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MODULE TWELVE

GROUNDWATER AND IWRM

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MODULE 12

INTEGRATED GROUNDWATER RESOURCES MANAGEMENT

RATIONALE	Groundwater resources are essential resources in the ESCWA region which require careful planning and management, so that groundwater can continue to sustain human socio-economic development and the various ecosystems that depend on it. However despite their importance, groundwater resources are often misused, usually poorly understood and rarely well managed. In most of the ESCWA Region, groundwater resources are under threat of degradation both by inappropriate use (mismanagement) and by contamination. Groundwater needs to be carefully managed if its use is to be sustained for future generations. Proper management is required to avoid serious degradation and there needs to be increased awareness of groundwater at the planning stage to ensure equity for all stakeholders, and, most important of all to match water quality to end use. This module presents the status of groundwater resources in the ESCWA region and their major issues, and discusses the conundrum of exploitation and sustainability and the impacts of over-exploitation on society (socio-economic and environmental) with case studies from the region. Then, groundwater resources management and strategies from an IWRM perspective are introduced and relevant approaches are presented. Furthermore, the issue of utilization of non-renewable groundwater resources from a socially sustainable approach is presented and discussed.
OBJECTIVES	1. Introduce groundwater resources in the ESCWA region, dependency and their status, and their main management issues and challenges 2. Provide special insight into groundwater conditions (quantity and quality) in the ESCWA and the impacts of over-exploitation on groundwater resources and society 3. Discuss the concept of "sustainable groundwater management" for in arid region 4. Introduce integrated groundwater resources management and practice 5. Present and discuss options for groundwater management and protection strategies in an integrated approach 6. Introduce and discuss a socially-sustainable approach for the utilization of non-renewable groundwater resources 7. Present monitoring considerations and simulation models as management tools
MAIN REFERENCES AND BACKGROUND MATERIAL	- Updating the assessment of water resources in ESCWA member countries, 2003, ESCWA, E/ESCWA/ENR/1999/13. - Implication of groundwater rehabilitation, water resources protection and conservation: artificial recharge and water quality improvement in the ESCWA region, 2001, ESCWA, E/ESCWA/ENR/2001/12. - Current water policies and practices in selected ESCWA member countries, 2001, ESCWA, E/ESCWA/ENR/1999/15. - إرشادات عامة لوضع دليل لإدارة موارد المياه الجوفية في دول الاسكوا في إطار الإدارة المتكاملة للموارد المائية، ٢٠٠٣، الاسكوا، E/ESCWA/SDPD/2003/WG.4/7 - Groundwater and its susceptibility to degradation: A global assessment of the problem and options for management, 2003, UNEP, Nairobi, Document UNEP/DEWA/RS.03-3. - Sustainable Groundwater Management: Concepts and Tools, 2003, World Bank, GW-MATE Briefing Note Series (1-12), www.worldbank.ogr/gwmate. - Proceedings of International Conference on "Regional Aquifer Systems in Arid

	Zones –Managing non-renewable resources", Tripoli, Libya, 20–24 November 1999, General Water Authority of the Libyan Arab Jamahiriya, IHP-V Technical Documents in Hydrology No. 42, UNESCO, Paris, 2001. - Groundwater contamination inventory: A methodological guide, 2002, Ed. Alexander Zaporozec, UNESCO, Paris, IHP-VI, Series on Groundwater, No. 2. - ISARM (Internationally Shared (Trans-boundary) Aquifers Resources Management): A framework document, 2001, UNESCO/FAO/IAH/UNECE, UNESCO, Paris.
SUGGESTED INTERNET LINKS	
DELIVERY OPTIONS	
DIRECTLY RELATED MODULES	3, 5, 7 and 14

SESSION TOPIC SYNTHESIS	
QUESTIONS FOR DISCUSSION	1. What are the functions and socio-economic and ecological values of groundwater resources in your country/ESCWA region? 2. What are the main groundwater management issues in your country/ESCWA region? 3. What is the stage of groundwater resources development in your country (minor local stress, significant stress, over-exploited), if you have more than one aquifer choose one? Identify the applied groundwater management tools and interventions being practiced today in your country. Analyze the situation between **what should be done and what is being done**. Is there a gap between the two and in which area? 4. What are the major differences between groundwater and surface water in terms of characterization and management? 5. How should integrated groundwater resources management be practiced? 6. In terms of groundwater management strategies, what are the most efficient and suitable "demand-side" and/or "supply-side" actions for groundwater resources management under the prevailing socio-economic and political conditions of your country? 7. In your country, is groundwater resources protection included in the groundwater management strategy? If yes, how it is practiced? Is it effective? 8. Is there a formula for sustainable management of non-renewable groundwater resources? What are the main factors to be considered in the management of these resources?

1. Introduction

In the ESCWA region groundwater is a vital and essential source for all sectors. In eight ESCWA member countries (Palestine, Jordan, Yemen, Saudi Arabia, Kuwait, Bahrain, Oman, Qatar, and UAE) groundwater is the main source for domestic consumption (particularly in rural areas) and irrigation, with groundwater dependency ratio of more than 50% and reaches more than 80% in some countries (e.g., Saudi Arabia and Yemen). Furthermore, for the other relatively surface water-rich countries, groundwater utilization and reliance is emerging and is on the rise due to the steady increase in water demands (due to rising population, per capita use, increasing need for irrigation, urbanization, tourism industry, etc.), and groundwater dependency is expected to increase with time. Groundwater resources are therefore an essential resource in the ESCWA region that requires careful planning and management so that they can continue to sustain human socio-economic development and the various ecosystems depending on them. Proper management is required to avoid serious degradation and there needs to be increased awareness of groundwater at the planning stage, to ensure equity for all stakeholders, and most important of all, to match water quality to end use.

In the last four decades, rapid increase of population, ambitious agricultural policies in several countries, increase of economic activities, as well as unplanned utilization and mismanagement, all have lead to extensive groundwater withdrawal leading to its "over-exploitation[1]" in most of the countries. This has been manifested by continuous water level declines and degradation of water quality due to salinization. In addition to their over-exploitation and quality deterioration, groundwater resources in the region are being threatened and polluted by numerous point and non-point sources of pollution generated from anthropogenic activities,

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[1] When speaking of aquifer "over-exploitation" we are invariably much more concerned about the consequences of intensive groundwater abstraction than in its absolute level. Thus the most appropriate definition is probably an economic one: that the 'overall cost of the negative impacts of groundwater exploitation (including social, economic, and environmental) exceed the net benefits of groundwater use', but of course these impacts can be equally difficult to predict and to cost

such as agricultural (saline and contaminated irrigation return flows with pesticides, fertilizers, herbicides, etc.), industrial (discharge of hazardous and toxic industrial wastes, underground storage tanks, surface and deep disposal of oil and gas brines, etc.), and domestic activities (discharge of inadequately treated domestic wastewater, septic tanks, municipal land fills, etc.).

The deterioration of groundwater quality has become a critical issue throughout most of the countries in the ESCWA region. As the quality of groundwater deteriorates its availability to use diminishes, thereby reducing available groundwater supplies, increasing overall water shortages, and intensifying the problem of water scarcity in the region. The loss of groundwater resources may have dire consequences on the countries' socio-economic development, increases health risks, and damages the environment. When evaluating the impact of groundwater depletion on society, two key issues are usually considered. These are the *level of reliance on groundwater* and *the marginal cost* (Valuing Water and Pricing Modules), which is the cost of providing replacement supplies from another source. Moreover, in the arid ESCWA region groundwater has a scarcity value, and hence the *opportunity cost* (Valuing Water and Pricing Modules) for alternative or competing uses need to be incorporated, as well as its functional value in maintaining the fragile ecosystem of the region (Environment and IWRM Module). Furthermore, in many countries of the ESCWA region, groundwater resources are non-renewable (fossil), and the issue of "sustainability" of these resources is problematic, and requires clear definition. Sustainability of these resources should be interpreted in a social rather than a physical context, implying that full considerations must be given not only to the immediate benefits, but also to the "negative impacts" of development, and to the "what comes after?" question. Therefore, an "exit strategies" need to be identified, developed, and implemented by the time that the aquifer is seriously depleted. An exit strategy scenario must include balanced socio-economic choices on the use of aquifer storage reserves and on the transition to a subsequent less water-dependent economy, and the replacement water resource.

During the past few decades, economic policies in several ESCWA member countries have given priority and support to the development and expansion of irrigated agriculture. Food security is the major economic goal and it is used to justify the expansion of certain grains and crops characterized as water-intensive. Economic policies in some countries encourage over-pumping of groundwater for irrigation use. Subsidized prices of gasoline and electricity, subsidized credit for buying water pumps and irrigation equipment, exemptions of tariffs on imported fertilizers and equipment, subsidized prices of certain agricultural products, protection against foreign competition in the domestic markets, are all examples of the tools used to implement these agricultural-based economic polices. It is obvious that none of these policies have been subject to serious assessment in terms of their impact on the sustainability of water resources in general, and groundwater resources in particular. Although agriculture is the largest user of water in the region, rapid urbanization and improved quality of life in terms of health, sanitation and social services have also resulted in a sharp increase in water demand for municipal purposes. Conflict between the agricultural and domestic sectors is rising in most of the region, and as a result, groundwater over-exploitation and mining is expected to continue in order to meet growing demand in all sectors.

2. Integrated Groundwater Resources Management

Groundwater differs from surface water because of the contrasting physical and chemical environment in which it occurs, although the water itself is essentially part of the same overall cycle. Surface water flows relatively rapidly in small streams, which feed the main river draining the catchment area concerned. The catchment area of each river basin is determined by land surface topography and generally does not change with time. On the other hand, groundwater moves through aquifers from areas of recharge to areas of discharge, normally at slow rates ranging from 1 m/year to 100s m/day. Tens, hundreds or even thousands of years may elapse between initial recharge and eventual discharge, to a spring, stream, or the sea. Furthermore, the flow boundaries of groundwater (in space and depth) are generally more difficult to define and may vary with time. The difference is further accentuated because groundwater forms the 'invisible part' of the hydrological cycle, which can lead to misconceptions amongst stakeholders.

Key Challenge for Groundwater Resources Management
Groundwater resources management has to deal with balancing the exploitation of a complex resource (in terms of quantity, quality, and surface water interactions) with the increasing demands of water and land users (who can pose a threat to resource availability and quality). Calls for groundwater management do not usually arise until a decline in well yields and/or quality affects one of the stakeholder groups. If further uncontrolled pumping is allowed, a 'vicious circle' may develop and damage to the resource as a whole may result, with serious groundwater level decline, and in some cases aquifer saline intrusion (or even land subsidence). To transform this 'vicious circle' into a 'virtuous circle' it is essential to recognize that managing groundwater is as much about managing people (water and land users) as it is about managing water (aquifer resources). Or, in other words, that the socio-economic dimension (**demand-side management**) is as important as the hydrogeological dimension (**supply-side management**) and integration of both is always required. In most situations, groundwater management will need to keep in reasonable balance the costs and benefits of management activities and interventions, and thus take account of the susceptibility to degradation of the hydrogeological system involved and the legitimate interests of water users, including ecosystems and those dependent on downstream base-flow. In practical terms it will be necessary to set possible management interventions in the context of the normal evolution of groundwater development, and for this it is convenient to distinguish a number of levels. However, it must be noted that ***preventive management approaches are likely to be more cost-effective than purely reactive ones.***

3. Groundwater Management Strategies

Strategies needed to stabilize heavily stressed Aquifers are generally sub-divided into demand-side management interventions and the supply-side engineering measures. Furthermore, it should be noted that although groundwater management is conducted at local aquifer level, national food and energy policies can exert an overriding influence on the behavior of groundwater abstractors, and thus on resource development pressures and management strains. Among these, subsidies on electricity, well drilling, pumpsets, grain and milk prices are probably the most significant. In general terms these subsidies should always be reviewed, and consideration be given to re-targeting the revenue involved into water-saving technology and/or assisting only the neediest members of the community.

It is always essential to address the issue of constraining demand for groundwater abstraction, since this will normally contribute more to achieving the groundwater balance, and in the more arid and densely-populated areas, such as the ESCWA region, will always be required in the longer run. Complementary local supply-side measures, such as **rainwater harvesting, aquifer recharge enhancement** (with excess surface run-off or other sources of water such as desalination and treated wastewater, or even through soil aquifer treatment techniques (SAT)), and **urban wastewater reuse** should always be encouraged, especially where conditions are favorable. They are often important in terms of building better relationships with groundwater users and can provide an initial focus for their participation in aquifer management. Moreover, reducing groundwater resource used for irrigated agriculture is of paramount importance in the ESCWA region, for it is the main consumer of groundwater resources (>85%), and where major savings can be achieved (irrigation efficiencies 30-50%). If larger water savings are needed (e.g., Arabian Peninsula) then consideration should also be given to changes in crop type and land use (e.g. through higher-value crops under greenhouse cultivation or returning a proportion of the area to dryland cultivation of drought-resistant crops). An even more radical option would be to place a ban on the cultivation of certain types of irrigated crop in critical groundwater areas. The success of agricultural water-saving measures in reducing the decline in aquifer water levels depends directly on these savings being translated into permanent reductions in well abstraction rights and actual pumping. It is essential that water savings are not used to expand the irrigated area or to increase water usage in other sectors.

4. Groundwater Quality Protection

In several ESCWA countries, groundwater is a vital natural resource for the reliable and economic provision of potable water supply in both the urban and rural environment. It thus plays a fundamental role in human well-being, as well as that of some aquatic and terrestrial ecosystems. For municipal water supply, high and stable raw-water quality is a prerequisite, and one best met by protected groundwater sources. Recourse to treatment processes (beyond precautionary disinfections) in the achievement of this end should be a last resort, because of their technical complexity and financial cost, and the operational burden they impose. As indicated above, many aquifers in the ESCWA region are experiencing an increasing threat of pollution from urbanization, industrial development, agricultural activities and mining enterprises. Thus proactive campaigns and practical actions to protect the natural quality of groundwater are widely required, and can be justified on both broad environmental-sustainability and narrower economic-benefit criteria. If groundwater becomes polluted, it is difficult and usually very costly to rehabilitate; clean-up measures nearly always have a high economic cost and are often technically problematic. Low microbial activity, low recharges and slow flow rates, which reduce mixing, mean that self-purification of groundwater is very limited. Degradation processes, which take days or week in surface water, are likely to take decades in groundwater systems. It is therefore advisable to prevent or reduce the risk of groundwater contamination rather than have to deal with the consequences of pollution. **Groundwater protection should therefore be the top priority**, and be an essential part in the overall management strategy of groundwater.

Groundwater Vulnerability Assessment

The goal of vulnerability assessment is to provide policy makers with groundwater regions most susceptible to contamination so that land management practices can be optimized to protect the groundwater resource, as major contaminates of concern have been significantly correlated to certain land uses and practices. **In other words, in order to protect groundwater, we must map vulnerable aquifers, then implement and enforce policies restricting harmful land use practices at the country level and the municipal level.** Groundwater vulnerability assessment is an issue of spatial distribution and therefore typically carried out using geographic information systems (GIS).

Wellhead Protection Area (WHPA)

Whether this hazard will result in a threat to a public-supply source depends primarily on its location with respect to the groundwater sources (and their flow-zones and capture areas), and secondarily on the mobility of the contaminant(s) concerned within the local groundwater flow regime. A number of areas and zones should normally be defined, using hydrogeological data on the local groundwater flow regime. Various analytical and numerical models are available to facilitate their delineation.

Groundwater pollution hazard assessments should prompt municipal authorities or environmental regulators to take both preventive actions (to avoid future pollution) and corrective actions (to control the pollution threat posed by existing and past activities). **To protect aquifers against pollution it is essential to constrain land-use, effluent discharge and waste disposal practices**. However, in practice it is necessary to define groundwater protection strategies that accept trade-offs between competing interests. Thus instead of applying universal controls over land use and effluent discharge, it is more cost-effective (and less prejudicial to economic development) to utilize the natural contaminant attenuation capacity of the strata overlying the aquifer, when defining the level of control required to protect groundwater quality. Simple and robust zones (based on aquifer pollution vulnerability and source protection perimeters) need to be established, with matrices that indicate what activities are possible where at an acceptable risk to groundwater. Groundwater protection zoning also has a key role in setting priorities for groundwater quality monitoring, environmental audit of industrial premises, pollution control within the agricultural advisory system, determining priorities for the clean-up of historically-contaminated land, and in public education generally. All of these activities are essential components of a sustainable strategy for groundwater quality protection.

5. Utilization of Non-Renewable Groundwater

The use of the term 'sustainability' in the case of non-renewable groundwater resources requires clarification. **It is interpreted here in a social, rather than a physical context**, implying that full consideration must be given, not only to the immediate benefits, but also to the 'negative impacts' of development and to the 'what comes after?' question—and thus to time horizons of 100s of years. There are two very different situations under which the utilization of non-renewable groundwater occurs:

- Planned schemes in which the mining of aquifer reserves is contemplated from the outset, usually for a specific development project in an arid area with little contemporary groundwater recharge (e.g., the Libyan Sarir Basin).
- On an unplanned basis with incidental depletion of aquifer reserves, as a result of intensive groundwater abstraction in areas with some contemporary recharge but where this proves insufficient or where there is limited hydraulic continuity between deep aquifers and their recharge area (e.g., Saq aquifer, the shared Disi aquifer and the Paleogene aquifer in the Arabian Peninsula).

In the **'planned depletion scenario'** the management goal is the orderly utilization of aquifer reserves (of a system with little pre-existing development), with expected benefits and predicted impacts over a specified time frame. Appropriate 'exit strategies' need to be identified, developed and implemented by the time that the aquifer is seriously depleted. This scenario must include balanced socio-economic choices on the use of aquifer storage reserves and on the transition to a subsequent less water-dependent economy. A key consideration in defining the 'exit strategy' will be the identification of the replacement water resource, such as desalination of seawater or brackish groundwater.In the unplanned situation a **'rationalization scenario'** is needed in which the management goal is:

- Hydraulic stabilization (or exceptionally recovery) of the aquifer, or
- More orderly utilization of aquifer reserves, minimizing quality deterioration, maximizing groundwater productivity and promoting social transition to a less water-dependent economy

In both cases the **groundwater abstraction rate will have to be reduced**, and thus the introduction of **demand management measures** (including realistic groundwater charges and incentives for real water-saving) will be needed. In the longer run potable water supply use will have to be given highest priority and some other lower productivity uses may have to be discouraged.Furthermore, it is equally important to identify all aquatic and/or terrestrial ecosystems that may be dependent on, or actively using, the aquifer concerned and to make predictions of the likely level of interference that will occur as a result of the proposed development. It has to be recognized that some aquatic ecosystems may only be capable of being sustained (even in a reduced form) through the provision of compensation flows, sometimes accomplished by local irrigation and/or aquifer recharge. This consideration will need to be realistically factored in to the evaluation of the acceptability of the proposed groundwater development. Non-renewable groundwater in aquifer storage must be treated as a **public-property** (or alternatively common-property) resource. It is also important to agree on the level in government to which the decision on mining of aquifer reserves must be referred. In countries with a non-sectoral water resources ministry, such as many of the ESCWA countries, the decision could rest with the corresponding minister, but in others it would be better taken by the president's, prime minister's or provincial governor's office (according to the territorial scale of the aquifer) with advice from a multi-sectoral committee. The preferred institutional arrangement is for all groundwater management functions to be handled by a **single government agency**, with representation at a territorial scale appropriate to the aquifer concerned. If this is not possible then all ministries and agencies with a stake in groundwater development and environmental management should be involved, through a coordinating committee. In both instances the water resources administration should have authority to:

- Declare the aquifer that is, or will be, subject to mining of non-renewable resources as a 'special area' subject to specific demand management programs.

- Establish, under the appropriate government minister (at national or provincial level), a special unit to coordinate the resource management of the aquifer concerned

The full participation of groundwater users will be key to successful implementation of management measures. This will be best approached by establishment of an aquifer management organization (AMOR), which should include representatives of the entire main sectoral and geographically based user groups, together with those of government agencies, local authorities and other stakeholders. **National groundwater legislation** will not generally provide a sufficient basis alone for addressing the management of non-renewable resources. Specific provisions for a given aquifer's storage reserves will have to be made through regulations, which, in turn, need to be supported by administrative and technical guidelines. It is also important not to treat groundwater law in isolation from legislation in other sectors (such as land-use planning, public works construction, agricultural development, environmental protection, etc.), which can impact directly on groundwater resources.

A high priority will be to put in place a system of **groundwater abstraction rights** (sometimes known as permits, licenses or concessions). These must be consistent with the hydrogeological reality of continuously declining groundwater levels, potentially decreasing well yields and possibly deteriorating groundwater quality. Thus the permits (for specified rates of abstraction at given locations) will need to be time-limited in the long term, but also subject to initial review and modification after 5–10 years, by which time more will be known about the aquifer response to abstraction through operational monitoring.The value of detailed **monitoring of groundwater abstraction and use**, and the aquifer response (**groundwater levels and its quality**) to such abstraction, cannot be overemphasized. Monitoring of water quality, water levels, and water extraction in an aquifer is the foundation on which groundwater resource management is based. The water resource administration, stakeholder associations and individual users should carry this out. The existence of time-limited permits subject to initial review will normally stimulate permit holders to provide regular data on wells.

6. Groundwater Simulation Modeling – An Essential Management Tool

Numerical groundwater models are an efficient management and planning tool for the development of complex aquifer systems. Models, if properly constructed are useful to estimate the effects of future development/management schemes on the groundwater system. In addition, they can aid in understanding of the overall behavior of a given aquifer system. The computed result of an aquifer simulation is the potentiometric surface distribution of the aquifer and the salinity distribution in the aquifer or the concentration of a particular contaminant species, which are the critical factor in water resources management and planning. While the aquifer in reality can be developed only once at considerable expense, a numerical model can be run many times at low expense over a relatively short period of time. Observations of model performance under different development and management options aids in selecting an optimum set of operating conditions to use the aquifer without endangering its sustainability.

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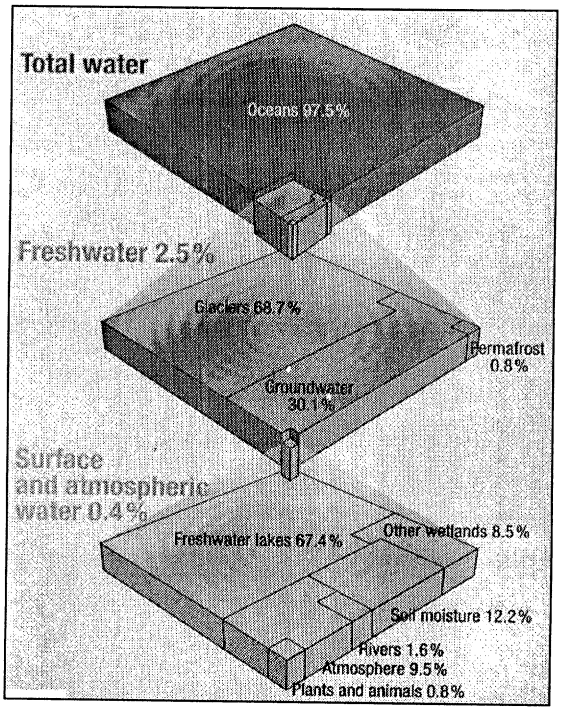
A. INTRODUCTION

Most of the Earth's liquid freshwater is found, not in lakes and rivers, but is stored underground in aquifers (Figure 1). Aquifers are convenient sources of water because they are natural underground reservoirs and can have enormous storage capacity, often with good quality water owing to their natural protection from contamination. Groundwater is a vital natural resource for the reliable and economic provision of water supply in both the urban and rural environment. It thus plays a fundamental (but often little appreciated) role in human well-being, as well as that of some aquatic and terrestrial ecosystems.

Groundwater importance and usefulness to society stems from their being relatively easy and cheap to use, as they can be brought on-stream progressively with little capital outlay and boreholes can often be drilled close to where the water supply is needed; they are a resource that is organizationally easy to develop, as individuals can construct, operate and control their own supply, often on their own land; and many aquifers able to offer natural protection from contamination, so untreated groundwater is usually cleaner and safer than its untreated surface water equivalent.

FIGURE 1. THE EARTH WATER



Source: Ramsar, 2003: www.Ramsar.org

The importance of groundwater is even more pronounced in arid regions, such as the ESCWA region, where surface water resources are scarce; groundwater in eight ESCWA member countries (Palestine, Jordan, Yemen, Saudi Arabia, Kuwait, Bahrain, Oman, Qatar, and UAE), is the main source for domestic consumption and irrigation, with groundwater dependency ratio of more than 50% and reaches more than 80% in some countries (Saudi Arabia, Oman, and Yemen). Furthermore, for the other countries, groundwater utilization and reliance is on the rise due to the steady increase in demand for water in these countries (from rising population, per capita use, increasing need for irrigation, etc.). In the future, it is expected that groundwater dependency in all the ESCWA countries increase.

