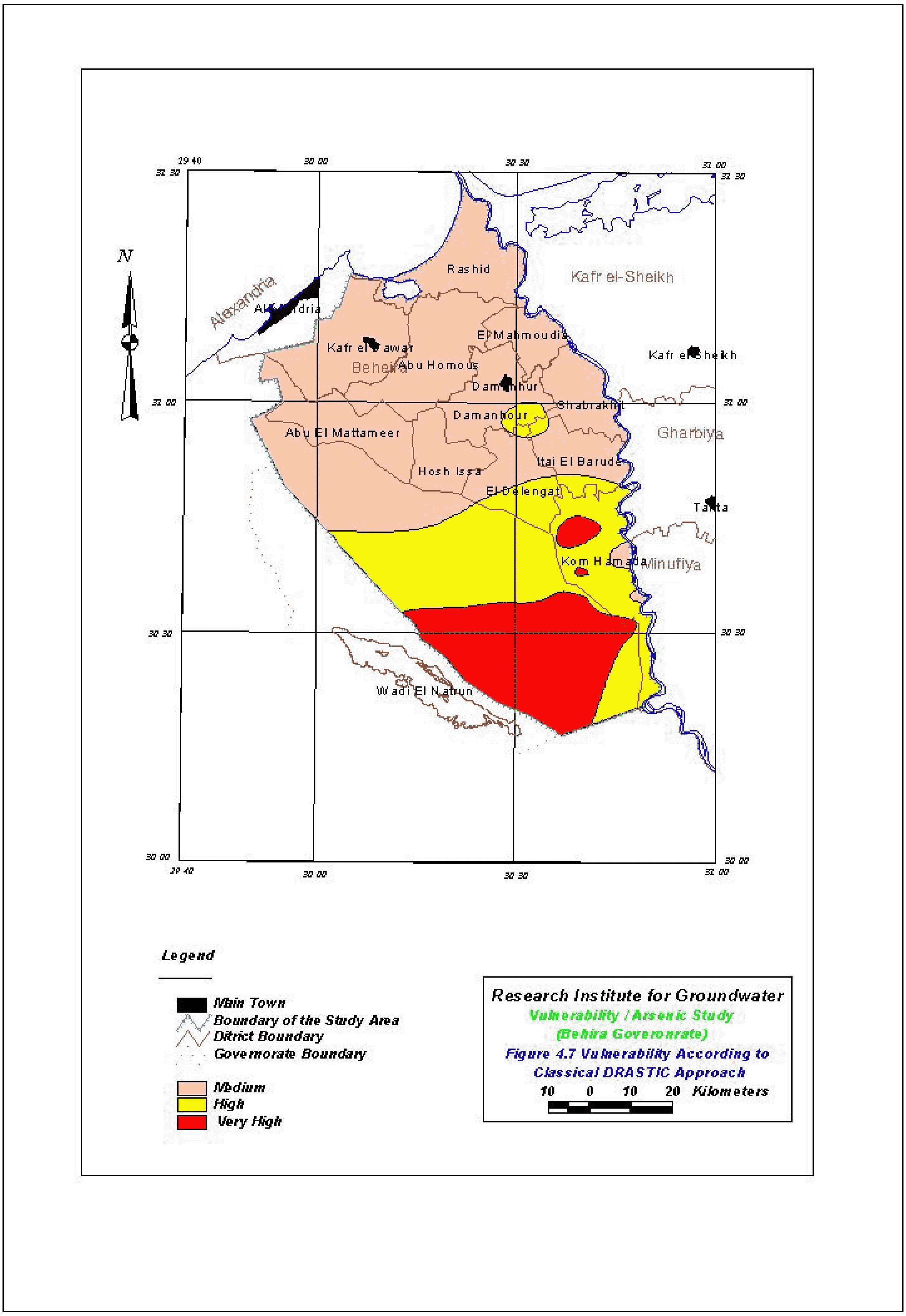

Figure 21. Vulnerability according to the classical approach.

