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Shared Natural Resources: first report on outlines

By Mr. Chusei Yamada, Special Rapporteur

I. Introduction

1. This addendum to the first report (A/CN.4/533) is intended to provide an overview of groundwater resources in the eyes of hydrogeologists. In his first report, the Special Rapporteur stated that the scope of groundwaters that the Commission is supposed to address covers water bodies that are shared by more than two States but are not covered by article 2 (a) of the Convention on the Law of the Non-Navigational Uses of International Watercourses and that such water bodies should be termed for the time being "confined transboundary groundwaters".[1] It is essential, however, for the Commission to know exactly what the scope of such groundwater resources should be in order to regulate and manage them properly for the benefit of humankind. The legal norms that the Commission is to formulate must be easily understood and be able to be readily implemented by hydrogeologists and administrators. With a view to having a dialogue with hydrogeologists and administrators who have profound knowledge of groundwater resources, the Special Rapporteur has requested the assistance of Alice Aureli, hydrogeologist of the International Hydrological Programme of the United Nations Educational, Scientific and Cultural Organization (UNESCO), who co-opted expertise from the Internationally Shared Aquifer Resources Management Programme (ISARM), the programme coordinated by UNESCO jointly with the Food and Agriculture Organization of the United Nations (FAO), the United Nations Economic Commission for Europe (UNECE) and the International Association of Hydrogeologists (IAH).

2. This addendum is based on the contribution of the following experts; Jacob Burke (FAO), Bo Appelgren (ISARM/UNESCO), Kerstin Mechlem (FAO), Stefano Burchi (FAO), Raya Stephan (UNESCO), Jaroslav Vrba (Chairman of the IAH Commission on Groundwater Protection), Yongxin Xu (UNESCO Chair on

[1] First report (A/CN.4/533), para. 19.

Groundwater, University of the Western Cape, South Africa), Alice Aureli (UNESCO), Giuseppe Arduino (UNESCO), Jean Margat (UNESCO) and Zusa Buzas (ISARM/UNECE Task Force on Monitoring Assessment on Transboundary Waters).[2] The Special Rapporteur expresses his deepest appreciation to all those experts, who provided contributions and data. He, however, takes full responsibility for the wording and content of this addendum.

3. Groundwater is contained within sets of aquifer systems throughout the earth's crust. Groundwater provides the globe with its largest store of freshwater, exceeding the volumes stored in lakes and watercourses. From the human perspective, groundwater is a vital resource. It is often the only source of water in arid and semi-arid regions and on small islands. Groundwater plays an important role in maintaining soil moisture, stream flow, springs discharge, river base flow, lakes, vegetation and wetlands. In general groundwater is ubiquitous, relatively cheap to lift and of high quality, usually requiring little or no pre-treatment for potable use. Owing to these characteristics, during the past few decades there has been a rapid expansion in groundwater use, particularly in developing countries. Over half of the world's population depends on groundwater for its potable water, and approximately 35 per cent of the world's irrigation relies on continued access to groundwater.

4. This report will deal with the following issues:

basic terminology;

characteristics of groundwater, including transboundary aquifers;

groundwater resources of the world and their use;

causes and activities that adversely affect the resource;

preliminary survey of shared groundwater aquifers under pressure from cross-border pumping or from cross-border pollution;

social, economic and environmental aspects of management of non-connected groundwaters, with a special focus on non-renewable groundwater;

preliminary questions regarding the adequacy of the main principles of international water law for international groundwater.

II. Confined versus decoupled aquifers

5. It is the intention of the Special Rapporteur to deal with confined transboundary groundwaters. The term "confined" is already contained in the Commission's resolution on confined transboundary groundwater.[3] In the preamble of the resolution the Commission defined "confined groundwater" as "groundwater not related to an international watercourse". Hence, it seems to employ the term "confined" as meaning "unrelated". This differs from the definition hydrogeologists

[2] The following data have been extracted; A. Aureli, J.J. Burke, S. Burchi, S. Puri, B. Appelgren (ISARM Framework Document, UNEXCO 2000), A. Zaporozec & J. Miller (Groundwater Pollution, UNESCO 2000), Igor Zekstr & Everet Lorne (ibid. 2003), Stephen Foster (W.B/GWMATE Briefing Note No. 1), Regional Groundwater Reports. Natural Resources/Water Series Nos. 12-27 United Nations (1983-1990), Burke, J. J. and Moench, M. Groundwater and Society, Resources, Tensions And Opportunities, United Nations, New York (2000).