Groundwater resources are therefore an essential resource in the ESCWA region that requires careful planning and management so that groundwater can continue to sustain human socio-economic development and the various ecosystems that depend on it. However, groundwater resources are under threat of degradation both by inappropriate use (mismanagement) and by contamination. ***Despite its importance, groundwater is often misused, usually poorly understood and rarely well managed.*** The main threats to groundwater sustainability arise from the steady increase in demand for water and from the increasing use and disposal of chemicals to the land surface. Overuse of groundwater resources in the ESCWA region has put great pressure on its further development and management, especially deep groundwater, as a result of extensive mining and increasing pollution levels. Furthermore, increasing urbanization, the use of pesticides and fertilizers in agriculture and the dumping of industrial waste have resulted in the contamination of groundwater sources, especially shallow ones, and further upset the balance between supply and demand. In many countries, the cost of developing new supplies is becoming prohibitive and no effort has been made to rehabilitate contaminated aquifers. **The challenge of meeting future demand for water lies in efficient use, monitoring quantity and quality, avoiding over-consumption and pollution, and rehabilitation.**

Groundwater sources are being lost as a result of pollution and are posing health risks and damaging the environment. Over the last few decades, cases of groundwater quality degradation and pollution in the ESCWA region have been reported around some major urban centers and irrigation regions. Increased salinity of groundwater in aquifers along the Mediterranean, Red Sea and the Arabian Gulf coasts from salt water intrusion is common, while the rise of the water table in some urban centers has had environmental and health consequences. There is a need to increase awareness of these problems and encourage decision-makers to explore ways of managing this vital resource to the region.

Groundwater needs to be carefully managed if its use is to be sustained for future generations. Proper management is required to avoid serious degradation and there needs to be increased awareness of groundwater at the planning stage, to ensure equity for all stakeholders and most important of all to match water quality to end use. A particular water management difficulty arises from the small scale and incremental nature of groundwater development because highly dispersed ownership/use needs imaginative regulatory and financial measures. In such cases there is often the problem that the generally high quality of much groundwater is not reflected in the value of the uses to which it is put.

The longstanding conflict in peri-urban aquifers between groundwater for irrigation versus public water supply is a case in point. A vital aid to good groundwater management is a well-conceived and properly supported monitoring and surveillance system. ‘Out of sight, out of mind’ is a poor philosophy for sustainable development. The general neglect of groundwater resources in terms of national planning, monitoring and surveillance will only be overcome once effective monitoring is regarded as an investment rather than merely a drain on resources. For this reason monitoring systems should be periodically reassessed to make sure that they remain capable of informing management decisions so as to afford early warning of degradation and provide valuable time to devise an effective strategy for sustainable management.

B THE STATUS OF GROUNDWATER RESOURCES IN THE ESCWA REGION[2]

Water resource issues are probably more significant in the ESCWA region than in any other part of the world because of the scarcity of water and its mismanagement. When projected water requirements for all purposes are compared with available surface and groundwater resources, serious questions arise as to the long-term economic and environmental sustainability of existing water resource development and water usage patterns. Under existing patterns of water usage and prevailing water scarcity, it is unlikely that the expansion of irrigated agriculture can proceed without leading to water shortages, especially in the domestic sector. Water resources consist of surface water from major rivers in Egypt, Iraq, Syria, Lebanon and Jordan, estimated at 150.7 billion cubic meters (bcm) and renewable groundwater in shallow aquifers with limited reserves receiving recharge at 18.7 bcm. There are significant reserves in deep aquifers with fossil water and poor water quality. Treated wastewater and drainage water is estimated at 8.3 bcm and desalinated water at 2.1 bcm. In 2000, total consumption was 150.5 bcm, use of groundwater being 30 bcm. The water resources of the ESCWA region are shown in Table 1.

B.1. Groundwater Resources

Groundwater is a vital source for all sectors, the irrigation sector and rural communities, especially in the Arabian Peninsula, being heavily dependent on it. Groundwater is the main source of water for some ESCWA countries. Groundwater as a percentage of total supply varies, not only from one country to another, but also from sector to sector within the same country. It is the main domestic water supply in many rural areas of the

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[2] Based on ESCWA document “Implication of groundwater rehabilitation, water resources protection and conservation: artificial recharge and water quality improvement in the ESCWA region”, 2001, ESCWA, E/ESCWA/ENR/2001/12.

ESCWA region, and even in GCC countries, where desalination is extensively used; groundwater sources are mixed with desalinated water to increase mineral content. It is also the main water supply for irrigation purposes in the Arabian Peninsula. A similar picture of varying degrees of reliance on groundwater also emerges for the irrigation sector in the remaining member states. Furthermore, in terms of annual replenishment, groundwater aquifers receive and store the bulk of the annual run-off in the Arabian Peninsula and Jordan (*For details refer to Annex A*).

At the regional level, groundwater accounts for about 11% of total annual renewable water resources (i.e. groundwater recharge). At country level, however, groundwater can be much more significant, especially in GCC countries, Jordan and the West Bank, as is shown in Table 1. In the countries of the Arabian Peninsula and part of Jordan, where there are no major renewable surface water sources such as rivers, the depletion of groundwater is demonstrated through the use of a sustainability indicator and is shown in Table 2. Sustainability of groundwater is associated with groundwater recharge that may occur seasonally or intermittently.

B.2. Groundwater Utilization

Groundwater reserves in both renewable shallow and non-renewable deep aquifers are currently the main source of water in Jordan, the Syrian Arab Republic, Egypt, Republic of Yemen, the GCC countries and Gaza, and have been exploited to meet domestic and agricultural water requirements. Jordan, Saudi Arabia and Bahrain have been exploiting their non-renewable groundwater, while Qatar, the United Arab Emirates, Oman and Yemen are using fossil water sources over 20000 years old to meet rising demand in the agricultural sector. Groundwater utilization has exceeded the safe yield of the aquifers. Safe yield, which is regional groundwater recharge of the sustainable use of groundwater, is estimated at 18.5 bcm. In 1996, groundwater utilization in the ESCWA region was 28.3 bcm, compared to 18.5 bcm of groundwater recharge, with 67% withdrawal in the GCC countries and Yemen.

Agriculture is the largest user of water in the region, but rapid urbanization and improved quality of life in terms of health, sanitation and social services have resulted in a sharp increase in water demand for municipal purposes. When combined with industrial and agricultural uses, high demand for water has caused an imbalance between water availability and water required for socio-economic development (ESCWA, 1999). Groundwater mining is expected to continue in order to meet growing demand in all sectors. The percentage of water requirements in the ESCWA region in the year 2000 is shown in Table 3.

TABLE 1. SUMMARY OF AVAILABLE WATER RESOURCES, WATER CONSUMPTION, AND GROUNDWATER DEPENDENCY IN THE ESCWA REGION (MCM)

	Conventional water resources[a/,b/,c/]				**Non-conventional water resources**					
Country/area	**Surface water**	**Ground-water use**	**Ground-water recharge**	**Total renewable (mcm)**	**Desalinated water**	**Waste-water and drainage reuse**	**Total renewable and non-conv. res., (mcm)**	**Water consump.**	**Utilization %**	**Groundwater dependency (%)**
Bahrain	0.2	258	100	100.2	75	17.5 (3)*	192.7	350.7	181.99	73.57
Egypt	55 500	4 850	4 100	59 600	6.6	4920 (3800)	64526.6	65 276.6	101.16	7.43
Iraq	70 370	513	2 000	72 370	7.4	1500	73877.4	72 390.4	97.99	0.71
Jordan	350	486	277	627	2.5	61	690.5	899.5	130.27	54.03
Kuwait	0.1	405	160	160.1	388	30	578.1	823.1	142.38	49.2
Lebanon	2 500	240	600	3 100	1.7	2	3103.7	2743.7	88.4	8.75
Oman	918	1 644	550	1 468	51	23	1542.0	2636.0	170.95	62.37
Qatar	1.4	185	85	215	131	28	245.4	345.4	140.75	53.56
Saudi Arabia	2 230	14 430	3 850	86.4	795	131 (24)	7006.0	17 586.0	251.01	82.05
Syrian Arab Republic	16 375	3 500	5 100	6 080	2	1447 (1270)	1447.0	21 324.0	93.02	16.41
United Arab Emirates	185	900	130	21 475	455	108	878.0	1 648.0	187.7	16.41
West Bank & Gaza	30	200	185	315	0.5	2	217.5	232.5	106.9	54.61
Yemen	2 250	2 200	1 400	3 650	9	52	3711.0	4511.0	121.56	86.02
Total	150 709.7	29 811	18537.0	169 246.7	1924.7	8321.5	179492.9	190 766.9		48.77

Source: Compiled by the ESCWA Secretariat from country papers, EGM and international sources 1995, 1996, 1997, and 1999.

* *Volume of drainage water.*

a/ *The flow of the Tigris and Euphrates rivers may be reduced by upstream abstraction in Turkey.*

b/ *ACSAD paper submitted to the 2nd Symposium on Water Resources Development and Uses in the Arab World, Kuwait, 8-10 March 1997.*

c/ *Consolidated Arab Economic Report, 1997.*

TABLE 2. SUFFICIENCY OF RENEWABLE WATER RESOURCES IN THE ESCWA REGION

	Renewable water resources (MCM)			Annual water per capita[b/] (m)^3			Sustainability indicator[c/] (%)		
Country/area	Surface water	GW Recharge	Total	1997	2015	2025	1997	2000	2025
Bahrain	0.2	100	100.2	137	131	99	309	349	608
Egypt	55 500	4 100	59 600	925	698	658	110	115	145
Iraq	70 370	2 000	72 370	2 963	1 832	1 359	68	88	118
Jordan	475	277	752	168	78	70	101	168	235
Kuwait	0.1	160	160.1	89	62	57	438	500	874
Lebanon	2 500	600	3 100	995	437	341	40	53	124
Oman	918	550	1 468	613	403	309	117	103	169
Qatar	1.4	85	86.4	98	70	60	345	580	943
Saudi Arabia	2 230	3 850	6 080	311	182	150	268	292	398
Syria	16 375[a/]	5 100	21 475	1 438	948	609	46	80	110
UAE	185	130	315	137	103	67	388	692	1 015
Palestine	30	185	215	-	-	-	205	230	600
Yemen	2 250	1 400	3 650	303	165	114	79	72	97
Total	152 335	18.5	169 372	-	-	-	-	-	-

Source: *Updating the Assessment of Water Resources in ESCWA Member Countries* E/ESCWA/ENR/1999/13.

a/ The flow of rivers may be reduced by upstream extraction.

b/ Water barrier index. Renewable resources/population.

c/ Sustainability indicator. Water use/renewable resource. Future sustainability is based on 2000 and 2025 water demand programs (10-20% indicate better management practices while more than 40% mismanagement).

\- Data not available.

TABLE 3. PERCENTAGE OF WATER REQUIREMENTS IN THE ESCWA REGION IN 2000

Country	**Domestic water demand (%)**	**Industrial water demand (%)**	**Agricultural water demand (%)**
Bahrain	46.8	9.2	44.0
Egypt	4.4	7.8	87.8
Iraq	7.4	1.7	90.9
Jordan	31.3	5.0	63.7
Kuwait	63.6	17.8	18.6
Lebanon	22.0	10.6	67.4
Oman	14.2	4.6	81.2
Qatar	42.4	4.3	53.3
Saudi Arabia	13.3	2.3	84.4
Syrian Arab Republic	7.5	2.8	89.7
United Arab Emirates	34.0	1.4	64.3
West Bank and Gaza Strip	52.5	3.6	43.9
Yemen	10.0	1.7	88.3

Source: Compiled by the ESCWA Secretariat from country papers, regional and international sources, 1992, 1994, 1995, 1996, 1997, 1999, and questionnaires.

B.3. Groundwater Quality Deterioration and Pollution

In the ESCWA region, groundwater quantity and quality are threatened by various development activities, and mismanagement. Groundwater has been over-exploited through excessive, uncontrolled pumping in many groundwater basins in the ESCWA region, and groundwater quality is deteriorating as a result of seawater or brackish/connate water intrusion into aquifers. All these factors have resulted in a progressive reduction in available groundwater resources in the region, to the extent that sustainable agricultural development may be hindered in the future, and municipal water supplies are reduced. In addition to their over-exploitation and their quality deterioration, groundwater resources in the ESCWA region are being threatened and polluted by numerous point and non-point sources of pollution generated from anthropogenic sources (agricultural, industrial, urban, and domestic activities). As the quality of groundwater deteriorates, due to over-exploitation or direct pollution, its uses diminishes, thereby reducing groundwater supplies, and increasing water shortages, and intensify the problem of water scarcity in the countries of the ESCWA region.

1. Groundwater Quality Deterioration due to Over-Exploitation - Salinization

Quality degradation of the ESCWA coastal aquifers from saltwater intrusion is the result of the pumping of groundwater exceeding recharge. This is happening in the coastal aquifers of Egypt, Syria, Lebanon, the Gaza Strip and all countries of the Arabian Peninsula. One of the major groundwater pollution sources in Lebanon is saltwater intrusion along the coastal zone as a result of over-pumping of groundwater. The karstified coastal aquifers were exposed to increased sea water intrusion and chloride content increased from 250 mg/l in 1968, to 1200 in 1973 and 2000 mg/l in 2000 (ESCWA, 2001). The excessive utilization of groundwater has resulted in continuous and sharp decline in groundwater levels and severe quality deterioration in all the GCC countries due to seawater intrusion and connate waters encroachment. For example, in Al-Hassa Oasis in Saudi Arabia water levels decline of more than 70 m in the Umm Er Radhuma aquifer occurred in the period 1984-1978, accompanied by groundwater salinity increase of more than 1000 mg/L (Al-Mahmood, 1987). In Bahrain, the Dammam aquifer water levels have dropped by more than 4 m in the period 1960-1990, resulting in the loss of more than half the original aquifer due to seawater intrusion and deep brackish water upflow, and the increase of the salinity of the remaining parts of the aquifer (Al-Zubari, 1999). In Kuwait, water levels in the Dammam aquifer in Sulaibiya and Al-Shagaya wellfields have dropped by about 40 and 50 m, respectively, during the period 1960-1990 (Sayid and Al-Ruwaih, 1995), accompanied with seawater and connate water intrusion causing sharp increases in groundwater salinity (Al-Murad, 1994).

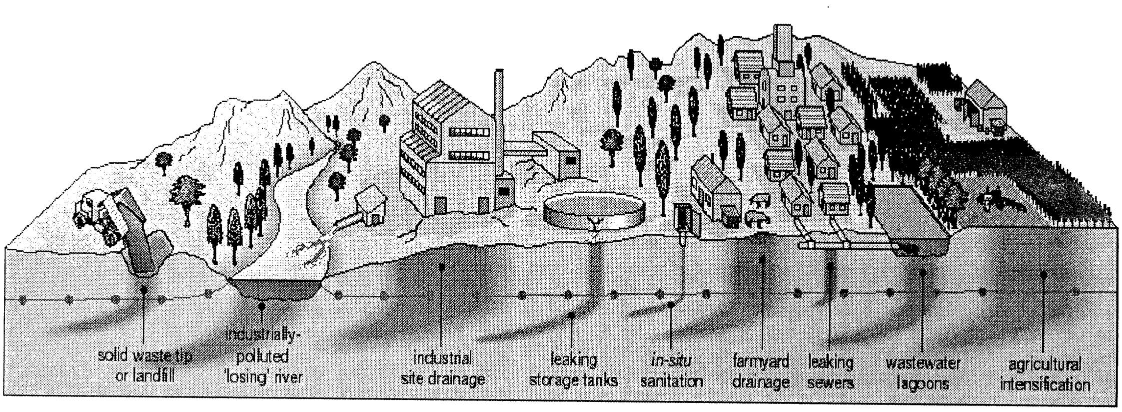
In the United Arab Emirates, excessive groundwater pumping has created cones of depression ranging from 50-100 km in diameter in Al-Dhaid, Hatta, Al-Ain, and Liwa areas. These cones have caused declines of groundwater levels, dryness of shallow wells, and saltwater intrusion problems (Rizk et al., 1997). Al-Asam and Wagner (1997) indicated that intensive groundwater abstraction in the eastern coastal plains of the United Arab Emirates caused a wide-spread increase in water salinity, and abandoned irrigation wells and dying date plantations are an obvious signs of the adverse effects of groundwater over-extraction. In Oman, saline intrusion is a serious source of pollution of coastal areaas. In an isotope study conducted by the Ministry of Water Resources in northern Oman (Macumber et al., 1997) it was reported that seawater intrusion is widespread in Al-Batinah coastal plain and that at Al-Khawd fan seawater intrusion has migrated about 6 km inland from the coast. In eastern Saudi Arabia saltwater intrusion was observed with reported values of 15000 to 21 00 mg/l total dissolved solids (Abdulrahman 2000). A similar situation was observed in the coastal aquifers in Yemen, with high chloride content as a result of saltwater intrusion.

2. Groundwater Quality Deterioration by Anthropogenic Activities

In addition to their over-exploitation and quality deterioration, groundwater resources in the ESCWA region are being threatened and polluted by numerous point and non-point sources of pollution generated from anthropogenic sources (agricultural, industrial, and urbanization activities). The level of groundwater pollution differs from one country to another depending on the intensity of social and economic development activities, the infiltration-recharge mechanism and hydrogeological conditions. Potential groundwater pollution sources are shown in Figure 2. Groundwater degradation in the ESCWA region is the result of a number of factors, the most important being:

1. Increases in the discharge of untreated or inadequately treated domestic and industrial water in open areas, rivers and wadis;
2. Discharge from agro-processing plants and a high level of agrochemicals in rivers, wadis and dump sites;
3. Discharge of hazardous and toxic industrial waste in inadequate dump sites;
4. Infiltration of saline agricultural drainage from large scale irrigation into shallow aquifers (irrigation return flows);
5. Overuse of fertilizers and pesticide in agriculture and their migration to the shallow groundwater formations;
6. Injection of brine and hydrocarbon by-products from oil production and refinery operations into deep zones, ultimately returning to aquifers;
7. Leaking underground fuel storage tanks.

***FIGURE 2**. LAND-USE ACTIVITIES COMMONLY GENERATING A GROUNDWATER POLLUTION THREAT*



SOURCE: GW-MATE, 2003

Groundwater pollution is especially prevalent in shallow aquifers beneath rivers, for example, in the Nile Delta, southern Iraq, Jordan and the Damascus basin in Syria. The discharge of industrial and domestic wastewater and irrigation return flow into rivers are the main sources of contamination of these aquifers, as a result of river-groundwater hydraulic interconnection. The development of major irrigation schemes and industrial and domestic wastewater facilities along the four major rivers - the Nile, Tigris, Euphrates and Jordan - has led to a deterioration of water quality in the connecting shallow aquifers.

Fractured limestone aquifers in Lebanon and Syria are also especially prone to contamination and the use of septic tanks in mountainous limestone areas is a major pollution source. Extensive agriculture in Saudi Arabia, Oman, the United Arab Emirates and Republic of Yemen, and to a certain extent in the remaining countries, has caused high nitrate and other fertilizer compound concentrations in the soil and shallow groundwater sources. Fertilizer and pesticides leaching from irrigated fields are often found in shallow alluvial aquifers of the Arabian Peninsula, while the discharge of untreated or semi-treated wastewater into dry wadis and its reuse in irrigation is another common pollution source in all countries of the peninsula. An overview of exposure to contaminants in the ESCWA region is shown in Table 4.

TABLE 4. REPORTED TYPE OF WATER SOURCE UTILIZATION, QUALITY AND EXPOSURE TO QUALITY DEGRADATION AND POLLUTION CONTAMINANTS IN THE ESCWA REGION

Bahrain	Groundwater (GW) Desalinated sea water	Poor -fair N/A	Excessive exploitation – brackish water and saline water
Egypt	Surface water (SW) Groundwater (GW)L	Good Fair	Municipal: overloaded sewerage disposal systems Industrial: discharge of untreated effluents Agriculture: pesticides
Iraq	Surface water (SW) Groundwater (GW)	Poor-good	Excessive construction in neighbouring countries Saline water intrusion Municipal: overloaded sewerage systems Industrial: discharge of treated effluents Agricultural: water drainage and run-offs
Jordan	Groundwater (GW)	Variable	Excessive exploitation – brackish water, saline water intrusion. Industrial: uncontrolled discharge of untreated effluents Agriculture: irrigation water drainage, pesticides and toxic materials
Kuwait	Groundwater (GW)	Poor	Excessive exploitation – brackish water, saline water intrusion, transboundary underflow Industrial: oil pools
Lebanon	Groundwater (GW) Surface water (SW)	Good Good	Municipal: solid waste disposal, sewerage systems Industrial: management of waste Silent trade: transboundary movement, dumping of hazardous industrial wastes
Oman	Surface water (SW) Groundwater (GW)	Good	Excessive exploitation – brackish water, saline water intrusion, transboundary underflow Industrial: oil pools
Qatar	Groundwater (GW) Desalinated sea water	Fair N/A	Excessive exploitation – brackish water, saline water intrusion
Saudi Arabia	Groundwater (GW) Surface water (SW) Desalinated sea water	Good N/A	Excessive exploitation: brackish water-, saline water intrusion
Syrian Arab Republic	Surface water (SW) Groundwater (GW)	Fair-Good N/A	Industrial: disposal of industrial and other types of waste water
United Arab Emirates	Surface water (SW) Groundwater (GW) Reclaimed water	Fair N/A N/A	Over-exploitation (alluvial aquifers), saline water Industrial – oil spills and oil-sludge
Yemen	Groundwater (GW) Surface water (SW)	Fair-good	Over-exploitation (alluvial aquifers), saline water Sewage disposal systems

Source: UNESCWA, 1995a, Assessment of Water Quality in the ESCWA Region. United Nations, New York, (E/ESCWA/ENR/1995/14), chapter II and III.

Nitrogen, which is overused in the form of manure, sewage sludge and chemical fertilizer, is a major groundwater pollutant in the ESCWA region. As an essential plant nutrient, it is an important fertilizer, but high levels of nitrate in drinking water have a major health impact. Furthermore, too much nitrate in the soil leads to the destruction of organic matter by oxidation, thus increasing the amount of nitrate leached by infiltrating rain and decreasing the self-purification capacity of the soil and the unsaturated zone near the surface. Pesticides are widely used in agriculture and industry. The use of synthetic organic pesticides has grown rapidly since the 1950s because, when used in conjunction with fertilizers, they increase crop yields. Pesticides are, however, a risk to human health. Some soluble pesticides can move fast through the unsaturated zone, but their progress may be delayed by adsorption and biological degradation processes. Rapid flow in fractured aquifers is a high risk (Refer to Annex B). Pollution is further compounded by failure to implement appropriate groundwater monitoring and protection programs. This brief discussion gives only an indication of the type and extent of pollution from different activities. Groundwater contamination is taking place in all ESCWA countries, but limited data make it very difficult to estimate the total extent of pollution. There are believed to be many other cases of pollution in the ESCWA region, with varying environmental and health impacts. The documented cases of groundwater pollution demonstrate that serious efforts are required to implement protection and rehabilitation measures.

BOX 1: CONTAMINATION OF GROUNDWATER BY AGRICULTURE IN THE BEQA'A VALLEY, LEBANON

The Beqa'a Valley is a major agricultural region in Lebanon. The overuse of fertilizers and the reuse of wastewater have caused soil and groundwater pollution. These activities have resulted in elevated levels of nitrate and heavy metals, such as chromium, nickel, cadmium, lead and zinc in the Beqa'a soil profile and shallow groundwater aquifer. The aquifer is vulnerable to contamination, including by heavy metals, as its depth below the soil surface is in some locations very shallow with a minimum of only 0.5 m. Heavy metal concentration in the soil profile decreases with depth with highest reported values of 0.28, 28.5, 93.6, 28, 72.8, 15.5 and 97.2 mg/l for cadmium, copper, chromium, cobalt, nickel, lead and zinc, respectively. In the groundwater, concentrations of 13.9, 6.4, 0.06, 115.2, 0.86 µg/l of Ni, Cr, Cd, Zn, and Pb, respectively, were found at a depth of 2 m, and similar levels of 12.5, 5, 0.03, 219.5, and 0.95 µg/l at a depth of 8 m, while in the 70-meter deep well, concentrations were significantly lower at 5, 4, 0.02, 36.8 and 0.4 µg/l, respectively. Although these values indicate elevated levels of heavy metals, all concentrations are still well below WHO drinking water quality standards. In contrast, nitrate concentration in the groundwater was sometimes above the WHO drinking water quality standard of 50 mg/l, reaching maximum values of more than 200 mg/l.