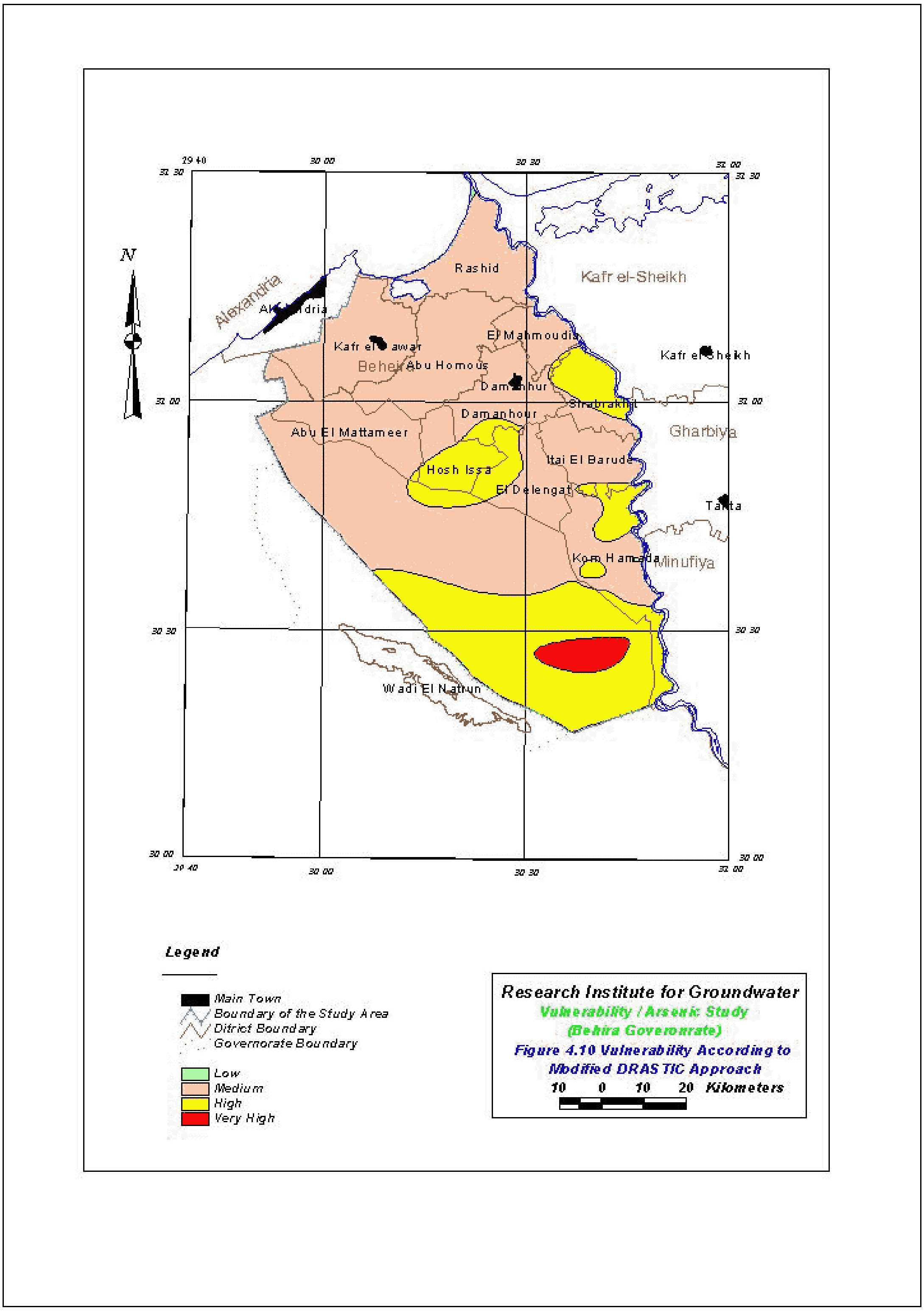

Figure 22. Vulnerability according to the modified approach.

5 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

6 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.

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Annex B-4: Evaluation of the Current Practice of Water Protection in Tunisia

Document prepared by D. El Batti

المركز العربي لدراسات المناطق الجافة والأراضي 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

***

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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

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