Heavy metal accumulation in the upper soil layers with low quality irrigation water (mg/kg)

Profile D	**Soil depth, cm**	**Cd**	**Co**	**Cr**	**Cu**	**Ni**	**Pb**	**Zn**	**Water table depth, cm**
Za-3	0-20	0.28	28.5	93.6	28.6	72.7	15.5	95.7	800
	20-150	0.26	28.1	93.5	28.3	72.8	13.2	97.2	
	150-200	0.24	17.9	60.7	19.2	48.8	7.2	64.4	

Analysis of water from wells in the central Beqa'a Valley (mg/l)

Source	**Ni**	**Cr**	**Cd**	**Zn**	**Pb**
Shallow open water reservoir, 2m depth nourished from water table seepage.	13.9	6.4	0.06	115.2	0.86
Superficial well (Arab well) 8 m.	12.5	5	0.03	219.5	0.95
Deep well 70 m.	5	4	0.02	36.8	0.4
Level of Intervention*	15-37	1-26	1.5-6	150-290	15- to be defined
WHO drinking water quality standard	20	50	3	3 000	10

**The level beyond which measures should be undertaken to limit hazards of heavy metal input to the soils.*

The status of nitrates and salts in the deep wells of the central Beqa'a Valley

Number of wells	NO3 mg/l	No. of wells	Electrical Conductivity (dSm/m)	Total dissolved solids mg/l
10	>200	13	1.0-2.0	650-1300
6	100-200	4	0.6-1.0	400-650
8	40-100	13	<0.6	<400
6	10-40			

Source: Darwish et al., 2000

C. HEALTH IMPACTS OF GROUNDWATER POLLUTION

Contaminated drinking water is the main cause of illness and death in the world. Ingestion of, or exposure to, contaminated water causes a number of diseases. Others may be caused by exposure to naturally found harmful chemicals or man-made pollutants in groundwater. There are short-term and long-term health risks associated with contaminated water. These may be **microbial** (bacteria, viruses, parasites), **chemical** (metals, pesticides, disinfectants by-products, etc.) or **toxin-related** (toxins produced by micro-organisms). Contaminants in irrigation water can also affect agricultural products and cause health problems by entering the food chain. Consequently, the absence of proper wastewater collection systems and the persistence of open channels or pools of wastewater will serve as breeding grounds for many diseases (*Refer to Annex B)*. Information on human morbidity and mortality of water related diseases are not available in most of the countries of the ESCWA region due to its sensitivity. Furthermore, available data and its documentation by most of the countries make it difficult to trace the effect of poor environmental conditions on human health. These restrictions have now been lifted, but it is still difficult to collect data because methods are not standardized (Jurdi, 2000).

BOX 2. REGIONAL GROUNDWATER REMEDIATION (BLUE-BABY SYNDROME)

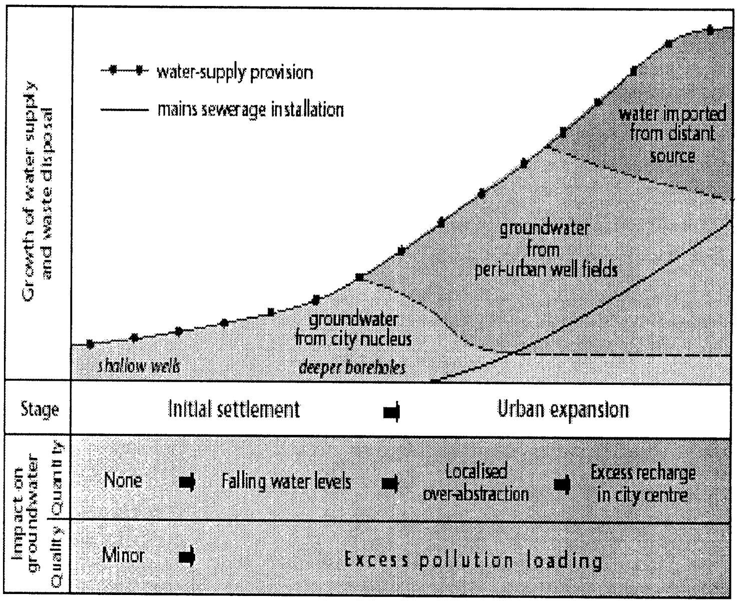
A pilot project on nitrate contamination of groundwater, began in 2002 in Syria, is now nearing completion. ***It has confirmed the seriousness of nitrate pollution as a source of illness in infants***. Most small villages in Syria and elsewhere lack adequate wastewater disposal systems, relying on individual household cesspits. This contributes to contamination of groundwater, which is often used, without treatment, for drinking. Extensive use of manure as fertilizer aggravates the problem as runoff seeps into aquifers. A major contaminant in such situations is nitrate, which poses health risks, particularly for infants three months old and younger, as it leads to a diminished capacity of the blood to transport and transfer oxygen. Infants consequently suffer an ailment commonly called "Blue Baby Syndrome". With funding from the Arab Gulf Fund for United Nations Development (AGFUND), UNU/INWEH examined groundwater pollution from cesspits, the impact of fertilization techniques and the relationship between nitrate concentration and the proximity of drinking water wells to pollution sources. Guidelines are now being finalized for ***cesspit design***, for ***fertilization practices***, and for ***buffer zones*** around wells to minimize nitrate pollution. The initiative ***promotes the planting of special crops capable of reducing nitrate*** from seeping wastewater around cesspits. Local staff is also being trained to implement the guidelines. The results of this project are of sufficient concern that a new proposal to the European Union is now being prepared to undertake a major regional groundwater assessment and nitrate remediation program in Lebanon, Syria, Jordan and Palestine. The proposal is being prepared jointly with national environmental officials from the four countries involved.
Source:http://www.inweh.unu.edu/inweh/projects/Groundwater%20Remediation%20in%20Syria%20(Blue-Baby %20Syndrome) 1.htm, visited September, 2003.

D. Other Groundwater Problems – Urbanization Process

In a growing city, as the demand for water and the need for safe disposal of wastewater increase, so the changing combination of supply source, from local to peri-urban to hinterland, are matched by new urban sources of recharge such as losses from the piped infrastructure, on-site sanitation and pluvial drainage (Figure 3). Subsurface water levels, both within the city and outside, undergo major changes as the twin pressures of competing demand for water and concern about the quality of the water shift the supply emphasis from city center to peri-urban areas.

The radical changes in frequency and rate of subsurface infiltration caused by urbanization tend overall to increase the rate of groundwater recharge. If the underlying aquifer system is not utilized, or the shallow subsurface is not sufficiently permeable to allow the extra water to flow away, then groundwater levels will rise. Initially as the water table rises towards the land surface, tunnels and service ducts may suffer structural damage or be flooded, followed later by hydraulic and corrosion effects on building foundations and tunnel linings. In extreme cases, where the water table reaches the land surface, there may be a health hazard because septic tanks malfunction and water polluted with pathogens may accumulate in surface depressions.

FIGURE 3. *STAGES IN THE EVOLUTION OF A WATER INFRASTRUCTURE IN A CITY OVERLYING A PRODUCTIVE AQUIFER*



Source: UNEP, 2003

On the other hand, where the city is underlain by a productive shallow aquifer and groundwater abstraction is significant, a declining water table will mask the presence of increased urban infiltration rates and, indeed, in some unconsolidated aquifers the geotechnical problems associated with pumping induced subsidence can result. However, as cities evolve, intra-urban abstraction often declines, either as a direct result of groundwater quality deterioration or as a consequence of unrelated economic factors. In these circumstances, the water table begins to recover and may eventually (over decades) rise to levels higher than it was before urbanization as a result of the additional urban recharge. This can provide a widespread threat to a well-established urban infrastructure constructed when foundations, piped and cabled services did not need to be designed to cope with a water table near the surface. Thus the hydrogeological regime continues to exert a major control over an urban infrastructure, **even when the city has ceased to depend significantly on local groundwater for its water supply.**

BOX 3: THE PROBLEM OF URBAN GROUNDWATER: RISING WATER LEVELS

The water balance of an aquifer once its catchment is urbanized becomes much more complex due to the presence of both new potential sources of recharge and of new abstraction. This effects water levels, which rise and fall to maintain a balance between inflow and outflow. In many aquifer systems, these changes will not be immediately obvious due to the large volume of available storage, and it may be many years before they reach equilibrium with the hydrological changes induced by urbanization. Disregard of the lag in response time between cause and effect in aquifer systems can unwittingly compound aquifer degradation effects, which can arise from changes in inflow and outflow components. An example of the problem is one of the paradoxes of arid-zone hydrology, and is seen in the waterlogging problems experienced by several Arabian cities due to increased urban recharge.

The city of **Riyadh**, Saudi Arabia grew from a town of 20000 in 1920 to more than 1.2 million in the 1990s. Per capita consumption rates also rose, to more than 600 l/person/day in 1990. By the early 1980s, the high water demand was met by long-distance imports of desalinated water. This coincided with reduced pumping from a deep underlying limestone aquifer, abandoned due to serious pollution. New urban recharge sources have arisen from high water mains leakage rates (over 30%), underground storage tank losses, percolation from septic tank systems and over-irrigation of amenities such as parks, road verges, gardens. Waterlogging has occurred because much of the city is underlain by a shallow aquitard and adequate drainage through it cannot occur. The vertical permeability is low and there is now insufficient pumping by users from the deep aquifer system to provide a vertical hydraulic gradient to induce leakage from the overlying aquitard. The waterlogging has caused deformation of basements and pipe networks, and dewatering equipment was required to alleviate flooding. Horizontal drains have been demonstrated to be ineffective, and the problem has required more complex and expensive pumping of the aquifer underlying the aquitard to induce drainage. Thus for Riyadh an urban water management strategy to control the waterlogging problem would need to include not only control of mains and tank leakage, and over-irrigation (inputs), but also a means of coping with the large volume of imported water, for example local groundwater pumped from the deep aquifer system could be substituted for non-sensitive uses such as amenity irrigation.

Another Arabian example shows that rises in level do not have to be more than a very few meters before degradation effects become serious. Both **Kuwait** and **Doha** cities share with Riyadh the pattern of much increased recharge due to a rapid growth in population, an increase in per capita water consumption and water imports from desalination plants, high water mains leakage, amenity over-irrigation and on-site sanitation returns. But in addition both are low-lying coastal areas with underlying evaporite deposits, and evaporative salinization of the near-surface adds serious water quality deterioration to the geotechnical effects described for Riyadh. The percolating desalinized water dissolves salts and makes shallow groundwater much less attractive for other, non-potable uses as well as making it more aggressive and harmful to concrete and steel reinforcing materials. A typical groundwater budget from one of these arid-zone cities shows how insignificant the contribution of recharge from rainfall is in comparison with human sources. The corollary is that urban planning and control policies, if effective and enforced, can be very influential in controlling the extent and rate of groundwater degradation. For instance, hydrographs from monitoring wells confirm the groundwater budget calculation that garden irrigation is a very important new recharge source. Control of such domestic and municipal over-irrigation could be put in place very quickly and comprise either financial (metering and increasing block tariffs, drip irrigation incentives) regulatory (sprinkler/hosepipe bans) or operational (supply restrictions, pipe resizing) measures.

Groundwater budget for a typical Arabian Gulf coastal city (from Walton, 1997)

Groundwater recharge source	% total	Groundwater outflow source	% total
Seepage from amenity over-irrigation	45	Seepage and channeling to coast	46
Mains supply leakage	30	Groundwater abstraction	21
Septic tank/soak away seepage	22	Drainage into sewerage system and storm water drains	25
Effective recharge from rainfall	3	Groundwater flow inland	6
-	-	Groundwater evaporation	2
Total recharge inflows=29.8 x 106 m3/a	100%	*Total discharge outflows=28.9 x 106 m3/a*	100%
Addition to storage= 0.9 x 106 M m3/a, resulting in typical annual water table rise of 0.3-0.4m			

Source: UNEP 2003

E. SUSTAINABLE GROUNDWATER RESOURCES MANAGEMENT- AN IWRM PERSPECTIVE[3]

E.1. Groundwater Exploitation and Sustainability

Aquifers serve the important function in the hydrological cycle of storing and subsequently releasing water. The water thus discharged from aquifer storage fulfills two major roles. First, it can benefit the environment by naturally maintaining and sustaining river flow, springs and wetlands. Secondly, it can provide a valuable water supply to meet the growing demand for water for drinking and domestic use, crop irrigation and industry. **Within the IWRM context, reconciliation of these different roles is a major task for water resources managers concerned with sustainable use of water resources**. In most of the countries in the ESCWA region, where rainfall is scarce, groundwater is the main source of freshwater available, and as a consequence is often heavily exploited.

The Conundrum of Safe Yield and Sustainable Use

Although groundwater development can have many advantages, such as providing access to safe potable water and improved agricultural production, its use can also have undesirable side effects such as the drying-up of shallow wells, increasing costs of pumping and deterioration of water quality due to salinization. Recognizing these problems, the idea of a safe level of exploitation or ***Safe Yield*** has long been discussed. ***The Safe Yield of an aquifer has been defined as the amount of water that can be withdrawn from the aquifer without producing an undesired result.***

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[3] This section and the following ones, unless indicated otherwise, are based mainly on documents: "Sustainable Groundwater Management: Concepts and Tools, GW-MATE Briefing Notes", 2003, World Bank; and "Groundwater and its susceptibility to degradation: A global assessment of the problem and options for management", 2003, UNEP, UNEP/DEWA/RS.03-3.

At first glance this appears to be reasonable, but what is meant by an 'undesired result' and from whose perspective? All groundwater flow must be discharging somewhere, and abstraction will reduce these discharges, and any significant abstraction will necessarily result in some environmental impact by reducing spring discharge or stream flow. Clearly it is important to differentiate the "benefits of exploitation" from the "negative side effects". More recently the concept of ***sustainability*** has become current, and is ***defined as the level of development of groundwater that meets the needs of the present generation without compromising the ability of future generations to meet their needs***. The general rationale it represents is clear but each situation needs to be considered on its merits because issues of economics, equity, and the rights of different users are involved in any specific assessment.

For example, the development of deeper groundwater for irrigation may make good economic sense (and be sustainable) both for middle and high-income farmers (who can afford the cost of drilling deep wells) and for the local economy in general. However, a negative side effect may be the lowering of a shallow water table, which causes village drinking water supplies and shallow irrigation wells belonging to poorer farmers to dry up. Whether this is overexploitation or not will depend on the viewpoint of the different interested parties (or stakeholders). The exploiter, an affected third party, a licensing authority or regulator and an environmentalist may all have different perceptions. Similarly, views on whether such development is equitable may depend on compensation arrangements for those badly affected. However, although aquifer over-exploitation may be an ambiguous, controversial and somewhat emotive term, it is likely to become more important, especially in the semi-arid regions of the world, such as the ESCWA region, as competing demands grow on a limited resource.

The issue is further complicated because water is a dynamic resource. The different components of the water balance vary naturally with time, as during a drought or in response to changing patterns of rainfall. These dynamics also apply to human interventions. For example, increasing groundwater abstraction will cause groundwater levels to decline, which in turn generally reduces other outputs or discharges from the groundwater system, such as the through flow to the coast, discharge to streams, springs and oases. Human intervention may also increase aquifer recharge, for example in a shallow aquifer by creating storage or in a deeper aquifer by inducing downward leakage into the aquifer. Unless abstraction persistently exceeds recharge a new equilibrium will be reached, but the time taken will vary and depends principally on the dimensions of the groundwater system and the aquifer parameters. It could be many years or even decades, and sustainability considerations must take into account this long time-scale when calculating the response of an aquifer system. Thus declining groundwater levels are not by themselves a signal of "over-exploitation", but simply an indication that the system is not in equilibrium. Hydrogeologically, there is no objective measure or definition of over-exploitation. Although over-exploitation has usefully been defined as a failure to achieve maximum economic returns to the resource, applying economic analyses to the study of aquifer management may not necessarily include a consideration of the social impact. ***That a particular aquifer system is becoming or has become over-exploited is an economic and moral judgment***. The economic factors include considerations of the relative value of different water uses, and the moral factors should take into account the issues of social equity and protection of the environment.

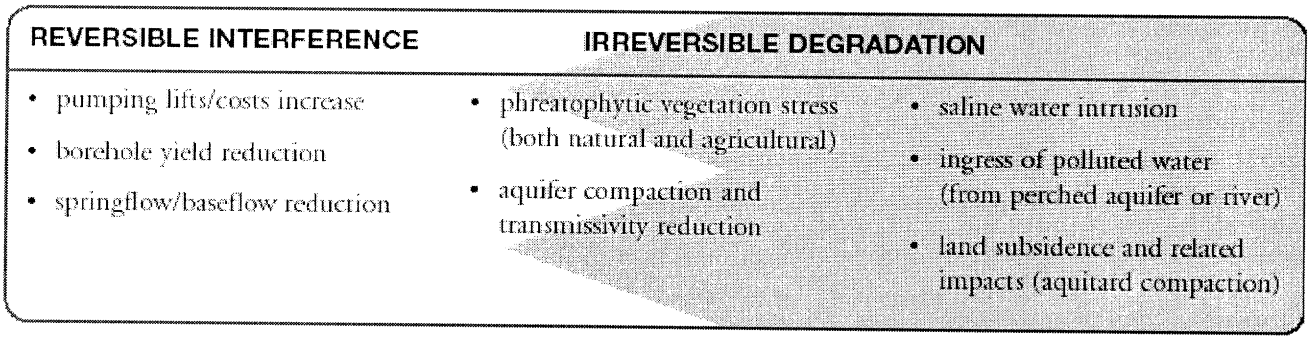
An example of the difficulty in reconciling sustainability with over-exploitation is the use of the non-renewable groundwater (palaeowater) beneath central and southern Libya, which was recharged thousands of years ago during a more humid climatic period. Seven million liters/minute of groundwater from over 1000 boreholes tapping the aquifer systems beneath Jabal, Sarir, Tazerbo and Kufra is transported by large diameter pipes (the 'Great Man-Made River') to the Mediterranean coast 500 to 900 km away, principally for irrigation purposes. The aquifer system receives effectively no present-day recharge and exploitation of this resource is clearly not sustainable. However, given the very large volumes of groundwater stored (and therefore the long timescales during which exploitation can continue), the significant economic benefit that may accrue, and the limited negative side effects, such groundwater mining may not be, at least by some definitions, over-exploitation.

E.2. Negative impacts of overexploitation

Despite the problem of defining 'over-exploitation' in a given aquifer setting, there are a number of well-known consequences of groundwater development that may not be desirable. In practice, when speaking of aquifer over-exploitation we are invariably much more concerned about the consequences of intensive groundwater abstraction than in its absolute level. Thus the most appropriate definition is probably an economic one: that the **'overall cost of the negative impacts of groundwater exploitation exceed the net benefits of groundwater use'**, but of course these impacts can be equally difficult to predict and to cost.

It is important to stress, in this context, that some of these consequences can arise well before the groundwater abstraction rate exceeds long-term average recharge. Thus the way in which a given situation is interpreted will vary with the type of aquifer system involved—that is with volume of exploitable storage and susceptibility to irreversible side effects during short-term overdraft. Amongst the most critical of potential impacts from intensive aquifer development (Figure 4) is groundwater salinization. This will be terminal for both potable water supply and agricultural irrigation uses.

***FIGURE 4**. CONSEQUENCES OF EXCESSIVE GROUNDWATER ABSTRACTION.*

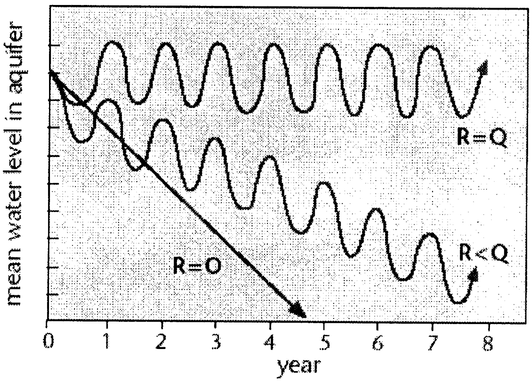


1. Groundwater Level Decline and Decrease in Spring Discharge, River Baseflow and Wetland Area

Most aquifers show a water level decline as part of a natural cycle (Figure 5), even when not exploited, at least in some areas for part of the time. This may be seasonal, during a normal dry season, or it may be longer term in response to a prolonged drought. During these periods river and spring flows and discharge to wetlands are provided by release of water from aquifer storage and, as a consequence, water levels in the aquifer decline. Subsequent periods of recharge permit water levels to rise again as water is brought back into aquifer storage.

Likewise, when groundwater is exploited water levels will decline and continue to do so until they either stabilize at a lower level or, if abstraction is persistently greater than recharge, the aquifer is dewatered. Extended declines can result in the drying-up of shallow wells, increased pumping costs, reduced borehole yields and efficiencies, the need to deepen or replace boreholes and, in coastal areas, saline intrusion (as will be indicated below). Likewise, when groundwater is exploited water levels will decline and continue to do so until they either stabilize at a lower level or, if abstraction is persistently greater than recharge, the aquifer is dewatered. Extended declines can result in the drying-up of shallow wells, increased pumping costs, reduced borehole yields and efficiencies, the need to deepen or replace boreholes and, in coastal areas, saline intrusion (as will be indicated below).

FIGURE 5. PATTERNS OF WATER LEVEL DECLINE IN AN AQUIFER UNDER DIFFERENT RECHARGE CONDITIONS,



R=Q Net recharge = natural discharge and/or abstraction
R<Q Natural discharge and abstraction exceed net recharge
R=O Abstraction in absence of recharge (arid zone situation)

SOURCE: *UNEP, 2003*

x Borehole yields are dramatically reduced and wholesale abandonment results. The resultant forced reduction in abstraction needs to be severe, beyond the long term rate of recharge, for water levels to recover, and this may take many years or even decades to occur. Such impacts can have severe socio-economic consequences. Declining groundwater levels may also cause drastic reductions in river flow and in wetland areas.

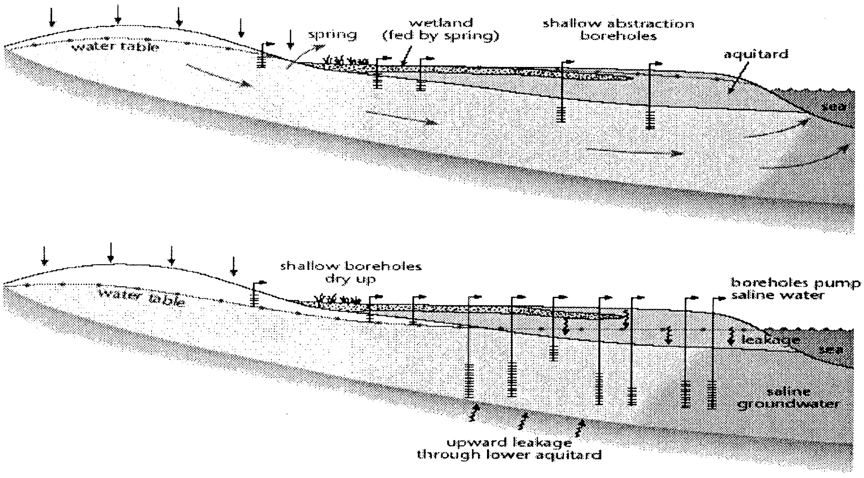
The consequences may be slow to develop, not apparent until the problem is well entrenched and may not be reversible (such as the loss of flora and fauna from a natural habitat (Box 4).

The extent to which water levels fall does not identify whether an aquifer is over-exploited, the important factor is whether the decline is acceptable or not acceptable in terms of the impact on water users and uses. Thus even a water level decline of a very few meters may be enough to threaten an important wetland habitat and be considered unacceptable, yet elsewhere a similar drawdown may be viewed positively as improving drainage and reducing water losses to stream flow and evaporation, and moreover the increase in abstraction for irrigation may permit improved agricultural productivity.

2. Changes in Flow Pattern Leading to Deterioration in Water Quality - Salinization

Changes in groundwater quality resulting directly, or indirectly, from groundwater abstraction can be classed as over-exploitation if the changes have a negative effect upon the socio-economic value of the resource. Such deterioration in quality can occur for a number of reasons including saline intrusion, geochemical evolution of groundwater and induced pollution. The induction of flow of low quality water into the aquifer as a result of a new hydraulic head distribution is perhaps the most common of these (Figure 6). Saline intrusion is an important consideration for aquifers adjacent to the coast or other saline bodies, above or underneath the aquifer. The mobility of such saline waters depends upon the hydraulic gradients (which are of course locally disturbed by groundwater abstraction), the permeability of the aquifer and the presence or absence of hydraulic barriers. A consideration of the time period involved in displacement of a saline front is important to an assessment of over-exploitation. A displacement time of a few years would be a matter of concern, indicating a high probability of 'overexploitation', but hundreds or thousands of years could well be acceptable in the context of long-term management strategies. Intrusion of water with dissimilar hydrochemistry can also alter the physical properties of the aquifer. For example, changes in porosity and permeability can result from the processes of consolidating sediments into rock through water–rock interaction. Such processes can irrevocably damage the fabric and hydraulic properties of the aquifer. Changes induced in the groundwater hydrochemistry due to water–rock interaction may also have detrimental health impacts where the aquifer is used for potable supply.

FIGURE 6. TYPICAL IMPACT OF EXCESSIVE ABSTRACTION ON COASTAL/LOWLAND AQUIFER SYSTEM.



Stage A : Initial condition
- groundwater flows from outcrop to coast
- springs help maintain wetland
- limited abstraction from shallow boreholes occurrs

Stage B : Groundwater abstraction increases leading to:
- groundwater level decline in aquifer
- springs feeding wetland cease
- shallow wells dry up
- coastal boreholes become saline
- leakage through upper and lower aquitards (if present) begins

Source: UNEP, 2003.

3. Land Subsidence

Sedimentary formations are initially formed as soft sand, silt or mud. As the sediment builds up and subsequent layers are deposited, the increasing weight of the overburden compresses the lower beds, but the system keeps in equilibrium because the intergranular stress in the skeleton of the formation balances the weight of the overburden. Pressure of the water within the pores between the individual sediment particles also helps to support some of this weight. Groundwater pumping has the effect of decreasing the *pore water pressure* and thus increasing the effective stress from the overlying strata on the matrix of the aquifer. When the increase in effective stress is greater than a critical value, known as the *pre-consolidation stress*, the sediment compaction becomes irrecoverable or *inelastic*. Sedimentary aquifer systems compact in different ways. In coarse-grained sediments groundwater abstraction results in a rapid readjustment of pore pressure and, if abstraction is excessive, in rapid compaction and subsidence. In fine-grained sediments the response is slower. Subsidence of heavily pumped rural aquifers can affect irrigation and natural land drainage by the reversal of surface topographical gradients but it is in urban areas where the impact can be most serious.

E.3. Impact of Groundwater Depletion on Society

When evaluating the impact of groundwater depletion on society, two key issues are usually considered. These are the ***level of reliance on groundwater*** and ***the marginal cost***, which is the cost of providing replacement supplies from another source. i.e., if groundwater is not widely used then the loss of the resource is unlikely to have a significant impact either on society or the economy, especially where alternative sources of water are available at only a marginal increase in cost. However, in most of the countries in the ESCWA region, groundwater is either the only source of water, because surface water resources are inadequate, or replacement sources of water would be prohibitively costly (e.g., desalination, transfer of water between basins, buying water, etc.). ***So there is a scarcity value to the groundwater resource.*** In addition, the marginal cost concept ignores the intangible but nonetheless real benefits to society of the role of groundwater in maintaining habitat and species diversity.

Furthermore, it ignores the fact that groundwater and surface water are often linked; the perennial flow of many rivers is sustained by groundwater and a decline in groundwater level may reduce this base-flow. The reduction in total flow volume is often secondary to the loss of timely availability of flow, be it for irrigation during the dry season, for dilution of urban or industrial wastewater or for maintenance of riverine habitat. Groundwater used for irrigation is rarely costed on the basis of its scarcity value or the value of alternative or competing uses. In some cases, it may contribute relatively little added value and, if the farmers paid the full economic value of the water, free of direct and indirect subsidies, then irrigation would not be economically viable. It is generally recognized that domestic water supply, especially to urban areas, has the highest economic and societal value and this makes it a priority use. Yet the assignment of relative value is not straightforward, and each case needs to be judged on its merits. For instance, many cities function perfectly well with per capita water use of 150 to 250 l/p/day, yet others in similar climatic and developmental circumstances are profligate, consuming 500 to 600 l/p/day or even more as a result of poor water management. On the margins of these same cities there may well be horticultural farms producing vegetables and fruit with highly efficient drip irrigation techniques to control nutrient and water application. Who is to say in such circumstances that public supply has the higher value and must be given priority in water resource planning?

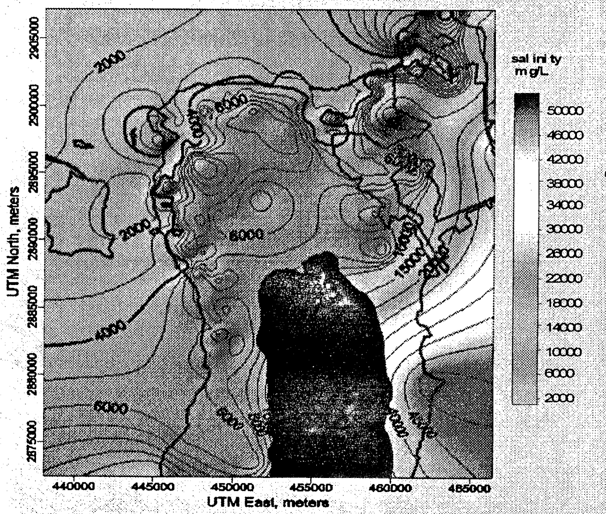
Although there are well-established economic methods of assigning value to water for human uses such as domestic supply, irrigation or industrial uses (Module 5 Economic Dimensions of IWRM), it is particularly problematic to assign ecological and amenity value. Indirect measures of the environmental value and benefit of wetlands or a river flowing during the dry season can be measured in some attractive locations in terms of tourism revenues. ***Because it is difficult to agree a way of assigning a value to amenity and habitat conservation, historically these water uses have been under-prioritized for many catchments.***

BOX 4: THE COST OF GROUNDWATER OVEREXPLOITATION AND DEPLETION ON SOCIETY: BAHRAIN

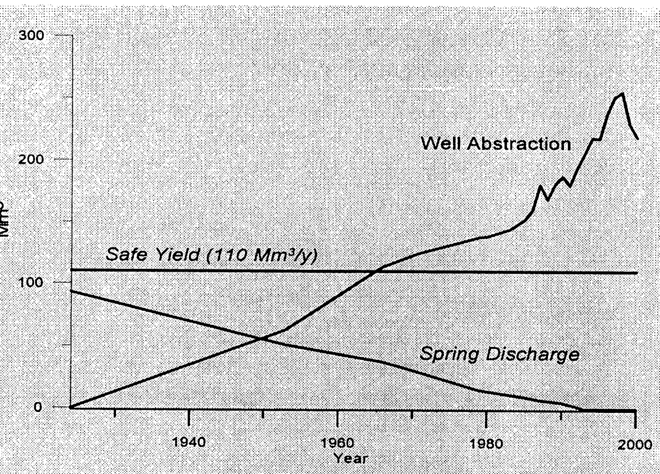
In Bahrain, groundwater in the Dammam aquifer is the only natural source of relatively freshwater to meet the increasing demands for water. The Dammam aquifer in Bahrain forms only a small part of the extensive regional aquifer system, termed the Eastern Arabian Aquifer, which extends from Central Saudi Arabia, where the aquifer rocks outcrop and its main recharge area is located, to the Arabian Gulf water, including Bahrain, Kuwait, and southern Qatar. It is this regional aquifer that provides Bahrain with its water by lateral under-flow. According to many hydrological investigation and simulation studies, the steady state rate of under-flow from Eastern Saudi Arabia to Bahrain ranges between 100 to 112 Mm^3/y – the water authority in Bahrain consider this rate as the safe yield of the Dammam aquifer.

Bahrain, like most of the GCC countries, has experienced an accelerated development growth since the early 1970s. This occurred as a direct result of the sudden increase in the country's oil revenues, which led to fast increase in its economic base and an improvement in the standard of living, resulting in a rapid increase in the country's population. The fast growth rate in population and the associated development processes, represented by rapid urbanization, expansion of irrigated agriculture and industrialization, in the last four decades have brought about substantial water demands increases, met mainly by groundwater abstraction

Heavy reliance on groundwater, particularly by the agricultural and municipal sector, and its prolonged overexploitation over the last four decades have led to severe deterioration of its water quality, as well as loss of all the naturally flowing springs. Currently, most of the original groundwater reservoir under steady-state conditions has been lost to salinization.



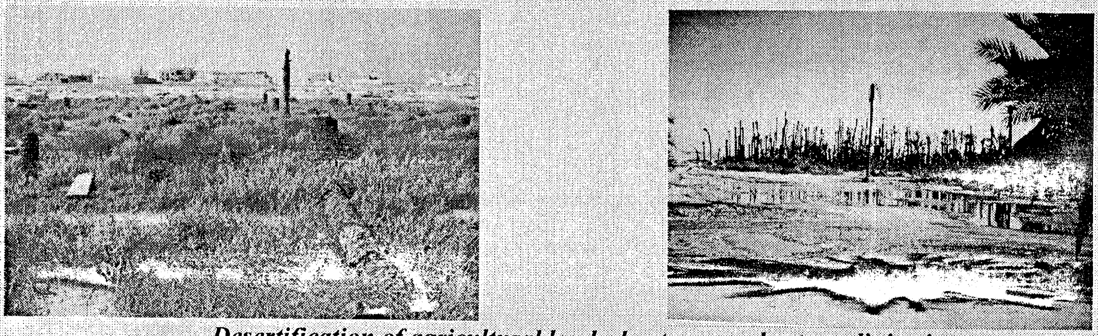
Groundwater salinity in the Dammam aquifer, 2001



Groundwater exploitation in Bahrain, 1920-2000.

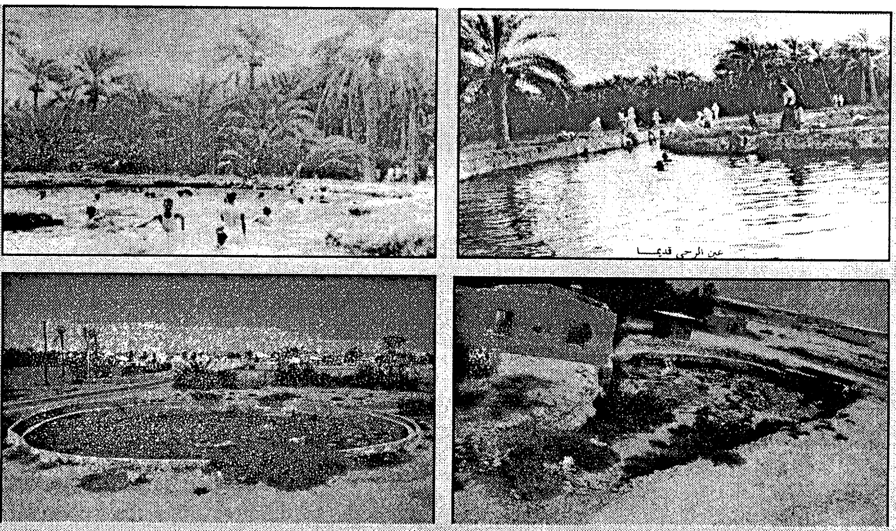
The loss of the natural groundwater resource to salinization in Bahrain has dire consequences on the country's socio-economic development as well as on the environment. The marginal cost, which is the cost of providing replacement supplies from another source is enormously high, and would be equal to the cost of producing about 100 Mm^3/y of sweater desalination and/or treated wastewater.

Moreover, the deterioration of groundwater quality had a significant and strong impact on agricultural activities in Bahrain, which depends exclusively on groundwater irrigation. As groundwater used for irrigation has become increasingly more saline, a vicious cycle have started: irrigating with salinized groundwater using traditional irrigation methods, coupled inefficient irrigation return have lead to soil salinization, and have lead farmers to resort to using high rates of irrigation water to leach salts from the soil top layer, causing more abstraction, accelerating groundwater quality deterioration and further soil salinization, thus escalating the situation, eventfully leading to the abandonment of major agricultural areas due to the loss of their productivity and desertification, and their transfer to urban areas.



Desertification of agricultural lands due to groundwater salinization

Furthermore, groundwater depletion had a significant impact on the environment, wetland, and biodiversity in Bahrain (although it is difficult to assign a value to it). The loss of all natural springs and the dryness of their surrounding environment had caused the destruction of wildlife flora and fauna habitats as well as the habitat of migratory birds, loss of animal species, and have definitely compromised the hidden ecosystem services and functions.



Examples of natural springs drying and loss of natural habitat, 1950s & 1990s

Source: Al-Zubari, 1999

F. GROUNDWATER RESOURCES MANAGEMENT- AN INTRODUCTORY TO ITS SCOPE AND PRACTICE[4]

F.1. Main Differences between Groundwater and Surface Water

Groundwater differs from surface water because of the contrasting physical and chemical environment in which it occurs, although the water itself is essentially part of the same overall cycle. Surface water flows relatively rapidly in small streams, which feed the main river draining the catchment area concerned. The catchment area of each river basin is determined by land surface topography and generally does not change with time. On the other hand groundwater moves through aquifers (permeable strata) from areas of recharge to areas of discharge (determined by the geological structure), normally at slow rates ranging from 1 m/year to 100s m/day. Tens, hundreds or even thousands of years may elapse between initial recharge and eventual discharge, to a spring, stream or the sea. These slow flow rates and long residence times, consequent upon large aquifer storage volumes, are amongst the numerous distinctive features of groundwater systems (Table 5).

The flow boundaries of groundwater (in space and depth) are generally more difficult to define and may vary with time. The difference is further accentuated because groundwater forms the 'invisible part' of the hydrological cycle, which can lead to misconceptions amongst stakeholders. Often water resource decision-makers (like many water users) have little background in hydrogeology and thus limited understanding of the processes induced by pumping groundwater from an aquifer. Both irrational underutilization of groundwater resources (compared to surface water) and excessive complacency about the sustainability of intensive groundwater use are thus still commonplace.

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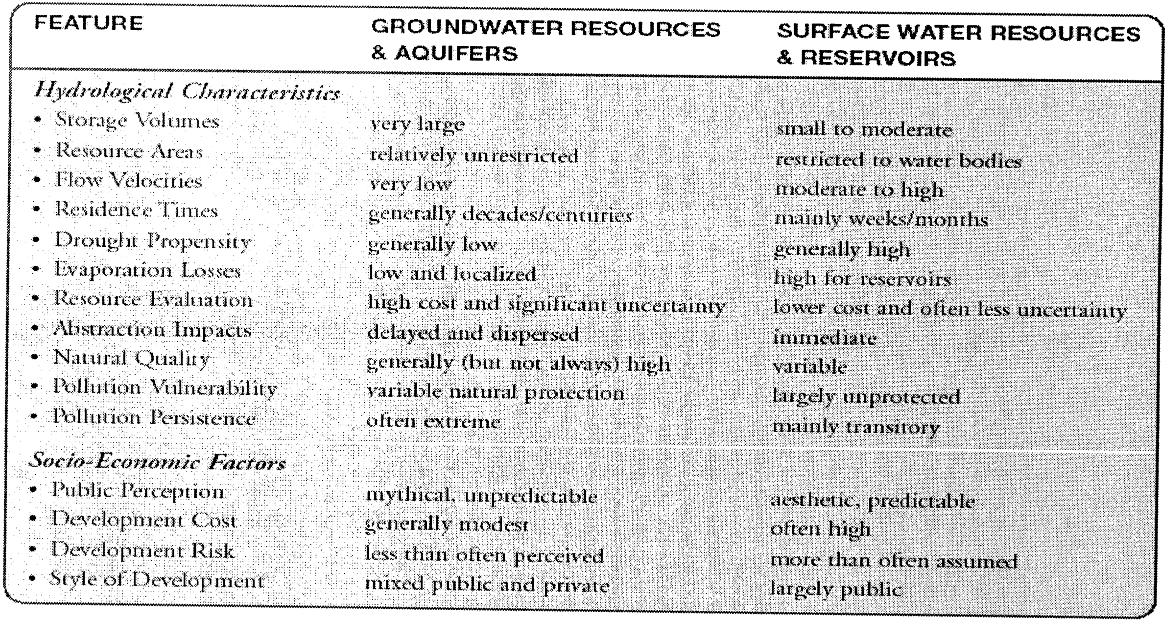
[4] World Bank GW-MATE (Groundwater Management Advisory Team), Briefing Note Series, Briefing Note 1, www.worldbank.ogr/gwmate, visited August 2003.

TABLE 5: COMPARATIVE FEATURES OF GROUNDWATER AND SURFACE WATER RESOURCES.



FEATURE	GROUNDWATER RESOURCES & AQUIFERS	SURFACE WATER RESOURCES & RESERVOIRS
Hydrological Characteristics		
• Storage Volumes	very large	small to moderate
• Resource Areas	relatively unrestricted	restricted to water bodies
• Flow Velocities	very low	moderate to high
• Residence Times	generally decades/centuries	mainly weeks/months
• Drought Propensity	generally low	generally high
• Evaporation Losses	low and localized	high for reservoirs
• Resource Evaluation	high cost and significant uncertainty	lower cost and often less uncertainty
• Abstraction Impacts	delayed and dispersed	immediate
• Natural Quality	generally (but not always) high	variable
• Pollution Vulnerability	variable natural protection	largely unprotected
• Pollution Persistence	often extreme	mainly transitory
Socio-Economic Factors		
• Public Perception	mythical, unpredictable	aesthetic, predictable
• Development Cost	generally modest	often high
• Development Risk	less than often perceived	more than often assumed
• Style of Development	mixed public and private	largely public

F.2. Key Challenge for Groundwater Resources Management

Groundwater resources management has to deal with balancing the exploitation of a complex resource (in terms of quantity, quality and surface water interactions) with the increasing demands of water and land users (who can pose a threat to resource availability and quality).

Calls for groundwater management do not usually arise until a decline in well yields and/or quality affects one of the stakeholder groups. If further uncontrolled pumping is allowed, a 'vicious circle' may develop (Figure 7) and damage to the resource as a whole may result, with serious groundwater level decline, and in some cases aquifer saline intrusion (or even land subsidence).

To transform this 'vicious circle' into a 'virtuous circle' (Figure 8) it is essential to recognize that managing groundwater is as much about managing people (water and land users) as it is about managing water (aquifer resources). Or, in other words, that the socio-economic dimension (demand-side management) is as important as the hydrogeological dimension (supply-side management) and integration of both is always required.

***FIGURE 7**. SUPPLY-DRIVEN GROUNDWATER DEVELOPMENT – LEADING TO A VICIOUS CIRCLE.*

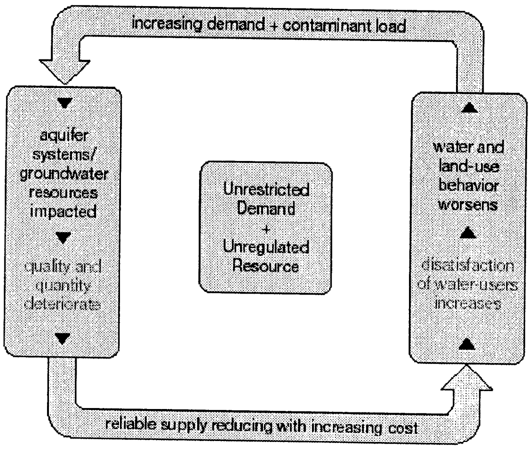
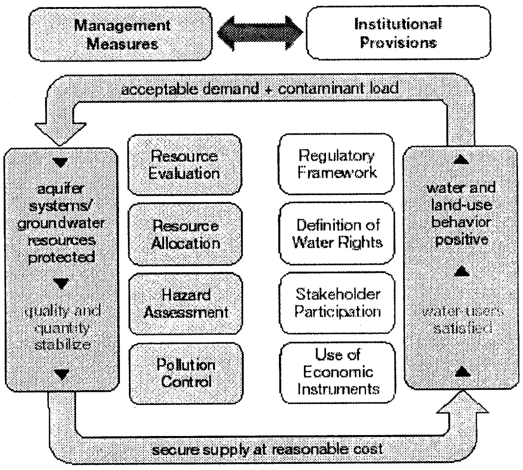


***FIGURE 8**. INTEGRATED GROUNDWATER RESOURCES MANAGEMENT – LEADING TO A VIRTUOUS CIRCLE.*



Key issues for *groundwater supply management* are the need to understand:
- Aquifer systems and their specific susceptibilities to negative impacts under abstraction stress
- Interactions between groundwater and surface water, such as abstraction effects (on river baseflow and some wetlands) and recharge reduction effects (due to surface-water modification).

All of these effects can be short-term and reversible or long-term and quasi-irreversible. Operational monitoring is a vital tool to develop the understanding needed for effective resource management.

On the *groundwater demand management* side it will be essential to bear in mind that:
- *Social development goals greatly influence water use, especially where agricultural irrigation and food production are concerned, thus management can only be fully effective if cross-sector coordination occurs*
- *Regulatory interventions (such as water rights or permits) and economic tools (such as abstraction tariffs) become more effective if they are not only encoded in water law but implemented with a high level of user participation*
- *Regulatory provisions should not go beyond government capacity to enforce and user capacity to comply.*

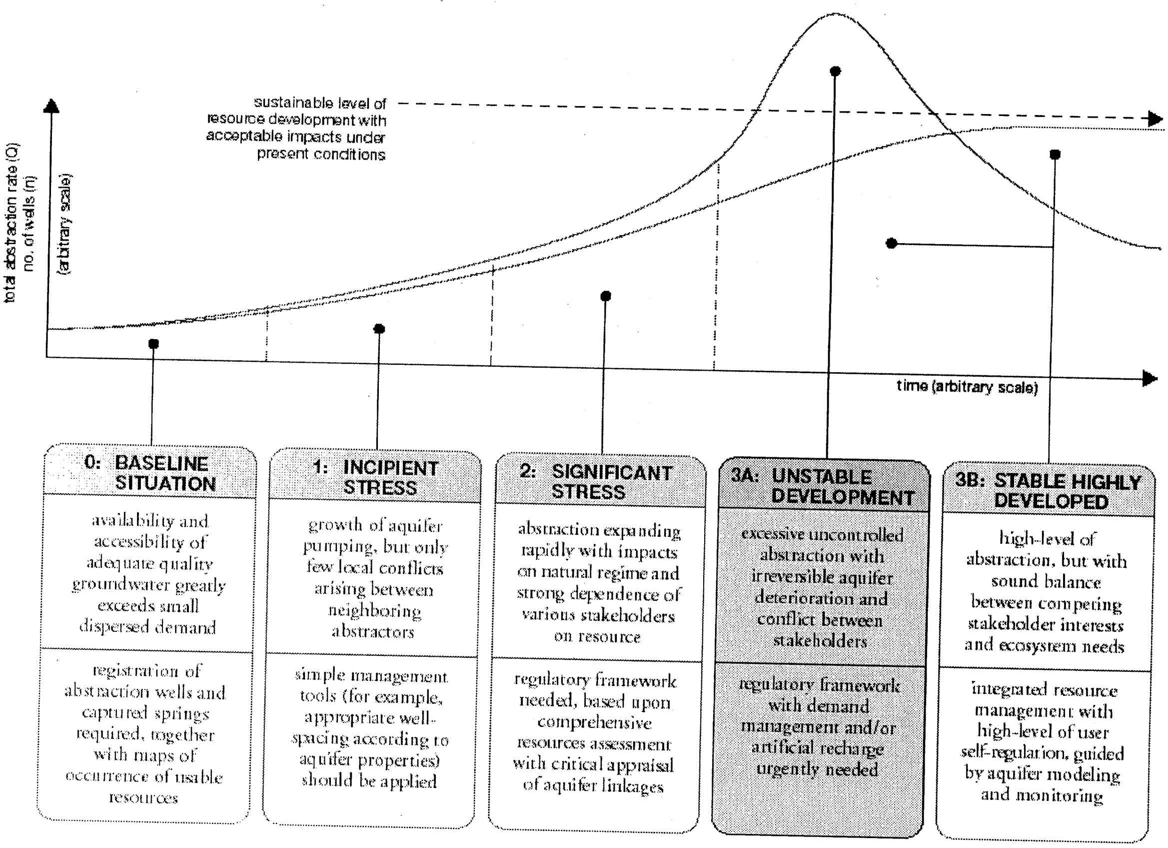
Other generic principles that emerge are that:
- *Both hydrogeologic and socio-economic conditions tend to be somewhat location-specific and thus no simple blueprint for integrated groundwater management can be readily provided*
- *The development of an effective and sustainable approach to management will always require involvement of the main stakeholders*
- *Implementing management measures will often require capacity building, both in water-resource authorities and amongst water users.*

F.3. How Should Integrated Groundwater Management be Practiced?

In most situations, groundwater management will need to keep in reasonable balance the costs and benefits of management activities and interventions, and thus take account of the susceptibility to degradation of the hydrogeological system involved and the legitimate interests of water users, including ecosystems and those dependent on downstream baseflow. In practical terms it will be necessary to set possible management interventions in the context of the normal evolution of groundwater development, and for this it is convenient to distinguish a number of levels (Table 6). However, it must be noted that ***preventive management approaches are likely to be more cost-effective than purely reactive ones.***The condition of excessive and unsustainable abstraction (3A—Unstable Development), which is occurring widely, is also included in Figure 9. For this case the total abstraction rate (and usually the number of production waterwells) will eventually fall markedly as a result of near irreversible degradation of the aquifer system itself.

The concept of an increasing need for integrated groundwater management is illustrated in Table 6, which breaks management down into a series of interrelated aspects and indicates levels of response appropriate for each level of resource development. It should be noted that the approach to groundwater resource development and management for minor aquifers (only capable of supplying rural domestic and livestock water supply) would not be expected to pass level 1 in Table 6.The framework provided in Table 6 can be used as a diagnostic instrument to assess the adequacy of existing groundwater management arrangements for a given level of resource development (both in terms of technical tools and institutional provisions). By working down the levels of development of each groundwater management tool or instrument, a diagnostic profile is generated which can be compared to the actual stage of resource development to indicate priority aspects for urgent attention. Such a diagnostic exercise can also be undertaken by each major group of stakeholders to promote communication and understanding. Through this type of approach necessary management interventions for a given hydrogeological setting and resource development situation can be agreed.

FIGURE 9. STAGES OF GROUNDWATER RESOURCE DEVELOPMENT IN A MAJOR AQUIFER AND THEIR CORRESPONDING MANAGEMENT NEEDS.



0: BASELINE SITUATION	1: INCIPIENT STRESS	2: SIGNIFICANT STRESS	3A: UNSTABLE DEVELOPMENT	3B: STABLE HIGHLY DEVELOPED
availability and accessibility of adequate quality groundwater greatly exceeds small dispersed demand	growth of aquifer pumping, but only few local conflicts arising between neighboring abstractors	abstraction expanding rapidly with impacts on natural regime and strong dependence of various stakeholders on resource	excessive uncontrolled abstraction with irreversible aquifer deterioration and conflict between stakeholders	high-level of abstraction, but with sound balance between competing stakeholder interests and ecosystem needs
registration of abstraction wells and captured springs required, together with maps of occurrence of usable resources	simple management tools (for example, appropriate well-spacing according to aquifer properties) should be applied	regulatory framework needed, based upon comprehensive resources assessment with critical appraisal of aquifer linkages	regulatory framework with demand management and/or artificial recharge urgently needed	integrated resource management with high-level of user self-regulation, guided by aquifer modeling and monitoring

TABLE 6. LEVELS OF GROUNDWATER MANAGEMENT TOOLS, INSTRUMENTS AND INTERVENTIONS NECESSARY FOR GIVEN STAGE OF RESOURCE DEVELOPMENT.

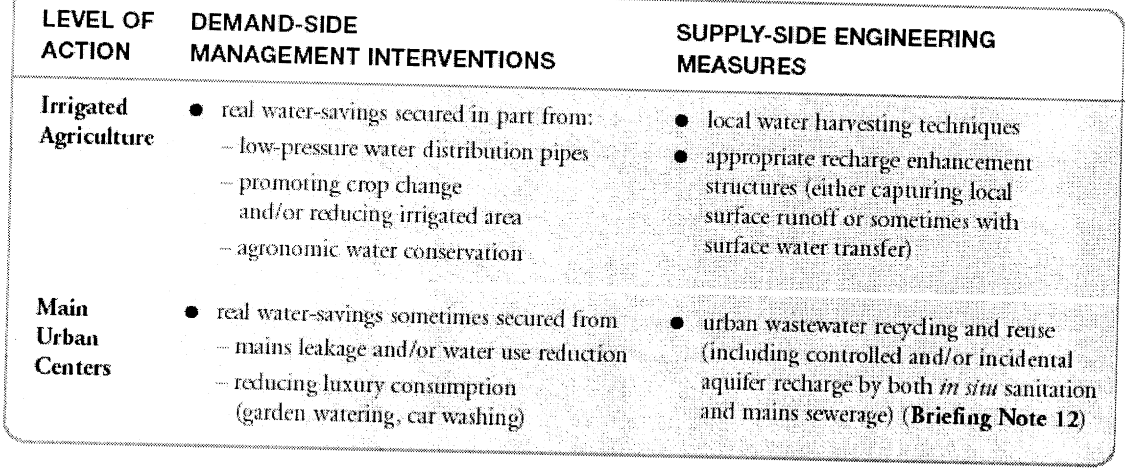
GROUNDWATER MANAGEMENT TOOLS & INSTRUMENTS	LEVEL OF DEVELOPMENT OF CORRESPONDING TOOL OR INSTRUMENT (according to hydraulic stress stage/see Figure 3)			
	0	1	2	3
TECHNICAL TOOLS				
Resource Assessment	basic knowledge of aquifer	conceptual model based on field data	numerical model(s) operational with simulation of different abstraction scenarios	models linked to decision-support and used for planning and management
Quality Evaluation	no quality constraints experienced	quality variability is issue in allocation	water quality processes understood	quality integrated in allocation plans
Aquifer Monitoring	no regular monitoring program	project monitoring, ad-hoc exchange of data	monitoring routines established	monitoring programs used for management decisions
INSTITUTIONAL INSTRUMENTS				
Water Rights	customary water rights	occasional local clarification of water rights (via court cases)	recognition that societal changes override customary water rights	dynamic rights based on management plans
Regulatory Provisions	only social regulation	restricted regulation (e.g. licensing of new wells, restrictions on drilling)	active regulation and enforcement by dedicated agency	facilitation and control of stakeholder self-regulation
Water Legislation	no water legislation	preparation of groundwater resource law discussed	legal provision for organization of groundwater users	full legal framework for aquifer management
Stakeholder Participation	little interaction between regulator and water users	reactive participation and development of user organizations	stakeholder organizations co-opted into management structure (e.g. aquifer councils)	stakeholders and regulator share responsibility for aquifer management
Awareness and Education	groundwater is considered an infinite and free resource	finite resource (campaigns for water conservation and protection)	economic good and part of an integrated system	effective interaction and communication between stakeholders
Economic Instruments	economic externalities hardly recognized (exploitation is widely subsidized)	only symbolic charges for water abstraction	recognition of economic value (reduction and targeting of fuel subsidies)	economic value recognized (adequate charging and increased possibility of reallocation)
MANAGEMENT ACTIONS				
Prevention of Side Effects	little concerns for side effects	recognition of (short- and long-term) side effects	preventive measures in recognition of *in-situ* value	mechanism to balance extractive uses and *in-situ* values
Resource Allocation	limited allocation constraints	competition between users	priorities defined for extractive use	equitable allocation of extractive uses and *in-situ* values
Pollution Control	few controls over land use and waste disposal	land surface zoning but no proactive controls	control over new point source pollution and/or siting of new wells in safe zones	control of all point and diffuse sources of pollution; mitigation of existing contamination

G. GROUNDWATER MANAGEMENT STRATEGIES- FACTS TO THE INTEGRATED APPROACH [5]

G.1. Approaches Needed to Stabilize Heavily-Stressed Aquifers

The following fundamental sub-division of resource management options (Table 7) is useful, the ***demand-side management interventions and the supply-side engineering measures***.

TABLE 7. DEMAND-SIDE AND SUPPLY-SIDE ACTIONS FOR GROUNDWATER RESOURCES MANAGEMENT.



LEVEL OF ACTION	DEMAND-SIDE MANAGEMENT INTERVENTIONS	SUPPLY-SIDE ENGINEERING MEASURES
Irrigated Agriculture	● real water-savings secured in part from: – low-pressure water distribution pipes – promoting crop change and/or reducing irrigated area – agronomic water conservation	● local water harvesting techniques ● appropriate recharge enhancement structures (either capturing local surface runoff or sometimes with surface water transfer)
Main Urban Centers	● real water-savings sometimes secured from – mains leakage and/or water use reduction – reducing luxury consumption (garden watering, car washing)	● urban wastewater recycling and reuse (including controlled and/or incidental aquifer recharge by both *in situ* sanitation and mains sewerage) (**Briefing Note 12**)

Although groundwater management is conducted at local aquifer level, **national food and energy policies** can exert an overriding influence on the behavior of groundwater abstractors, and thus on resource development pressures and management strains. Among these, subsidies on rural electricity, well drilling, pumpsets, grain and milk prices are probably the most significant. In general terms these subsidies should always be reviewed, and consideration be given to re-targeting the revenue involved into water-saving technology and/or assisting only the neediest members of the community.

It is always essential to address the issue of constraining demand for groundwater abstraction (Table 7), since this will normally contribute more to achieving the groundwater balance, and in the more arid and densely-populated areas, such as the ESCWA region, will always be required in the longer run. The **concept of real water savings** is critical in this regard—these savings include only reductions in evaporation (that is consumptive use) and in loss to saline water bodies, but not those reductions which would have generated aquifer recharge. For example, in urban areas, real water savings can be made by reducing water-mains leakage and wastewater seepage, but only where they generate discharge to brackish water bodies or create drainage problems.

Complementary local supply-side measures (Table 7), such as **rainwater harvesting, aquifer recharge enhancement** (with excess surface run-off or other sources of water such as desalination and wastewater), and **urban wastewater reuse** should always be encouraged, especially where conditions are favorable. They are often important in terms of building better relationships with groundwater users and can provide an initial focus for their participation in aquifer management.

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[5] World Bank GW-MATE (Groundwater Management Advisory Team), Briefing Note Series, Briefing Note 3, www.worldbank.ogr/gwmate, visited August 2003.

G.2. Reducing Groundwater Resource Used for Irrigated Agriculture

This subject is of paramount importance in the ESCWA region, given that agriculture is the predominant consumer of groundwater resources, and where major savings can be achieved. The primary aim of agricultural demand management for groundwater resource conservation should be to reduce:

(a) Evaporation from the irrigation water distribution (conveyance) system;
(b) Soil evaporation from between crop rows;
(c) Evapotranspiration by the crop itself ineffective in producing yield;
(d) Direct phreatic evapotranspiration by unwanted vegetation; and
(e) Direct evaporation during spray irrigation.

There is generally considerable scope for these types of agricultural water savings by:
Engineering measures: such as irrigation water distribution through low-pressure pipes (instead of earth canals) and irrigation water application by drip and micro-sprinkler technology
Management measures: to improve irrigation water scheduling and soil moisture management
Agronomic measures: such as deep ploughing, straw and plastic mulching, and the use of improved strains/seeds and drought-resistant agents.

If larger water savings are needed, then consideration should also be given to changes in crop type and land use (e.g. through higher-value crops under greenhouse cultivation or returning a proportion of the area to dryland cultivation of drought-resistant crops). An even more radical option would be to place a ban on the cultivation of certain types of irrigated crop in critical groundwater areas. The success of agricultural water-saving measures in reducing the decline in aquifer water levels depends directly on these savings being translated into permanent reductions in well abstraction rights and actual pumping. ***It is essential that water savings are not used to expand the irrigated area or to increase water usage in other sectors***. This will require a flexible system of abstraction rights and clear incentives for users to act in the collective interest of resource conservation. At the urban-rural interface resource reallocation to more productive commercial and industrial use can be best promoted if the corresponding municipality finances improvements in agricultural irrigation (generating real water savings) in return for abstraction rights over a proportion of groundwater saved. It should be noted, however, that the position will be significantly different where surface water is the primary source for irrigation and/or where the groundwater table is very shallow, since in such cases drainage to mitigate soil water-logging and salinization will be the major concern.

G.3. Supply Management of Groundwater Resources in the ESCWA Region - Artificial Recharge

Supply management can be implemented simultaneously with demand management to increase water supply availability and augment water supplies by such means as desalination, reuse of treated wastewater, recycling, weather modification, artificial recharge, water importation and the use of marginal quality water. Those supply management measures with the greatest potential to increase water resource availability in the ESCWA region are desalination, reuse of treated water, and artificial recharge. Artificial recharge is discussed below.

1. Increasing the Natural Storage Capacity of Aquifers

In many ways the vast ***storage of groundwater systems***—whose magnitude varies significantly with geological build - ***is their most valuable asset***. This storage capacity includes not only groundwater already stored in aquifer systems but also the potential of their void space (and elastic storage) to receive enhanced recharge (in part resulting from dewatering by pumping). Aquifer storage augmentation can be made through the use of surface spreading basins, injection wells, or the artificial modification of natural channels by means of dams and dikes (Table 8).

TABLE 8. SUMMARY OF TYPES OF AQUIFER RECHARGE ENHANCEMENT STRUCTURES.

TYPE	GENERAL FEATURES	PREFERRED APPLICATION
Water Harvesting	**dug shafts/tanks** to which local storm runoff is led under gravity for infiltration	in villages of relatively low-density population with permeable subsoil
	field soil/water conservation through terracing/ contour ploughing/aforrestation	widely applicable but especially on sloping land in upper parts of catchments
In-Channel Structures	**check/rubber dams** to detain runoff with first retaining sediment and generating clearwater	in gulleys with uncertain runoff frequency and high stream-slope
	recharge dam with reservoir used for bed infiltration and generating clearwater	upper valley with sufficient runoff and on deep water-table aquifer
	riverbed baffling to deflect flow and increase infiltration	wide braided rivers on piedmont plain
	subsurface cut-off by impermeable membrane and/or puddle clay in trench to impound underflow	only wide valleys with thin alluvium overlying impermeable bedrock
Off-Channel Techniques	**artificial basins/canals** into which storm runoff diverted to with pre-basin for sediment removal	where superficial alluvial deposits of low permeability
	land spreading by flooding of riparian land sometimes cultivated with flood-tolerant crops	on permeable alluvium, with flood relief benefits also
Injection Wells	**recharge boreholes** into permeable aquifer horizons used alternately for injection/pumping	storage/recovery of surplus water from potable treatment plants

It is ***important that groundwater resources are properly considered in national strategic planning***. Addressing the policy question 'what services are most required from groundwater' is necessary to provide targets for local management action, but it is one, which is frequently ignored. On the one hand, important components of the value of groundwater (such as pumping costs, individual accessibility, sustaining freshwater wetlands and dry weather streamflow) depend on the depth to water table and not on the volume in storage. On the other hand, in many situations groundwater storage is the only source of freshwater in extended drought, and ways need to be found to exploit this resource while mitigating the impacts on aquifer water level related services. The more widespread, and socially sustainable, use of groundwater storage to combat water-demand variability resulting from persistent drought and climatic change (on a scale of months to decades and beyond) is urgently needed.

Water resource management strategy in which groundwater and surface water are used in tandem, making use of the comparative advantages of both is termed **conjunctive use.** Examples include

- Use of surface water for inefficient flood irrigation to enhance aquifer recharge in the wet season,
- Use of groundwater in dry periods for irrigation to replace the normal surface water supply.

Currently, conjunctive use (where practiced) tends to have arisen more by accident than design.

2. Artificial Recharge in the ESCWA Region

Aquifer recharge enhancement and manipulation of subsurface storage will allow increased long-term average rates of groundwater abstraction benefiting all users. Seasonal storage may be practiced to take advantage of the availability of excess water during the wet season. Recovery of stored water can contribute to deferring expansion of water facilities or to their downsizing. Such practices may be beneficial for the storage of floodwater occurring over a short period in many parts of the ESCWA region. Long-term storage can be utilized in situations where desalination production is in excess of water demand. Emergency storage is of significance in building up strategic reserves of groundwater to meet demand when primary water sources are unavailable as a result of contamination, warfare or natural disasters.

Other advantages of artificial recharge schemes include restoration of groundwater levels, and water quality improvement (Pyne, 1995). ***Increasing the rate of recharge, possibly eliminating the effects of over-pumping, can reduce the rate of groundwater mining***. Increasing pumpage from confined aquifers located near the surface usually results in land subsidence. A remedial solution may be to increase the magnitude of recharge in order to maintain pressure. ***Furthermore, artificial recharge is considered one of the more effective means of combating saltwater intrusion along coastal zones***. In many of the GCC countries pumpage exceeds natural recharge, and withdrawal from alluvial and limestone aquifers is accelerating the advancement of the saltwater front. Before it drains into the coastal zone on both the eastern and western sides of the Arabian Peninsula, flood water, and reclaimed wastewater can be used to build up a groundwater barrier. The same methods can be used to control the movement of contaminant plumes.

The other important aspect of artificial recharge is the storage of reclaimed wastewater. High-quality treated water may be stored seasonally, to be recovered later for irrigation and industrial uses. Large volumes of treated wastewater are allowed to flow into the sea in a number of ESCWA member countries. Treated wastewater being disposed of along coastal zones or in wadi channels in most of the countries could be used to recharge the alluvial aquifers. However, the quality of treated effluent must be taken into consideration in order to avoid groundwater pollution and the consequent diminution of water supply availability. Treated effluent must meet certain water quality standards. Treated effluent used for recharge may entail further treatment following conventional secondary treatment in order to comply with health regulations concerning stable organisms, heavy metals and the presence of pathogenic organisms.

Sandy soil and alluvial material, characteristic of large areas of the ESCWA region and particularly of the Arabian Peninsula, provide favorable conditions for the storage of excess treated wastewater and the enhancement of its quality. The technique known as **soil-aquifer treatment (SAT)** can improve the quality of treated wastewater (Bouwer, 1985). This method involves recharging shallow aquifers through infiltration basins at the ground surface and takes advantage of the ability of the underlying unsaturated soil profile to accomplish *in situ* biodegradation and filtration of wastewater. The use of the SAT scheme with secondary effluent in arid regions of Arizona, in the United States, resulted in groundwater quality that met chemical and aesthetic requirements for unrestricted irrigation (Bouwer, 1985). Implementation of the SAT scheme in wadi channels and flood plains can increase the magnitude of recharge and improve the chemical and biological characteristics of the wastewater. SAT schemes are site-specific, however, and must be experimented with to determine the influencing factors of infiltration, percolation, and chemical and biological processes. Currently, this technique is being experimented in Kuwait (KISR) and Saudi Arabia (KFUPM).

Managing natural groundwater recharge and enhancing the magnitude by artificial means represents an excellent option for increasing water supply availability for all countries of the ESCWA region. Increasing the volume of groundwater recharge from surface runoff stored behind dams can provide additional water in time of need, especially for Oman, Saudi Arabia, the United Arab Emirates and Yemen. Large volumes of surface runoff lost to the sea from coastal drainage basins and evaporation from inland drainage basins can be utilized for artificial recharge purposes. The ratio of estimated flood volume to runoff being utilized ranges from a low of 0.25 to 1.35 mcm in Qatar to a high of 900 to 2,230 mcm in Saudi Arabia. Distribution ratios are estimated at 900 to 2,230 mcm in Saudi Arabia, 475 to 2,000 mcm in Yemen, 275 to 918 mcm in Oman, 75 to 125 mcm in the United Arab Emirates, and 0.25 to 1,055 mcm in Qatar (refer to Annex D).

BOX 5: MEASURES TO CONTROL SALT WATER INTRUSION –DEMAND-SIDE MANAGEMENT INTERVENTION AND SUPPLY-ENGINEERING MEASURES: SULTANATE OF OMAN

Salt water intrusion has been on-going on the Batinah coastal plain of northern Oman since the late 1970s, caused mainly by a rapid expansion in the number of farms and irrigated area, with a consequent increase in demand on shallow groundwater resources. Strategies have been implemented to limit the expansion of demand for water with the introduction of well permit regulations and restrictions on the allocation of new farmland. A case study of Wadi Taww illustrates the impact of saline intrusion on farm production, income and depreciation of assets, as well as on domestic water supplies for coastal villages. A number of strategies have been proposed to reduce demand to sustainable levels, including reducing cropped areas and growing different types of crops, land purchase, water allocation and the development of alternative drinking water supplies. The impact of saltwater intrusion was particularly evident in catchment areas of the southern Batinah, with deterioration in water quality, declining water levels and the abandonment of traditional farms near the coast. Since the 1990s, a number of strategies have been implemented to limit the expansion of demand, increase water supplies and improve efficiency of use, including:

(a) The introduction of well permit regulations to limit the allocation of permits for the construction of new wells and deepening and/or modifying existing wells;

(b) The construction of nine recharge dams on the Batinah with a total storage capacity of 47 million cubic meters;

(c) Limiting allocation of new land for agricultural development.

The impact of saltwater intrusion is reflected in a case study of the catchment area of Wadi Taww. From the mid 1970s to the early 1990s, there was a great increase in the number of farms and irrigated areas on the lower coastal plain. During this period, the number of farms increased by about 150 per cent, with a fivefold increase in cropped area. The impact of salt water is often most obvious on crop health and farm productivity. Farm productivity is affected by irrigation water quality in a number of ways, such as yield reduction, deterioration of fruit quality, toxicity to specific elements, induced nutrient deficiencies and toxicities, and foliar damage.The southern Batinah in particular has been the subject of a number of studies ***to define the problem more precisely and identify strategies for reducing water demand to a sustainable level and the provision and protection of domestic water supplies***. The essential elements of these strategies ***are to develop measures to reduce water abstraction for irrigation and alternative water supplies for coastal villages***. The recommended measures have include:

(a) *Purchasing 4900 hectares and removing them from production;*

(b) In tandem with the land purchase scheme, introducing a water allocation program, with the installation of water meters, for wells supplying irrigation water;

(c) A shift from high water demand perennial crops to winter vegetable crops has the potential both to reduce water demand and improve productivity and returns per unit volume of water. Such a shift could reduce water demand by about 20%;

(d) Modern irrigation methods have been promoted and could contribute to an overall reduction in water demand of 14%;

(e) The development of desalination could ultimately reduce the cost for the coastal communities;

(f) The development of a water supply and protection scheme based on upstream well fields and distribution mains to the coast;

(g) The development of inland well fields has the advantage of providing relatively low-cost water, and moving supplies from the direct impact of salt water intrusion and other potential pollution sources.

Source: ESCWA, 2001 (E/ESCWA/ENR/2001/12)

H. GROUNDWATER QUALITY PROTECTION – DEFINING STRATEGIES AND SETTING PRIORITIES[6]

H.1. Protection of Groundwater Supplies

Groundwater is a vital natural resource for the reliable and economic provision of potable water supply in both the urban and rural environment. It thus plays a fundamental (but often little appreciated) role in human well-being, as well as that of some aquatic and terrestrial ecosystems. For municipal water supply, high and stable raw-water quality is a prerequisite, and one best met by protected groundwater sources. Recourse to treatment processes (beyond precautionary disinfections) in the achievement of this end should be a last resort, because of their technical complexity and financial cost, and the operational burden they impose. However, all too widely in the past groundwater resources have, in effect, been 'abandoned to chance'. And all too often those exploiting such resources for the provision of potable water supply have taken no action to protect water quality.

In the ESCWA region aquifers are experiencing an increasing threat of pollution from urbanization, industrial development, agricultural activities and mining enterprises. Thus proactive campaigns and practical actions to protect the natural quality of groundwater are widely required, and can be justified on both broad environmental-sustainability and narrower economic-benefit criteria. If groundwater becomes polluted, it is difficult and usually very costly to rehabilitate; clean-up measures nearly always have a high economic cost and are often technically problematic. Low microbial activity, low recharges and slow flow rates, which reduce mixing, mean that self-purification of groundwater is very limited. Degradation processes, which take days or week in surface water, are likely to take decades in groundwater systems. It is therefore advisable to prevent or reduce the risk of groundwater contamination rather than have to deal with the consequences of pollution. Groundwater protection should therefore be the top priority.

H.2. Groundwater Pollution Mechanisms

The pollution of aquifers occurs if the subsurface contaminant load generated by man-made discharges and leachates (from urban, industrial, agricultural and mining activities) is inadequately controlled, and (in certain components) exceeds the natural attenuation capacity of the underlying soils and strata. Natural subsoil profiles actively attenuate many water pollutants and have long been considered potentially effective for the safe disposal of human excreta and domestic wastewater. The auto-elimination of contaminants during subsurface transport in the vadose (or unsaturated) zone is the result of biochemical degradation and chemical reaction, but contaminant retardation (due to sorption on the surfaces of clay minerals and/or organic matter) is also of importance, since it greatly increases the time available for processes resulting in contaminant elimination.

However, not all subsoil profiles and underlying strata are equally effective in contaminant attenuation, particularly those of karstic nature. Concern about groundwater pollution relates primarily to the so-called phreatic (unconfined) aquifers, especially where their vadose zone is thin and their water-table shallow, but may also arise even where aquifers are semi-confined, if the confining aquitards are relatively thin and permeable. It is important to recognize that activity capable of causing significant groundwater pollution hazard depart widely from the activities and compounds most commonly polluting surface water bodies. This is the result of the very different factors controlling the mobility and persistence of contaminants in the subsurface, due to the presence of the aquifer matrix and the much slower rates of biodegradation (consequent upon the low levels of organic carbon, the much reduced populations of bacteria and the constraints on diffusion of oxygen). It is also important to stress that certain industrial and agricultural practices (and specific incremental processes within such practices) often present disproportionately large threats to groundwater quality. Thus sharply focused and well-tuned pollution control measures can produce major benefits for relatively modest cost.

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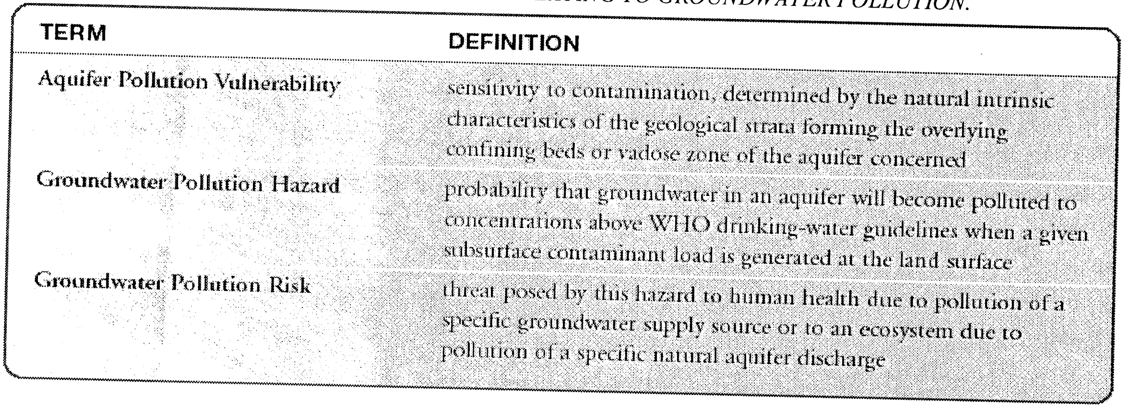
[6] World Bank GW-MATE (Groundwater Management Advisory Team), Briefing Note Series, Briefing Note 8, www.worldbank.ogr/gwmate, visited August 2003.

H.3. Assessment of Groundwater Pollution Hazard - Vulnerability Assessment

Regional groundwater quality protection is a growing area of research at the interface between hydrogeology and water resources policy and is typically described with the term "groundwater vulnerability". The goal of vulnerability assessment is to provide policy makers with groundwater regions most susceptible to contamination so that land management practices can be optimized to protect the groundwater resource, as major contaminates of concern have been significantly correlated to certain land uses and practices. In other words, in order to protect groundwater, we must map vulnerable aquifers, then implement and enforce policies restricting harmful land use practices at the country level and the municipal level. Groundwater pollution hazard assessments are needed for clearer appreciation of the actions needed to protect groundwater quality, and should become an essential component of ***environmental best practice***. The logical definition of groundwater pollution hazard (Table 9) is the interaction between the ***aquifer pollution vulnerability*** and the ***contaminant load*** that is, will be or might be, applied on the subsurface environment as a result of human activity at the land surface. Adopting such a scheme, we can have high vulnerability but no pollution hazard, because of the absence of a significant subsurface contaminant load. Moreover, contaminant load can be controlled or modified, but aquifer vulnerability is essentially fixed by the natural hydrogeological setting.

Aquifer pollution vulnerability is, in effect, the inverse of 'the pollutant assimilation capacity of a receiving water body' in the jargon of river quality management. It can be assessed from the hydrogeological characteristics of the overlying vadose zone or confining beds. Indexation of these characteristics (Figure 10) permits the generation of an overall vulnerability index, which can be readily mapped. On such maps the results of surveys of potential subsurface contaminant load can be superimposed to facilitate the assessment of *groundwater pollution hazard.*

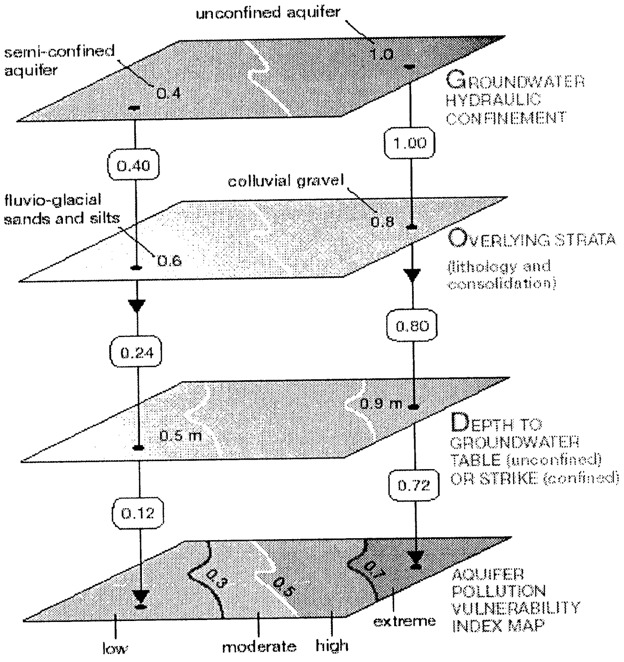
TABLE 9. *DEFINITIONS OF COMMON TERMS RELATING TO GROUNDWATER POLLUTION.*



TERM	DEFINITION
Aquifer Pollution Vulnerability	sensitivity to contamination, determined by the natural intrinsic characteristics of the geological strata forming the overlying confining beds or vadose zone of the aquifer concerned
Groundwater Pollution Hazard	probability that groundwater in an aquifer will become polluted to concentrations above WHO drinking-water guidelines when a given subsurface contaminant load is generated at the land surface
Groundwater Pollution Risk	threat posed by this hazard to human health due to pollution of a specific groundwater supply source or to an ecosystem due to pollution of a specific natural aquifer discharge

Numerous methods of assessing groundwater vulnerability have been developed over the past 20 years. All of them base assessment on selected parameters describing climatic, soil and hydrogeological properties known to affect the leaching of contaminants. These methods follow a procedure of combining maps from which parameters included in the groundwater vulnerability assessment can be deducted (soil, geology, groundwater table, rainfall etc.) to create zones of equal properties. In a second phase, scores or qualitative ratings are assigned to relevant attributes affecting vulnerability (Figure 10). Some much-used methods are DRASTIC (Aller et al., 1985), the common approach of the German Geological Surveys (Hölting et al., 1995), or EPIK (Doerflieger, 1996), which was developed in Switzerland especially for groundwater vulnerability assessment in carbonate (karst) regions.

FIGURE 10. *GENERATION OF AN AQUIFER POLLUTION VULNERABILITY MAP USING THE GOD METHODOLOGY BASED ON HYDROGEOLOGICAL CHARACTERISTICS OF THE OVERLYING VADOSE ZONE OR CONFINING BEDS.*

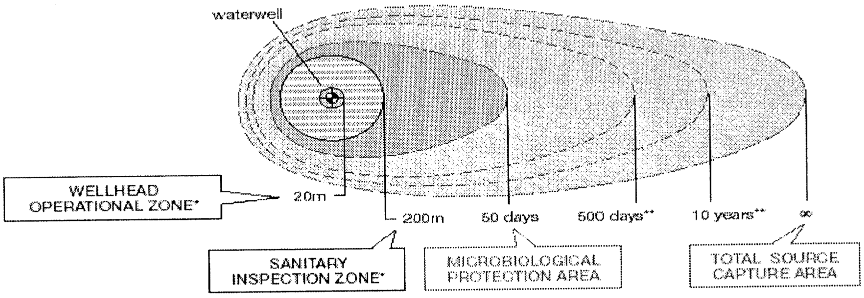


More sophisticated quantitative methods have also been developed, such as deterministic and probabilistic process based methods, which are based on mathematical descriptions of physical, chemical and biological processes occurring in the soil, the unsaturated zone or the aquifer. However, their application has so far been limited to pilot areas and research, as the effort and data availability required is high in comparison with the simpler qualitative methods. Groundwater vulnerability assessment is an issue of spatial distribution and therefore typically carried out using geographic information systems (GIS). Even when using a simple qualitative method, the complex processing of spatial information is completed faster using GIS than compiling the map by hand. Map overlay techniques can be used to combine different thematic maps (e.g. soil type, geology, depth to groundwater table) with the aim of defining homogeneous areas in terms of vulnerability. The resulting vulnerability map can be combined with a map of actual or expected hazards (e.g. intensive agricultural areas, industrial areas, landfills, waste disposal sites) to infer maps indicating risk of groundwater pollution.

H.4. Wellhead Protection Area (WHPA)

Whether this hazard will result in a threat to a public-supply source depends primarily on its location with respect to the groundwater sources (and their flow-zones and capture areas), and secondarily on the mobility of the contaminant(s) concerned within the local groundwater flow regime. A number of areas and zones should normally be defined (Figure 11), using hydrogeological data on the local groundwater flow regime. Various analytical and numerical models (section 8) are available to facilitate their delineation.

FIGURE 11. *IDEALIZED SCHEME OF SURFACE SANITARY ZONES AND GROUNDWATER FLOW PERIMETER FOR THE PROTECTION OF A WATER WELL IN AN UNCONFINED AQUIFER.*



** empirical fixed radius area*
*** intermediate flow-time perimeters sometimes used*

The scales at which the survey, mapping and analyses of the various components needed to assess groundwater pollution hazard are undertaken will vary with the main focus of the work, water-supply protection or aquifer resource protection. Groundwater pollution hazard assessments should prompt municipal authorities or environmental regulators to take both preventive actions (to avoid future pollution) and corrective actions (to control the pollution threat posed by existing and past activities).

H.5. What Does Groundwater Pollution Protection Involve?

To protect aquifers against pollution it is essential to constrain land-use, effluent discharge and waste disposal practices. However, in practice it is necessary to define groundwater protection strategies that accept trade-offs between competing interests. Thus instead of applying universal controls over land use and effluent discharge, it is more cost-effective (and less prejudicial to economic development) to utilize the natural contaminant attenuation capacity of the strata overlying the aquifer, when defining the level of control required to protect groundwater quality.

Simple and robust zones (based on aquifer pollution vulnerability and source protection perimeters) need to be established, with matrices that indicate what activities are possible where at an acceptable risk to groundwater. Groundwater protection zoning also has a key role in setting priorities for groundwater quality monitoring, environmental audit of industrial premises, pollution control within the agricultural advisory system, determining priorities for the clean-up of historically-contaminated land, and in public education generally. All of these activities are essential components of a sustainable strategy for groundwater quality protection.

A sensible balance needs to be struck between the protection of groundwater resources (aquifers as a whole) and specific sources (boreholes, wells and springs). While both approaches to groundwater pollution control are complementary, the emphasis placed on one or other (in a given area) will depend on the resource development situation and on the prevailing hydrogeological conditions.

If potable use comprises only a minor part of the available groundwater resource, then it may not be cost-effective to protect all parts of an aquifer equally. Source-oriented strategies will then be appropriate, working at scales in the range 1:25,000–100,000 and:

- Delineating groundwater source protection (capture) areas and flow-time perimeters (local scale)
- Assessing aquifer pollution vulnerability and subsurface contaminant load in the areas so defined (regional scale).

This approach is best suited to relatively uniform, unconsolidated, aquifers exploited only by a small number of high-yielding municipal water-supply boreholes with stable pumping regimes. It cannot be so readily applied where there are a very large and rapidly growing number of individual abstractions, which render consideration of individual sources and establishment of fixed areas impracticable.

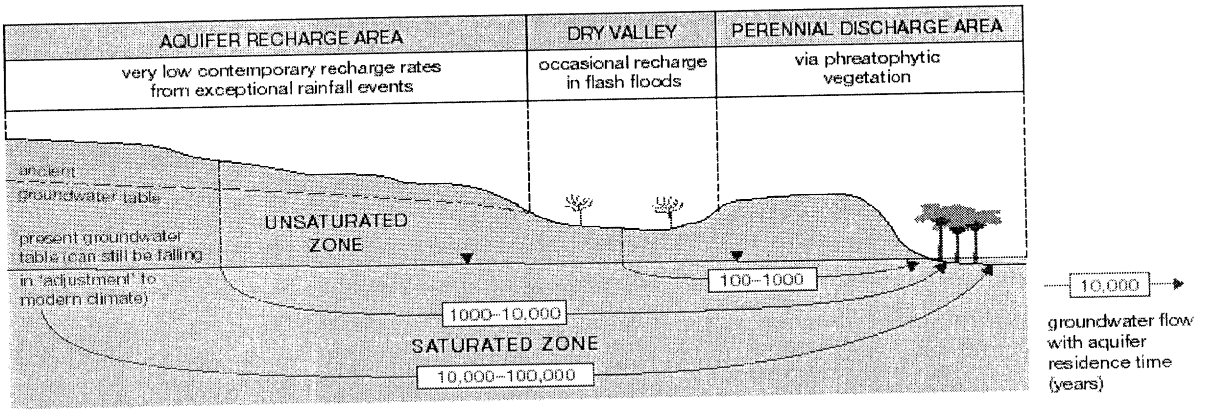
Aquifer-oriented strategies are more universally applicable, since they endeavor to achieve a degree of protection for the entire groundwater resource and for all groundwater users. They involve aquifer pollution vulnerability mapping over more extensive areas (including one or more important aquifers) working at a scale of 1:100,000, or greater if the interest is limited to general information and planning purposes. Such mapping would normally be followed by an inventory of subsurface contaminant load at more detailed scale, at least in the more vulnerable areas.

I. UTILIZATION OF NON-RENEWABLE GROUNDWATER - A SOCIALLY SUSTAINABLE APPROACH TO RESOURCES MANAGEMENT[7]

I.1. Non-Renewable Groundwater Resources

Groundwater resources are never strictly non-renewable. But in certain cases the period needed for replenishment (100s to 1000s of years) is very long in relation to the normal time-frame of human activity in general and water resources planning in particular (Figure 12). For this reason it is valid in such cases to talk of the utilization of non-renewable groundwater or the 'mining of aquifer reserves'.

FIGURE 12. *TYPICAL GROUNDWATER CYCLE IN MORE ARID REGIONS WHERE UNDERLAIN BY MAJOR AQUIFERS.*



The focus here is on management of aquifers with non-renewable groundwater such as:

- Unconfined aquifers in areas where contemporary recharge is very infrequent and also of small volume, and the resource is essentially limited to aquifer storage reserves.
- The 'confined sections' of very large aquifer systems, where groundwater development intercepts or induces little active recharge, and the potentiometric surface falls continuously with abstraction.

Both involve the abstraction of so-called 'fossil (or paleo) groundwater', which originated as recharge in past, more humid, climatic regimes. The volumes of such groundwater stored in some aquifers are huge (e.g. an estimated 150,000 km^3 in the Nubian Sandstone and 15,000 km^3 in the Arabian Rub-al-Khali basin). The use of the term 'sustainability' in this context requires clarification. It is interpreted here in a social (rather than a physical) context, implying that full consideration must be given, not only to the immediate benefits, but also to the 'negative impacts' of development and to the 'what comes after' question—and thus to time horizons of 100–1000 years.

I.2. How Does the Exploitation of Non-Renewable Groundwater Arise?

There are two very different situations under which the utilization of non-renewable groundwater occurs:

- Planned schemes in which the mining of aquifer reserves is contemplated from the outset, usually for a specific development project in an arid area with little contemporary groundwater recharge (e.g., the Libyan Sarir Basin).

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[7] World Bank GW-MATE (Groundwater Management Advisory Team), Briefing Note Series, Briefing Note 11, www.worldbank.ogr/gwmate, visited August 2003.

- On an unplanned basis with incidental depletion of aquifer reserves, as a result of intensive groundwater abstraction in areas with some contemporary recharge but where this proves insufficient or where there is limited hydraulic continuity between deep aquifers and their recharge area (e.g., Saq aquifer, the shared Disi aquifer and the Paleogene aquifer in the Arabian Peninsula).

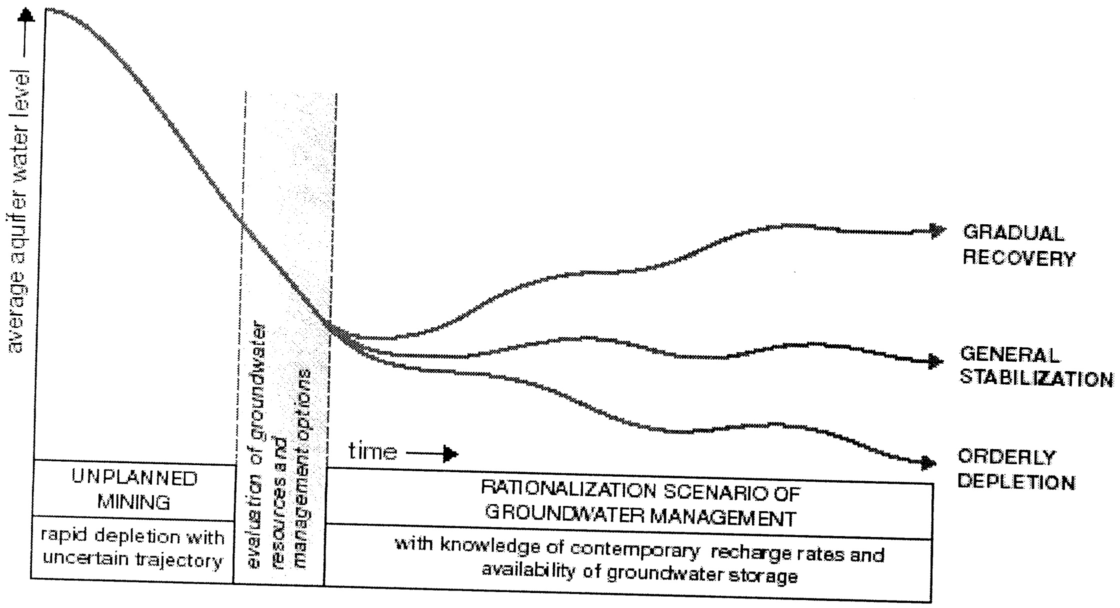
In the **'planned depletion scenario'** the management goal is the orderly utilization of aquifer reserves (of a system with little pre-existing development), with expected benefits and predicted impacts over a specified time-frame. Appropriate 'exit strategies' need to be identified, developed and implemented by the time that the aquifer is seriously depleted. This scenario must include balanced socioeconomic choices on the use of aquifer storage reserves and on the transition to a subsequent less water-dependent economy. A key consideration in defining the 'exit strategy' will be identification of the replacement water resource, such as desalination of brackish groundwater.

In the unplanned situation a **'rationalization scenario'** is needed in which the management goal is:

- Hydraulic stabilization (or exceptionally recovery) of the aquifer, or
- More orderly utilization of aquifer reserves, minimizing quality deterioration, maximizing groundwater productivity and promoting social transition to a less water-dependent economy.

In both cases the groundwater abstraction rate will have to be reduced, and thus the introduction of demand management measures (including realistic groundwater charges and incentives for real water-saving) will be needed. In the longer run potable water supply use will have to be given highest priority and some other lower productivity uses may have to be discouraged. This briefing note deals with groundwater management in situations where an orderly approach to the utilization of aquifer reserves is the target, either from the outset in a 'planned depletion scenario' or subsequently in a rationalization scenario' (Figure 13).

FIGURE 13. TARGETS FOR GROUNDWATER RESOURCES MANAGEMENT IN 'RATIONALIZATION SCENARIOS' FOLLOWING INDISCRIMINATE AND EXCESSIVE EXPLOITATION.



I.3. Key Management Needs in Respect of Non-Renewable Groundwater System Characterization

If the utilization of non-renewable groundwater is to be managed effectively, special emphasis must be put on aquifer system characterization to facilitate adequate predictions of:

- Groundwater availability, and the distribution of wells to abstract it over a given time horizon.
- The impact of such abstraction on the aquifer system itself, on third parties (especially traditional users) and on any related aquatic and terrestrial ecosystems.
- Anticipated groundwater quality changes during the life of intensive aquifer development.

Such characterization requires special hydrogeological investigation to evaluate certain key factors (Table 10). In contrast to the characterization of renewable groundwater resources a critical component will be assessment of the storage of those parts of the aquifer that will be (or are being) drained by groundwater pumping, together with the susceptibility of the aquifer system to saline intrusion. The application of environmental isotope analyses is particularly valuable for interpretation of the origin of both fresh and saline groundwater in aquifer storage and the quantification of any contemporary recharge.

System characterization will inevitably be subject to considerable initial uncertainty and it is thus recommended that 'worst-case parameter values' be used in the aquifer simulation modeling used as a basis for planning. The level of confidence in hydrogeological prognosis will increase greatly with the availability of some years of monitoring data on aquifer response to large-volume abstraction. Thus a carefully-designed and systematically-operated monitoring program is essential.

TABLE 10. *CHECKLIST OF SPECIAL FACTORS AND PROVISIONS REQUIRED FOR THE SOCIALLY-SUSTAINABLE MANAGEMENT OF NON-RENEWABLE GROUNDWATER RESOURCES.*

SPECIAL FACTORS & PROVISIONS	IMPORTANCE IN GIVEN SCENARIO	
	'planned depletion'	'rationalization' *
Aquifer System Characterization		
• quantification of aquifer storage reserves	●●	●●●
• assessment of contemporary recharge rates	●	●●
• prediction of risk of salinity/quality changes	●●●	●●●
• appraisal of depletion effects on 'traditional users'	●●●	●
• prediction of ecological impacts of aquifer depletion	●●●	●
Resource Management Strategy		
• comprehensive socioeconomic assessment	●●●	●●
• maximization of productivity of groundwater use	●●	●●●
• identification of post-depletion 'exit strategy'	●●●	●●●
Institutional Provisions		
• high-level political decision making	●●●	●
• establish government 'aquifer regulatory unit'	●●●	●●●
• mount intensive public awareness campaign	●●●	●●●
• constitute AMOR for stakeholder participation	●●	●●●
• issue time-limited abstraction permits	●●●	●●
• set aquifer management targets	●●	●●
• groundwater monitoring network and databank	●●●	●●●

In the 'planned depletion scenario' the impacts of the proposed exploitation of aquifer reserves on all traditional groundwater users need to be assessed, and some form of compensation provided for predicted or actual derogation. The fundamental concept should be to ensure that there are sufficient reserves of extractable groundwater of acceptable quality left in the aquifer system at the end of the proposed period of intensive exploitation to sustain the pre-existing activity (albeit at additional cost). Another way of achieving this end would be to restrict the 'design drawdown' of intensive exploitation to less than a given average figure over a stated period (for example, 20 m after 20 years).

It is equally important (Table 10) to identify all aquatic and/or terrestrial ecosystems that may be dependent on, or actively using, the aquifer concerned and to make predictions of the likely level of interference that will occur as a result of the proposed development. A degree of doubt over impact assessment is likely to arise for two reasons:

- hydrogeological uncertainty in the prediction of groundwater drawdown, especially at large distances from the proposed abstraction
- Difficulties in estimating how the given ecosystem will react to a certain level of drawdown.

It has to be recognized that some aquatic ecosystems may only be capable of being sustained (even in a reduced form) through the provision of compensation flows, sometimes accomplished by local irrigation and/or aquifer recharge. This consideration will need to be realistically factored in to the evaluation of the acceptability of the proposed groundwater development.

I.4. Socio-Economic Considerations for the Management of Non-Renewable Groundwater

A comprehensive socio-economic assessment of options for mining aquifer reserves and their impacts will also be a pre-requisite (Table 10) including consideration of:

- The potential alternative uses (present and future) of aquifer reserves
- The value of the proposed use(s) in relation to the *in-situ* value of groundwater
- Considering the 'what happens after' (aquifer reserves are depleted) question, and thus broadly identifying and costing (at outline level) the probable 'exit strategy'.

It is vital that the groundwater is used with maximum hydraulic efficiency and economic productivity, and this implies full re-use of urban, industrial and mining water supplies and carefully-controlled agricultural irrigation. An acceptable system of measuring or estimating the volumetric abstraction will be required as the cornerstone for both realistic charging and enforcing regulations to discourage inefficient and unproductive uses.

Public awareness campaigns on the nature, uniqueness and value of non-renewable groundwater will be essential to create social conditions conducive to aquifer management, including wherever possible full user participation. In this context all groundwater data (reliably and independently synthesized) should be made regularly available to stakeholders and local communities.

Non-renewable groundwater in aquifer storage must be treated as a public-property (or alternatively common-property) resource. It is also important to agree the level in government to which the decision on mining of aquifer reserves must be referred. In countries with a non-sectoral water resources ministry the decision could rest with the corresponding minister, but in others it would be better taken by the president's, prime minister's or provincial governor's office (according to the territorial scale of the aquifer) with advice from a multi-sectoral committee. 'High-level political ownership' of the 'rationalization plan for aquifers', whose reserves have been subject to mining on an unplanned basis, is also highly desirable.

I.5. Institutional Arrangements Required to Achieve Socially Sustainable Utilization of Non-Renewable Groundwater

The preferred institutional arrangement is for all groundwater management functions to be handled by a single government agency, with representation at a territorial scale appropriate to the aquifer concerned. If this is not possible then all ministries and agencies with a stake in groundwater development and environmental management should be involved, through a coordinating committee. In both instances the water resources administration should have authority to:

- Declare the aquifer that is, or will be, subject to mining of non-renewable resources as a 'special area' subject to specific demand management programs.
- Establish, under the appropriate government minister (at national or provincial level), a special unit to coordinate the resource management of the aquifer concerned.

The full participation of groundwater users will be key to successful implementation of management measures. This will be best approached by establishment of an aquifer management organization (AMOR), which should include representatives of all the main sectoral and geographically-based user groups, together with those of government agencies, local authorities and other stakeholders.

National groundwater legislation will not generally provide a sufficient basis alone for addressing the management of non-renewable resources. Specific provisions for a given aquifer's storage reserves will have to be made through regulations, which, in turn, need to be supported by administrative and technical guidelines. It is also important not to treat groundwater law in isolation from legislation in other sectors (such as land-use planning, public works construction, agricultural development, environmental protection, etc.), which can impact directly on groundwater resources.

A high priority will be to put in place a system of groundwater abstraction rights (sometimes known as permits, licenses or concessions). These must be consistent with the hydrogeological reality of continuously declining groundwater levels, potentially decreasing well yields and possibly deteriorating groundwater quality. Thus the permits (for specified rates of abstraction at given locations) will need to be time-limited in the long term, but also subject to initial review and modification after 5–10 years, by which time more will be known about the aquifer response to abstraction through operational monitoring. It is possible that use rules set by appropriately empowered communal AMORs could take the place of more legally formalized abstraction permits.

The value of detailed monitoring of groundwater abstraction and use, and the aquifer response (groundwater levels and quality) to such abstraction, cannot be overemphasized. The water resource administration, stakeholder associations and individual users should carry this out. The existence of time-limited permits subject to initial review will normally stimulate permit holders to provide regular data on wells. It will be incumbent upon the water resources administration to make appropriate institutional arrangements—through some form of aquifer database (databank or data center) —for the archiving, processing, interpretation and dissemination of this information.

Many major aquifers containing large reserves of non-renewable groundwater are transboundary, either in a national sense or between autonomous provinces or states within a single nation. In such circumstances there will much to be mutually gained through:

- Operation of joint or coordinated groundwater monitoring programs
- Establishment of a common groundwater database or mechanism for information sharing
- Adoption of coordinated policies for groundwater resource planning, utilization and management, and of procedures for conflict resolution
- Harmonization of relevant groundwater legislation and regulations.

*BOX 6: TRIPOLI STATEMENT, 1999**

It is recognized that:

- *In most arid countries* ***the scarcity of renewable water supplies infers a serious threat to sustainable and balanced socio-economic growth and environmental protection****. This threat is clearly more pronounced in the less wealthy countries.*
- *The mining of non-renewable groundwater resources* ***could provide an opportunity and a challenge****, and allow water supply sustainability within foreseeable time-frames that can* ***progressively modified as water related technology advances****.*
- *The conference marks a milestone in the discussion of the emerging concept of groundwater mining.*
- *A* ***national integrated water policy*** *is essential with, where feasible, priority given to renewable resources, and the use of treated water, including desalinated water.*

It is recommended that

- *Groundwater mining timeframes should account for both quantity and quality with criteria set for use priorities, and* ***maximum use efficiency, particularly in agriculture****.*
- *Care should be exercised to minimize the detrimental* ***impact on existing communities****.*
- *Consideration should be given to the creation of* ***economical, low water-consuming activities****.*
- *Development of mined groundwater depend upon many non-hydrogeological factors. Nevertheless, hydrogeological constraints need to be defined for both planners and end users.*
- *The* ***participation of end users*** *in the decisions-making process and the enhancement of their responsibility through water use education and public awareness are recommended.* ***Efficient water use, cost recovery*** *could eventually be necessary.*

In recognition of the fact that

- *some countries share aquifer system,*
- *international law does not provide comprehensive rules for the management of such systems yet; and*
- *groundwater mining could have implications for shared water bodies,*

There is a need for

- *Rules of equitable utilization of shared groundwater resources;*
- *Prevention of harm to such resources and the environment; and*
- *Exchange of information and data.*

Concerned countries are encouraged to enter into negotiations with a view to reach agreements on the development, management, and protection f shared groundwater resources.

**Adopted by more than 600 participants from more than 20 countries and regional and international organization and association in the International Conference on "Regional Aquifer Systems in Arid Zones - Managing non-renewable resources", Tripoli, 20-24 of November, 1999, UNESCO and the Libyan General Water Authority.*

J. MONITORING CONSIDERATIONS – A PRE-REQUISITE FOR MANAGEMENT

Monitoring of water quality, water levels, and water extraction in an aquifer is the foundation on which groundwater resource management is based. It provides the information that permits rational management decisions on all kinds of water resource and sustainability issues:

- Understanding the flow system and the baseline water quality before development changes both;
- Identifying actual and emerging problems of local overdraft (quantity) or water pollution (quality);
- Providing independent information on the rate of use of the resource, especially where the regulatory system is deficient;
- Evaluating the effectiveness of management actions, including remedial measures to halt or reverse adverse trends in water quality or quantity.

Nevertheless, despite the obvious benefits of monitoring programs to government and other institutions responsible for managing water resources, it is common, almost the norm, to find that monitoring programs are the first functions to be cut back when resources are scarce. At the other end of the spectrum, there are also cases where programs originally devised for preliminary survey purposes have been continued blindly long past the aquifer resource assessment stage and into the development phase without any revision to reflect emerging conditions and new groundwater priorities. The resultant hard-won data are then unsuitable, or poorly suited, for regulatory or planning use, are not used and progressively become discredited as irrelevant to the management process.

These experiences demonstrate that there are only two really vital monitoring axioms:

- Any program needs to be judged in terms of the information it will generate. The data must be truly useful and be tailored to management requirements;
- Regular reassessment of aims is the best protection for monitoring programs, which are often regarded as an optional luxury that is costly, resource-consuming, and potentially sensitive in the political arena.

Thus for instance the measurement of water levels is a simple but vital function that can generate enormously useful information on resource trends. Management is not however well served if the network design does not respond to aquifer exploitation tendencies, by measuring water level trend in major well fields for instance, or by not continuing with regional gradient observation wells that have become compromised by new nearby major pumping wells.

Similarly, once the baseline quality of an aquifer is established, there is no particular merit in continued frequent groundwater sampling for analysis of major ions, which typically change only very slowly with time. Rather the evolving pattern of activities at the land surface, on the aquifer outcrop and on the catchments to sensitive abstractions should be regularly assessed and indicators chosen to provide early warning of potential problems. It is a poor justification of laboratory resources to continue with an analytical suite just because particular parameters are easy to sample and the laboratory is already set up to determine them routinely. A significant advantage of such regular reassessment of monitoring objectives is not only that it helps ensure that programs provide the kind of up-to date and focused information that those managing water resources need, but also can keep the costs of surveillance down to acceptable levels. A responsive monitoring strategy does not need to be a major drain on hard-pressed national budgets and can provide information for management out of all proportion to the costs of collection and interpretation. Sometimes the organization of monitoring and how it can be conducted when available resources are very slim needs to be re-evaluated pragmatically in order to at least continue providing a basic level of surveillance.

Finally, the need for an integrated approach to monitoring design and resource management becomes even more important when dealing with transboundary aquifers, where the already complex interplay of geology, climate and human activities that defines a groundwater catchment is further complicated by political and legal differences of two or more neighboring countries

As the UN/ECE Task Force on Monitoring and Assessment points out:

- Monitoring of groundwater and surface water, of water quality and of quantity are often performed by different authorities, so the resultant information needs to be assessed in combination;
- The effects of groundwater and surface water interaction can be sensitive, especially when recharge is through seepage of (possibly highly polluted) surface waters, or in the case of vulnerable near-border ecosystems;
- There will be a rather wider variety of potential uses and users of the monitoring data than would be found with an aquifer wholly contained within one country, and this places an even greater than usual premium on the provision of unambiguous well-documented data. For example, the use of mutually agreed indicators of water level and water quality will not only help keep the range of parameters within manageable limits but also will foster convergence, at the technical level, at least in identifying and assessing a particular transboundary groundwater problem. The ability to work from a jointly agreed set of facts is a precondition for meaningful negotiations (at a political level) to resolve a given Transboundary water issue and the provision of clear, focused and uncontested groundwater monitoring data a prime component of such an array of facts.

K. GROUNDWATER SIMULATION MODELING - A TOOL FOR MANAGEMENT

Numerical groundwater models are an efficient management and planning tool for the development of complex aquifer systems. Models, if properly constructed are useful to estimate the effects of future development/management schemes on the groundwater system. In addition, they can aid in understanding of the overall behavior of a given aquifer system. The computed result of an aquifer simulation is the potentiometric surface distribution of the aquifer and the salinity distribution in the aquifer or the concentration of a particular contaminant species, which are the critical factor in water resources management and planning.

While the aquifer in reality can be developed only once at considerable expense, a numerical model can be run many times at low expense over a relatively short period of time. Observations of model performance under different development and management options aids in selecting an optimum set of operating conditions to use the aquifer without endangering its sustainability. There are numerous applications of simulation models in the development and management of groundwater resources, such as:

1) How should a field be developed and produced in order to maximize its economic recovery.
2) What is the best production scheme for production (well interference, spacing, depth of intake, etc..).
3) Why is the aquifer is not behaving as predicted.
4) What is the type of field and field data required?
5) What are the critical aquifer parameters that should be measured?
6) From what portion of the aquifer the production is coming.
7) What is the effectiveness of artificial recharge and other management schemes in combating salt water intrusion.
8) Delineate a domestic wellfield capture zone and define its wellhead protection area.
9) Interpretation of chemical data obtained from the field, and their transport history and source.
10) Prediction of the behavior of pollutant plumes, and the impact of designed remediation measures.

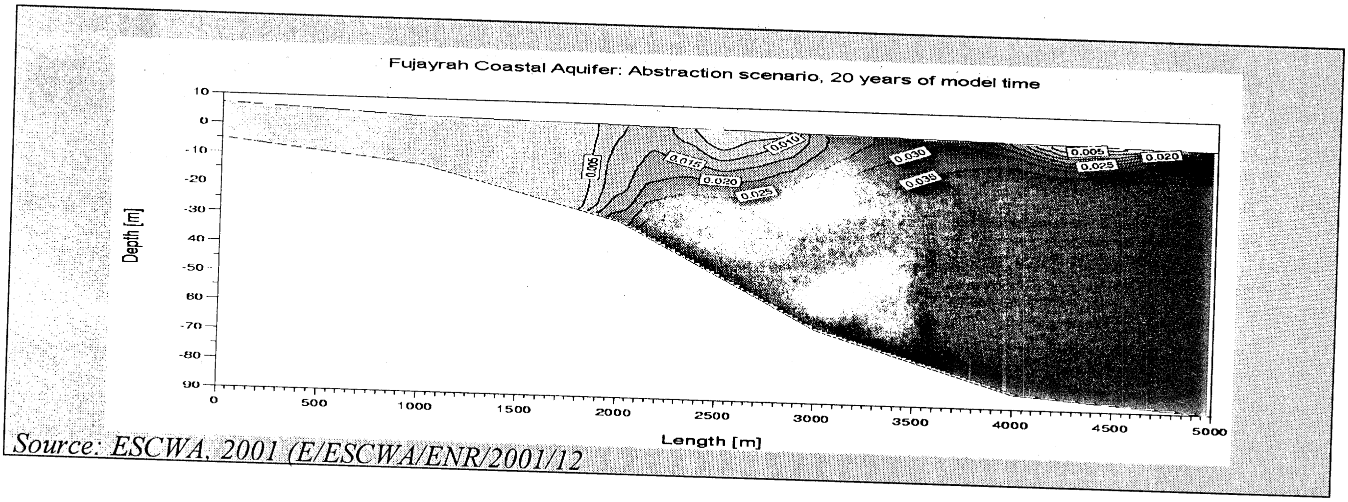
Generally, the use of numerical models in a given groundwater study involves four steps: (1) Aquifer date collection and conceptualization; (2) Model data preparation and initialization; (3) Model construction (Calibration and sensitivity analyses); and (4) Prediction. The objective of the first three steps is to construct a representative computer model that simulates the actual groundwater system behavior. The last step, predictive simulations, is run to estimate aquifer performance under a variety of development/management schemes. A fifth stage in the modeling practice is called post-auditing, where the results of the model are revisited after the implementation of the development and/or management scheme by a period and checked against observed aquifer data, and further adjustment in the model is made in order to replicate the aquifer system behavior.

BOX 7: USE OF SIMULATION MODELING IN STUDYING CONTROL OF SALTWATER INTRUSION IN THE COASTAL AQUIFER, UNITED ARAB EMIRATES

In many ESCWA countries, fresh water is obtained from coastal aquifers, which supply water to the often-urbanized areas on the coast, as well as remote areas. Saltwater intrusion has become a crucial issue as increased groundwater abstraction has caused the fresh water/salt water interface to advance inland. A numerical model was applied to the coastal area near Al Fujayrah in the United Arab Emirates to study the salt water intrusion problem and assess options for counteracting the intrusion.

Various geo-hydraulic simulation programs are available for planning sustainable withdrawal from coastal aquifers. They make it possible to assess scenarios with different well locations or artificial recharge. Finite difference or finite element models, such as HST3D, SUTRA, FEFLOW, and SALTFLOW, are most frequently used. In this case, the numerical groundwater model SimCoast was applied, which is based on a simplified, sharp-interface approach and was developed to simulate the time-dependent behavior of coastal aquifer systems in porous rock in cross-sectional models. It was used to model the advance of salt water assuming continued groundwater abstraction, and to assess the impact of groundwater recharge from a dam at Wadi Ham on the location of the fresh water-salt water interface. The effect of over-abstraction was clear: salt water intruded far into the aquifer. The modelling results showed that, although the dam across the wadi discernibly affects the groundwater system, the current rate of artificial recharge is not enough to prevent seawater from intruding into the coastal aquifer.

A comparative study was carried out for the same area of Al Fujayrah, this time using the two-dimensional SUTRA code, which is based on a system of partial differential equations with variable groundwater density. In order to save computation time, the modeled part of the cross section was shortened to five kilometers of the coastal plain, because it was only in this part of the aquifer that interaction between fresh and salt water was expected. The general trend in the results compared well with the results using the simpler SimCoast model. The effect of continued groundwater abstraction on saltwater intrusion as projected using the SUTRA model is shown. It shows the distribution of salt concentrations after 20 years without countermeasures. The upwelling of salt water at the location of the well fields is clearly visible. Development of salt concentration (kg/kg) in the coastal aquifer near Al Fujayrah Using SUTRA Model.



Source: ESCWA, 2001 (E/ESCWA/ENR/2001/12

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ANNEX A: GROUNDWATER RESOURCES IN THE ESCWA REGION [8]

Rainfall distribution and morphological, lithological and structural geological features govern groundwater occurrence, accumulation and movement. Rainfall and snowmelt are the main sources of groundwater recharge. Major geological features are the Arabian shield and shelf resulting from the split of the Afro-Arabian plate. The Neogene fold created the Taurid and Iranian mountain belts north and north-east of the Arabian shelf which extend from the Tauros and Zagros mountains in Turkey and Iran to the Oman mountains (ESCWA/BGR 1999). The shield covers one third of the Arabian Peninsula and extends from the Gulf of Aqaba in the north to the Gulf of Aden in the south. It is composed of hard igneous and metamorphic rocks, while the shelf is composed of a series of thick sedimentary formations dipping east toward the Gulf. Groundwater in the mountain belts in the north and the shield accumulates in the fractured folded and fissured formation. Significant groundwater reserves are found in the sedimentary formation of the Arabian shelf.

Groundwater in the region is found in numerous localized, regional and shared aquifer systems, such as the Paleogene aquifer in the Arabian Peninsula, the Basalt aquifer between Syria and Jordan and the Nubian Sandstone aquifer in Egypt. Major aquifers are those located in the Arabian Peninsula, part of the Syrian Arab Republic, Jordan and Iraq. The Arabian Shelf contains many major carbonate and sandstone aquifers. There are carbonate aquifers composed of limestone and dolomites of Jurassic and Cretaceous age in the western highlands and mountain ranges and in the Palmyrean Mountains. Paleogene aquifers composed of chalks limestone and dolomites extend over vast areas with mainly plateau-like landscapes in Syria, eastern Jordan, and southern Iraq, northwestern and eastern Saudi Arabia, the Gulf area and the southern fringes of the Empty Quarter in Yemen and Oman. The major water carbonate aquifers are known as the Eastern Mediterranean aquifers, composed of carbonate formations, are in Lebanon, the Syrian Arab Republic and the highlands of Jordan. The Jabal Al-Arab basaltic aquifers are located in southeastern Syrian Arab Republic, eastern Jordan and northern Saudi Arabia, and the Jezira tertiary limestone aquifers located in southern Turkey and the Syrian Arab Republic. Relatively deep aquifers include the upper and lower Fars formations, composed of gypsum interbedded with limestone in the Syrian Arab Republic and southern parts of Iraq.

There are sandstone aquifers of Paleozoic to Cretaceous age in the eastern part of Saudi Arabia, southern Jordan and the Rutbah area of Iraq, and deep, confined aquifers in northern Jordan and in Syria. The Disi-Saq sandstone aquifers are located in Jordan and Saudi Arabia. The Nubian aquifer, composed of thick sandstone, runs through Egypt, Libya and Sudan. This aquifer is overlain by a large carbonate aquifer which runs over the northern parts of Egypt. Groundwater from these formations is shared among a numbers of ESCWA countries. These aquifers are not usually at risk of pollution because of their great depth. Regional groundwater movement on the Arabian Shelf is directed towards several depression discharge areas of the Dead Sea, Yermouk, El Ghab, and Azraq-Wadi Sirhan valleys, Damascus, Palmyra and Euphrates basins and the Sabkha area in the Gulf region.

Renewable groundwater is available in the Shallow quaternary wadis, flood plain and river bed deposits located in the coastal plains and inland basins, which contain groundwater of good quality that is frequently recharged by perennial river flow and flood flow. The shallow aquifers in the Arabian Peninsula, Lebanon, the Syrian Arab Republic, western Jordan, Iraq and the Nile Delta hold groundwater reserves in the alluvial deposits and limestone formations sufficient to meet water requirements. The hydrogeology of major aquifers located in each ESCWA country is briefly discussed below.

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[8] Extracted from document "*Implications of Groundwater Rehabilitation, Water Resources Protection and Conservation: Artificial Recharge and Water Quality Improvement in the ESCWA Region*" (E/ESCWA/ENR/2001/12). For more details on groundwater resources in the ESCWA region, the reader is referred to two ESCWA documents: "*Updating the Assessment of Water Resources in the ESCWA Member Countries*" (E/ESCWA/ENR/1999/13); and "*Groundwater Resources in Paleogene Carbonate Aquifers in the ESCWA Refgion: Preliminary Evaluation*" (E/ESCWA/ENR/1999/6).

Lebanon. There are two main aquifers in Lebanon: the Jurassic limestone, with a thickness averaging 1200 m and the Cenomanian- Turonian, with a thickness ranging from 600 to 1000 m. In addition, the Neogene, Quaternary, and Carbonate aquifers overlie the two major aquifers. Recharge from precipitation is estimated at 2.5 bcm, and water quality ranges from 150 to 800 ppm (Country Papers 1997, 1999).

Syrian Arab Republic. The main groundwater aquifers are those of Anti-Lebanon and the Alouite Mountains. Folding and faulting of the geological layers has resulted in the mingling of the sub-aquifer systems. There are a number of springs discharging from this aquifer system, such as the Ari-Eyh, Barada, Anjar-Chamsine and Ras El-Ain. Recharge to the system occurs from intense precipitation in the mountainous regions which infiltrates through the fractures and fissures of the karstified surface layer. The estimated recharge is 5.43 bcm. Water quality ranges from 175 to 900 ppm. The other significant aquifer system is the Damascus plain aquifers that extend from the Anti-Lebanon Mountains in the west to the volcanic formations in the south and east of the country. This system is composed of gravel and conglomerates with some clay, and is represented by riverbeds and alluvial fan deposits with a thickness of up to 400 m. Recharge occurs from wadi and river flow, irrigation return, and leakage from the Cenomanian- Turonian aquifer estimated at 410 mcm. Groundwater quality ranges from 500 to more than 5000 ppm. The other major carbonate Haramoun mountain aquifer is located between Lebanon and the Syrian Arab Republic. The main discharging springs are those of the Banias and Dan tributaries of the Jordan River basin. The average spring discharge from the Haramoun aquifer is estimated at 464 mcm with a recharge rate estimated at 320 mcm. Groundwater quality is estimated at 250 ppm. Other aquifers with limited potential are located in the desert areas. These consist of marl and chalky limestone of the Paleogene age. Recharge occurs mainly from flood flow. Water quality ranges from 500 to 5000 ppm depending on the source of recharge.

Egypt. There are groundwater resources in the Nile Valley, the Delta and the Nubian sandstone and alluvial aquifers. The Nile Valley and the Delta are two distinct formations; the Quaternary and Tertiary sandstone and gravel of the upper formation are separated from the underlying Nubian sandstone formation by a layer of clay. The thickness of the Nile Valley and the Delta aquifers averages 300 and 1000 m, respectively, depending on the location, with reasonable production capacity. Sources of recharge in the Nile Valley are percolation from irrigation water and conveyance channels, while for the Delta they are irrigation percolation and river seepage. Recharge to the Valley and Delta aquifers are estimated at 6.2 and 2.6 bcm, respectively. Water quality ranges from 170 to 1700 ppm and in some areas the concentration may reach more than 6000 ppm. There is also groundwater in the extensive Nubian sandstone aquifer that extends into Libya and Sudan. Aquifer thickness ranges form 100 to 800 m, with large potential groundwater reserves of good quality. Water-bearing formations extend into the desert area of the Red Sea and the Sinai Peninsula.

West Bank and Gaza Strip. Groundwater resources occur mainly in the Cenomanian- Turonian mountain aquifers and coastal Pleistocene sand and sandstone aquifers (ESCW AINR/1997). The mountain aquifers in the West Bank consist of limestone and dolomite with a thickness of 700 m. In the mountain aquifer system, three groundwater provinces have been identified in the western, north-eastern, and eastern basins. These basins extend over most of the West Bank and discharge into the Yarkan River. The estimated recharge magnitude is 600 mcm. There are sandstone aquifers in the Gaza strip with a thickness ranging from 10 to 180 m and an estimated annual recharge volume of 70 mcm. Water quality ranges from 1200 to 3000 ppm.

Iraq. Groundwater aquifers in Iraq consist of extensive alluvial deposits of the Tigris and Euphrates rivers, and are composed of Mesopotamian-clastic and carbonate formations. The alluvial aquifers have limited potential because of poor water quality. The Mesopotamina-clastic aquifers in the north-western foothills consist of Fars, Bakhtiari, and alluvial sediments. The Fars formation is made up of anhydrite and gypsum interbedded with limestone, and covers a large area of Iraq. The Bakhtiari and alluvial formations consist of a variety of material, including silt, sand, gravel, conglomerate and boulders, with a thickness of up to 6000 m. Water quality ranges from 300 to 1000 ppm. Another major aquifer system is contained in the carbonate layers of the Zagros Mountains. Two main aquifers are found in the limestone and dolomite layers, as well as in the Quaternary alluvium deposits. The limestone aquifer contributes large volumes of water through a number of springs. The alluvial aquifers contain large volume reservoirs, and recharge is estimated at 620 mcm from direct infiltration of rainfall and surface run-off. Water quality is good, ranging from 150 to 1400 ppm.

Jordan. The major groundwater aquifers in Jordan are Wadi El-Sir of the Turonian age, Amman of the Cempanian age, and the Disi formations. The Wadi El-Sir and Amman formations consist of limestone, dolomite, chert and sandy limestone. One of these formations lies on top of the other throughout most of Jordan, with the exception of a small area in the south. The other aquifer system is a deep sandstone aquifer in the Disi formation that extends into the northern region of Saudi Arabia. Recharge takes place directly by infiltration of rainfall through fissures and karstified carbonate rocks, and from flood flow. Estimated recharge is 260 mcm. Base flow and spring discharge is estimated at 540 mcm, with water quality ranging from 500 to 3500 ppm.

Arabian Peninsula. Groundwater reserves for some of the countries of the Arabian Peninsula Saudi Arabia, Kuwait, Bahrain, Qatar, the United Arab Emirates, Oman and Yemen are found in the renewable shallow alluvial aquifers and non-renewable deep aquifers of sandstone and limestone formations (Abu Zeid 1992, ASCAD 1997, ESCWA 1996/139-1, ESCWA 1999). Alluvial deposits along the main wadi channels and flood plains of drainage basins in Kuwait, Saudi Arabia and the United Arab Emirates, Oman, Yemen and southern Jordan make up the shallow groundwater system in most of the southern ESCWA countries. Groundwater in the shallow aquifers is the only renewable water source, and is estimated at 131 bcm. Total reserves are estimated at 131 bcm, mainly in Saudi Arabia, where they are estimated at 84 bcm. Groundwater from the shallow alluvial is used mainly for domestic and irrigation purposes. The alluvial aquifer is being contaminated by the dumping of industrial and domestic wastewater.The other main source of water for the countries of the Arabian Peninsula is the non-renewable fossil groundwater stored in sedimentary deep aquifers. These aquifers store significant amounts of groundwater that is thousands of years old. The major aquifers are the Disi/Saq, Tabuk, Wajid, Minjur-Druma, Wasia-Biyadh, Tawilah and Amran sandstone aquifers and the Dammam, Um Er- Radhuma, and Neogene carbonate aquifers. Other aquifers are the Aruma, Jauf, Khuff, Jilh, Sakaka, Upper Jurassic, Lower Cretaceous, and Buwaib formations. These aquifers cover two-thirds of the eastern Arabian Peninsula, with large coverage of Saudi Arabia and extending into Kuwait, Bahrain, Qatar, the United Arab Emirates, Oman, and Yemen, as well as into Jordan, the Syrian Arab Republic and Iraq.

Saudi Arabia. Major aquifer systems are the alluvial deposits, carbonate and sandstone formations. Deposits consist of mainly coarse-grained sand, gravel, silt and clay. The alluvial aquifers range in thickness from 10 to 250 m, and contain large groundwater reserves. Groundwater recharge occurs from rainfall and flood flow, and may reach 2000 mcm per year. Water quality ranges from 300 to 5000 ppm. The other main groundwater source is located in the deep carbonate and sandstone formations of the Saq, Tabuk, Minjur, Wasia, Wajid, Dammam, Khobar, Sakaka, and Aruma aquifers. Vast amounts of groundwater stored in the deep aquifers serve as a dependable source of water for the central and northern regions of Saudi Arabia, and to a lesser extent, the other countries of the Peninsula. Total dissolved solids range from 400 to 20000 ppm. Good quality water is stored only in the Saq, Tabuk, Wajid, and Dammam aquifers.

Kuwait. Groundwater resources consist of water available from the Dibdiba, Fars, Gar, Dammam, Rus and Umm er-Radhuma formations. The aquifer system is divided into two main groups: the Kuwait group, which includes the Dibdiba, composed of sand and gravel, Fars of evaporite and Gar sand formations, and the Hassa group represented by the Dammam limestone, Rus anhydrite and Umm Er-Radhuma limestone formations. The main formations for groundwater utilization are the Kuwait group and the Dammam formation. Groundwater recharge is estimated at 160 mcm, with water quality ranging from 400 to 4000 ppm.

Bahrain. The main aquifers in Bahrain are the Neogene, Dammam, Rus and Umm Er-Radhuma. The Dammam aquifer provides most of Bahrain's water. The subdivisions of the Dammam formation are the Khabor (dolomite) and the Alat (limestone) formations, each containing major aquifers of average quality water (2000-4000 ppm) which serve as a domestic, industrial, and agricultural source for Bahrain. The Rus and Umm Er-Radhuma aquifers contain either brackish or saline water unfit for consumption. The aquifer system in Bahrain acts as a major recharge area for tertiary carbonate aquifers located in Saudi Arabia. Recharge is estimated at 100 mcm and occurs by underflow from the extensions of aquifers originating in Saudi Arabia. There are other aquifers, such as the Aruma and Wasia that have high salinity. Groundwater quality in the Dammam formations ranges from 2000 to 4000 ppm, while for the Umm er-Radhuma it may reach 18,000 ppm.

Qatar. The aquifers in Qatar are in the carbonate, Umm Er-Radhuma, Rus, Dammam and Neogene formations. The Aruma and Wasia formations are also present in Qatar. Groundwater from the Dammam, Umm Er-Radhuma, and Rus formations is used to provide water for use in all sectors. Water quality in some locations is good, ranging from 400 to 2000 ppm, however for most of the aquifer water quality ranges from 2000 to 6000 ppm.

United Arab Emirates. There are groundwater resources in the upper clastic and lower carbonate formations located in the Bajada region in the eastern part of the country .The aquifers consist of alluvial fan deposits along the base of the Oman and Ras El-Khaymah mountains extending over a large area. The upper aquifer is composed of gravel sand and silt, the lower aquifer of limestone, dolomite and marl. Both aquifers range in thickness from 200 to 800 m. In addition, the Dammam and Umm Er-Radhama formations extend into the western desert areas, with thickness ranging from 500 to 1000 m. Groundwater quality in the two aquifer systems, particularly in the Bajada region, ranges from 600 to 2000 ppm. The Dammam and Umm Er-Radhuma aquifers contain highly saline water.

Oman. The Batinah alluvial and Bajada alluvial fan deposits and the Umm er-Radhuma and Rus tertiary carbonate formations are the major aquifer systems in Oman. The Batinah alluvial aquifer is composed of gravel, conglomerate, medium and coarse sand, silt and clay. Thickness ranges from 240 to 600 m. A large number of fissures drain the mountain catchment areas into the Piedmont zones. Water quality ranges from 800 to 6000 ppm. The alluvial fan aquifer of the Bajada region consists of Quaternary deposits and Fars group formations, with water quality ranging from 900 to 6000 ppm. The tertiary carbonate aquifers, represented by the Umm Er-Radhuma, Rus and Dammam formations, have very poor water quality in excess of 4000 ppm.

Yemen. There are groundwater resources in the Tihama and Gulf of Aden alluvial deposits. The Tihama alluvial aquifers are an extensive system extending along the coastal plains, and range in thickness from 20 to 500 m. The aquifers receive extensive direct recharge from rainfall and wadi flood flow. Water quality ranges from fair to good. The Gulf of Aden alluvial aquifers extend into the coastal area of the Gulf, with major wadis separated by intrusive rock, and thickness averaging 400 m. The major aquifers are those in wadis and the Delta of Tuban, Abian, Ahwear and Meifa. Water quality varies from 600 to 2000 ppm. The Hadramaut aquifer system consists of sandstone and carbonate aquifers in the eastern Arabian Peninsula. The system consists of the Umm Er-Radhuma limestone and Mukalla sandstone formations. The aquifer is overlaid with thick alluvial deposits. Recharge from rainfall, run-off and intermittent flow is estimated at 160 mcm. Water quality from the Mukalla aquifer ranges from 440 to 1000 ppm. The other major groundwater source is contained in the highland aquifers located in the rugged volcanic and crystalline mountains in the central region of Yemen. They are located in the sub-basin and mountain plains of the center of the country. The main aquifers are in the alluvium, the volcanic formations, and the Taqilah, Amran, Kohlan and Wajid sandstone formations. Water Quality is generally good.

ANNEX B: GROUNDWATER POLLUTION CASES IN THE ESCWA REGION

A water quality study in Saudi Arabia reported a relatively high nitrate concentration in shallow aquifers located at a depth ranging from 30 to 50 m (Al Zubari, 2000). It was reported that the sampling of 388 wells located in the six regions of Saudi Arabia in 1989 had nitrate levels ranging from 0.01 to 95 mg/l. The ammonia level in eight per cent of the wells reached more than 0.05 mg/l, with some values as high as 5 mg/l. Faecal coliform bacteria were present in 21.4 per cent of the wells. Another field study (Abdulrahman, 2000) carried out in the eastern part of Saudi Arabia investigated pollution from the application of fertilizers and herbicides. The main pollution sources were nitrogen, phosphorus and potassium fertilizers and organic nitrogen from manure. Pesticide and herbicide concentrations in the shallow aquifer were below detection levels. Because of its great depth, the deep aquifer showed no sign of pollution. The sampling of the shallow aquifer indicated high levels of nitrate and sulphate and trace elements of boron, iron, and copper.

The nitrate values indicated seasonal variation, with the highest values of 620 mg/l in the winter and 568 mg/l in the summer. The high sulphate values ranged from 7 690 in the summer to 5990 mg/l in the winter, while for boron the range was from 18.7 in the summer to 24 mg/l in the winter. The highest fluoride values also ranged from 5.4 in the summer to 15.4 mg/l in the winter (Abdulrahman 2000).

In Egypt, the application of nitrogen, phosphorus and potassium fertilizers increased by 62, 81, and 115%, respectively, between 1976 and 1996 (Shamrukh et al., 2001). Extensive application has resulted in pollution of the shallow Nile aquifer, Nile Delta and Nile Valley aquifers located at depths of 30-70 m. Concentrations were 20-350 for nitrate, 7-34 for phosphate, 7-28 for potassium and 96-630 mg/l for sulphate. The permissible limits are 0.25-3.5 for phosphate, 12 for potassium and 250-400 mg/l for sulphate.

Highly toxic organic pollutants have also been found in groundwater in some ESCWA countries. The sources of these pollutants are petrol spillage, brine from oil refinery by-products and medical waste. In the GCC countries, injection wells are frequently used to discharge brines into the deep zones. In addition to their high salinity, brines are usually contaminated by hydrocarbons, their content depending on the efficiency of the process used to separate oil from water. Injection wells can cause groundwater contamination if the injected fluid enters overlying fresh water aquifers as a result of poor well design or vertical migration through cracks, fault zones and abandoned well casings. In Bahrain and eastern Saudi Arabia, brine has been injected into the Rus - Umm er-Radhuma aquifers (Al-Zubari, 2000). The injected brine in Bahrain had an average oil content of 260 mg/l, equivalent to 60 000 cubic meters of crude oil (Al- Zubari, 2000). Because of its serious environmental impact, this type of pollution is not being reported. Treatment of such waste before injection is very costly.

In northern Bahrain, petrol leakage from storage tanks has resulted in a petrol plume 0.5 km wide and 1.5 km long floating over the shallow groundwater sources (Al-Zubari, 2000). There is a similar problem in the industrial city of Jubail in Saudi Arabia. Petrol pollution is common in most urban centers because of lack of monitoring and poor design.

ANNEX C: GROUNDWATER POLLUTION- HEALTH IMPACT[9]

Contaminated drinking water is the main cause of illness and death in the world. Ingestion of, or exposure to, contaminated water causes a number of diseases. Others may be caused by exposure to naturally found harmful chemicals or man-made pollutants in ground water. The morbidity and mortality rates of water-related diseases that may result from pollution are shown in table B.1. There are short-term and long-term health risks associated with contaminated water. These may be microbial (bacteria, viruses, parasites), chemical (metals, pesticides, disinfectants by-products, etc.) or toxin-related (toxins produced by micro-organisms), as shown in tables B.2 and B.3. Contaminants in irrigation water can also affect agricultural products and cause health problems by entering the food chain. Consequently, the absence of proper astewater collection systems and the persistence of open channels or pools of wastewater will serve as breeding grounds for many diseases.

Illness resulting from water consumption may be caused by chemical contamination, such as radioactive material, arsenic, cadmium, lead etc. or biological contamination by viruses, parasites and bacteria. The symptoms of illness caused by groundwater contaminants include the following:

(a) Symptoms of chemical poisoning may include mental confusion, dementia, mental retardation in babies, etc. Long-term exposure may be carcinogenic. Industrial and agro-industrial pollution, particularly by hydrocarbons and heavy metals, can cause severe health damage;

(b) Biological contaminants can lead to uncontrollable outbreaks of disease, especially in developing countries. Symptoms may include diarrhoea, gastro-intestinal manifestations, fever, etc. Infectious diseases caused by pathogenic bacteria, viruses and protozoa or by parasites are the most common and widespread health risks associated with drinking surface and groundwater. Water can carry a number of infectious diseases, such as viral hepatitis, Norwalk virus, cholera, typhoid fever, camphylobacteriosis, gastro-enteritis, amoebic dysentery, giardiasis and cryptosporidiosis. Water-borne infectious diseases can be fatal: globally, two million people die from diarrhoea every year;

(c) Illness may also be caused by water containing naturally occurring trace elements, which may be beneficial to health at low concentrations, but are very harmful in high dosages. Lead, arsenic, fluoride, and radioactive isotopes are the most dangerous of these.

Table C.1 classifies water-related disease(Jurdi, 2000).

For many years a ban on human morbidity and mortality data operated by some countries made it difficult to trace the effect of poor environmental conditions on human health. These restrictions have now been lifted, but it is still difficult to collect data because methods are not standardized.

Adequate, safe water supply and treated wastewater can reduce the occurrence of water-related diseases and death. Some preventive measures are shown in table C.4 (Jurdi, 2000).

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[9] based on Jurdi, 2000 and ESCWA, 2001 (refer to the references list)

TABLE C.1. ESTIMATED MORBIDITY AND MORTALITY OF WATER-RELATED DISEASES (*After Jurdi, 2000*)

Disease	**Morbidity (episodes/ year, or as stated)**	**Mortality (deaths/year)**	**Relationship of disease to water supply and sanitation**
Diarrhoeal disease	1 000 000 000	3 300 000	Strongly related to unsanitary excreta disposal, poor personal and domestic hygiene, and unsafe drinking-water.
Infection with intestinal helminths	1 500 000 000[a/]	100 000	Strongly related to unsanitary excreta disposal, and poor personal domestic hygiene.
Schistosomiasis	200 000 000[a/]	200 000	Strongly related to unsanitary excreta disposal and absence of nearby sources of safe water.
Dracunculiasis	100 000[a/,b/]		Strongly related to unsafe drinking water.
Trachoma	150 000 000[c/]		Strongly related to insufficient face washing, often in the absence of nearby sources of safe water.
Malaria	400 000 000	1 500 000	Related to unsatisfactory water management, water storage, operation of water points and drainage.
Dengue fever	1 750 000	20 000	Related to unsatisfactory solid waste management, water storage.
Poliomyelitis	114 000		Related to unsanitary excreta disposal, poor personal and domestic hygiene, and unsafe drinking-water.
Trypanosomiasis	275 000	130 000	Related to the absence of nearby sources of safe water.
Bancroftian filariasis	72 800 000[a/]		Related to unsatisfactory water management, water storage, operation of water points and drainage.
Onchocerciasis	17 700 000[a/,d/]	40 000[e/]	Related to unsatisfactory water management in large-scale projects.

a/ People currently infected.

b/ Excluding Sudan.

c/ Active Trachoma. There are approximately 5 900 000 cases of blindness or severe complications of the disease annually.

d/ Includes an estimated 270 000 blind people.

e/ Mortality resulting from blindness.

TABLE C.2. CLASSIFICATION OF WATER-RELATED DISEASE (*After Jurdi, 2000*), TYPE OF PATHOGENIC AGENT AND RECOMMENDED ENVIRONMENTAL INTERVENTION

Category	**Infection**	**Pathogenic agent**	**Recommended environmental intervention**
Water-borne (faecal-oral)			
Diarrhoeas and dysenteries	Amoebiasis	Protozoa	Improve water quality
	Camphylobacter gastro-enteritis	Bacterium	
	Cholera	Bacterium	
	E. Coli diarrhoea	Bacterium	Prevent casual use of unauthorized water sources
	Giardiasis	Protozoa	
	Rotavirus	Virus	
	Salmonellosis	Bacterium	
	Shigellosis	Bacterium	
Enteric Fevers	Typhoid	Bacterium	
	Paratyphoid	Bacterium	
	Poliomyelitis	Virus	
	Ascaiasis (giant roundworm)	Helminth	
	Trichuriasis (whipworm)	Helminth	
	Strongyloidiasis	Helminth	
	Taenia solium taeniasis (pork tapeworm)	Helminth	
Water-washed	Infectious skin disease	Miscellaneous	Improve water quality
	Infectious eye disease	Miscellaneous	Improve water quality
	Louse-borne relapsing fever	Spirochaete	Improve hygiene
Water-based	Schistosomiasis	Helminth	Regulate the need for water contact
	Dracunculiasis	Helminth	Control snail population
	Clonorchiasis	Helminth	Improve water quality
	Others	Helminth	Improve water quality
Water-related insect vector	Trypanosomiasis	Protozoa	Improve surface water
	Malaria	Protozoa	Eliminate breeding sites of insect
	Yellow fever	Virus	Control water storage
	Dengue fever	Virus	Improve design of water storage vessels
	Other	Virus	

- Adapted from R.G Feachman, 1984 "Infection Related to Water and Excreta: The health dimension of the decade" in P.G Bourne (ed). Water and Sanitation. Academic Press Inc. , Orlando, Florida, pp. 21-47.

- Adapted from Cairncross, Sandy et al. Evaluation for village water supply planning. Chichester, New York Published in association with International Reference Centre for Community Water Supply by J. Wilev IRC.

TABLE C.3. A SAMPLE CLASSIFICATION OF WATER-RELATED DISEASES BY AGENT, INCUBATION PERIOD AND SIGNS AND SYMPTOMS (*AFTER JURDI, 2000*)

Disease entity	**Agent**	**Incubation period**	**Signs and symptoms**
Cadmium poisoning	Cadmium	<1hr	Upper gastrointestinal symptoms predominate (nausea, vomiting)
Fluoride poisoning	Sodium fluoride		
Arsenic poisoning	Arsenic		
Cholera	Vibrio cholera	<1week	Lower gastrointestinal symptoms predominate (abdominal cramps, diarrhoea)
Camphylobacter gastro-enteritis	Camphylobacter foetus jejuni	<1week	Lower gastrointestinal symptoms predominate (abdominal cramps, diarrhoea)
Viral agents enteritis	Variety of viral Agents (Coxackiek's-adenovirus, rotavirus)	<1week	Lower gastrointestinal symptoms predominate (abdominal cramps, diarrhoea)
Amoebiasis	Entamoebia histolytica	<1week	Lower gastrointestinal symptoms predominate (abdominal cramps, diarrhoea)
Giardiasis	Lamblia	<1week	Lower gastrointestinal symptoms predominate (abdominal cramps, diarrhoea)
Lead poisoning	Lead and lead salts	Variable/dose dependent	Lower gastrointestinal symptoms predominate (abdominal cramps, diarrhoea)
Hepatitis A	Hepatitis A virus	<1week	General infection (fever, chills)
Typhoid fever	Salmonella typhoid	<1week	
Methaemoglobania	Nitrates	Variable/dose dependent	Cyanosis
Organophosphate poisoning	Organophosphate compounds, insecticides	<1 hr	Neurological symptoms (visual disturbances, tingling paralysis)
Chlorinated hydrocarbon poisoning	Chlorinated hydrocarbons, insecticides	1-6 hrs	Paralysis
Pseudomonas auruginosa infection	Pseudomonas auruginosa	<1week	Paralysis
Schistosoma dermatitis	Schistosoma larvae (many species)	<1week	Neurological Symptom (visual disturbances, and/or tingling).
Schistosoma dermatitis	Schistosoma haematobium	<1week	

Source: Balance, R.C. and Glun, R.A. (1984)). "Drinking–water and sanitation projects: criteria for resource allocation". World Health Organization WHO Chronicle, 38(6), pp. 243-248 (1984).

General signs and symptoms should be carefully investigated, in addition to disease specific spectrum.

TABLE C.4. IMPORTANCE OF WATER SANITATION-RELATED INTERVENTIONS AND DISEASE CONTROL

	Intervention				
Disease	**Water quality**	**Water quantity convenience**	**Personal and domestic hygiene**	**Wastewater disposal drainage**	**Excreta disposal**
Diarrhoeas					
Viral diarrhoeas	++	+++	++	0	++
Bacterial diarrhoeas	+++	+++	+++	0	++
Protozoa diarrhoeas	+	+++	+++	0	++
Poliomyelitis and Hepatitis A	+	+++	+++	0	++
Worm infections					
Ascaris, Tricharis	+	+	+	+	+++
Hookworm	+	+	+	0	+++
Pinworm, dwarf tapeworm	0	+++	+++	0	++
Other tapeworm	0	+	+	0	+++
Schistomiasis	+	+	+	0+	+++
Guinea-worm	+++	0	0	0	0
Other worms, with aquatic hosts	0	0	0	0	++
Skin infections	0	+++	+++	0	0
Eye infections	+	+++	+++	+	+
Insect-transmitted diseases					
Malaria	0	0	+	+	0
Urban yellow fever, dengue	0	0	+	++	0
Bancroftian filariasis	0	0	0	+++	+++
Onchocerciasis	0	0	0	0	0

Source: Adapted from Balance, R.C and Glun, R.A (1984). "Drinking-water and sanitation projects: criteria for resource allocation". World Health Organization, WHO Chronicle, 38(6), pp. 243-248 (1984).

Notes: Degree of importance of intervention:
+++ high,
++ medium,
\+ low,
0 negligible

ANNEX D: GROUNDWATER RECHARGE IN THE ESCWA REGION

Three types of flood runoff utilization techniques are currently practiced in Jordan, Oman, Qatar, Saudi Arabia, the United Arab Emirates and Yemen to augment groundwater supplies by artificial means. These management practices include the use of storage facilities such as dams, dikes and water spreading basins, and lowland in depressions with recharge wells are being used in areas with adequate rainfall and runoff potential to recharge the shallow aquifers

Recharge dams. This management practice focuses on the use of storage facilities including dams of various sizes (ESCWA, 1993) to recharge the aquifers. Runoff is impounded behind these dams, recharges the underlying alluvial aquifers from within the dam reservoirs area, as well as through the downstream channels when water from the dam is released. In addition to enhancing the recharge process, the dam traps most of the sediment load and reduces the magnitude of peak discharge, thereby diminishing flood damage downstream. Most of the dams built in Jordan, Oman, Saudi Arabia and the United Arab Emirates were built for groundwater recharge and flood control and, in a few cases, to provide water for irrigation or domestic purposes. The majority of dams built in Yemen were intended for the diversion of floodwater for irrigation and groundwater recharge. A few large dams in Saudi Arabia were constructed to serve a variety of purposes, including irrigation, flood control and groundwater recharge. These dams have been built either at the headwaters of catchments in the mountainous regions or in the downstream areas of catchments in Oman, Saudi Arabia, the United Arab Emirates and Yemen. More than 256 dams have been constructed in the Arabian Peninsula within the last 10 years, and at least 58 new dams are planned for the next decade (ESCWA, 1995b). Approximately 95 dams of various sizes have been constructed in Saudi Arabia with a combined storage capacity of 475 mcm, especially in the western and southwestern regions, where relatively abundant runoff is available. In Yemen 10 dams have been built with a combined storage capacity of 72 mcm. Most of the dams in these two countries have been constructed in mountainous regions to the availability of runoff from frequent rainfall and the high infiltration characteristics of the coarse wadi bed deposits. Fewer dams have been or are being constructed in Oman and the United Arab Emirates. In cases in which dams have not served their intended purposes, problems have been attributed to inadequate operation and maintenance procedures. Problems of high evaporation losses as a result of prolonged storage of water in the reservoir, high siltation rates and inadequate removal of the silt, and poor operation and maintenance of controlled outlets also exist. Infiltration rates from reservoirs have gradually diminished as a result of the progressive build-up of silt and clay deposits. Siltation of reservoirs is a major problem in many parts of the Peninsula. Sparse vegetation, in combination with steep slopes, exposed rocks and intensive rainfall, results in high concentrations of silt and clay being carried along by floodwaters. Lack of regular water release, especially at low water levels in the reservoir, contributes to significant water losses through evaporation. Dam efficiency is sometimes improved by the removal of silt from reservoir lakes and by the regulated downstream release of water with the object of contributing significant volumes of water to the recharge of the underlying aquifers.

Water spreading basins. Water spreading, known as flood irrigation or spate irrigation, is the simplest type of water harvesting, where cultivated areas lie within and immediately adjacent to an ephemeral stream or wadi. In many areas of the Arabian Peninsula, direct use of floodwater for irrigation or groundwater recharge is small in comparison with the amount of available surface runoff. Spreading involves the use of small-cultivated basins adjacent to the main wadi channel, where floodwater is diverted to meet crop requirements. This method was once commonly used in Oman, Saudi Arabia, the United Arab Emirates and Yemen. Flood irrigation within basins is still widely practiced in the downstream areas of major wadis in the southwestern region of Saudi Arabia, and in most regions of Oman and Yemen. Cultivation of the flood plain is carried out in small basins prepared ahead of the rainy season along the main wadi course. They may extend laterally for many kilometers, as far as the flat terrain allows. Water sources include either direct rainfall or floodwater diversion.

Recharge wells. Recharge efforts in the Arabian Peninsula have concentrated mainly on the construction and use of recharge dams. However, Kuwait and, more recently, Qatar have been experimenting with artificial recharge wells and pits. The anticipated water sources include excess desalinated water, floodwater and imported water. The purpose is to build a strategic groundwater reserve to be used during shortages.