[3] *Yearbook … 1994*, vol. II (Part Two), p. 135.

use for "confined". In hydrogeological terms, a confined aquifer is an aquifer overlain and underlain by an impervious or almost impervious formation, in which water is stored under pressure. Confinement is thus a matter of hydraulic state and not a question of being connected or related to a body of surface waters. The Commission did not, in fact, mean to refer to "confined" aquifers in the hydrogeological sense, but simply to those groundwaters not connected to bodies of surface waters. In this sense, it used the term "confined" simply to distinguish groundwaters that were not connected or were decoupled from a body of surface water that may or may not be confined in the strict hydraulic sense.

6. Groundwater connected with a body of surface water can fall within the scope of the Convention on the Law of Non-Navigational Uses of International Watercourses. The Convention applies to "international watercourses". A "watercourse" is a "system of surface and groundwaters constituting by virtue of their physical relationship a unitary whole and normally flowing into a common terminus". An "international watercourse" is "a watercourse parts of which are situated in different States". For groundwater to be covered by the Convention, four criteria must hence be fulfilled: (1) it must be part of a *system* of surface and groundwaters; (2) this system must be part of a *unitary whole*; (3) the system must normally flow into a *common terminus*; and (4) parts of the system must be located in *different States*. Looking at groundwater, this definition poses a number of problems that cannot be discussed in detail here. Groundwater does not normally flow into a common terminus and also the "unitary whole" criteria is more suitable for surface water than for groundwater. What are excluded from the scope of the Convention are groundwaters emplaced in aquifer systems that are decoupled from active surface water systems. Such aquifer systems may or may not be confined — i.e. contain water under pressure. A sub-set of these aquifers, which have received no contemporary recharge, are often called fossil aquifers. As indicated, these aquifers can be confined or unconfined. It is the fact that they are not renewable under present climate regimes that renders them distinctive, not the degree of pressure under which these waters are stored.

7. Fossil aquifers can be considered depletable resources like oil and gas. The Commission is therefore considering dealing with aquifer systems decoupled from surface water systems, providing particular focus to a sub-set of these aquifers called fossil aquifers. Fossil aquifers should also fall under a specific legal regime, as they are particularly vulnerable to pollution and depletion. While the waters of these aquifers are of vital importance for many arid regions of the world they are almost impossible to clean once polluted, as there is almost no flow within the aquifer. This sheds doubt on the suitability of the "significant harm" principle and raises the question whether a stricter standard should apply. Furthermore, these waters can only be depleted over shorter or longer periods of time and the law should deal with the question of what this means for the principle of equitable and sustainable utilization. The remainder of the text covers groundwater resources in general in order to give a more comprehensive picture of this important resource. Where the specific characteristics of fossil aquifers merit special attention this will be pointed out.

III. Characteristics of groundwater and aquifers

A. General characteristics

8. Groundwater occurs in aquifers, or, broadly, geological formations capable of producing usable amounts of water. Aquifers are rarely homogeneous and their geological variability conditions the nature of the groundwater flowing through their respective lithologies and structures. The greatest variations in groundwater flow patterns occur where changes in rock types — for example, limestone overlying sediments and a hard crystalline rock — induce discontinuities in flow and may bring groundwater flow to the surface on the junction between the two rock types. Practically all groundwater originates as precipitation. Rain falling or collecting on the earth's surface soaks through the ground and moves downward through the unsaturated zone (Fig. 1). Once it reaches the top of the saturated zone, the water table, it recharges the aquifer system, building up hydrostatic pressure at the point of recharge and inducing pressure changes where the aquifer happens to be capped by a confining layer of impermeable material.

9. Aquifer systems constitute the predominant reservoir and strategic reserve of freshwater storage on planet Earth (Shiklomanov, 1998). But it should be noted that only a fraction of the quantity of groundwater is economically recoverable and it is the groundwater levels, not the volumes of stored water, that are significant in determining access to groundwater resources. Groundwater can move sideways as well as up or down. This movement is in response to gravity, differences in elevation, and differences in pressure. As a general rule, groundwater moves along hydraulic gradients driven by differences in hydrostatic pressure and ultimately discharges in streams, lakes, and springs and into the sea. Groundwater moves through the aquifers very slowly, with flow velocities measured in fractions of meters per day or meters per year, compared to meters per second for stream flow. Time and space scales are the key phenomena for understanding groundwater regime and flow dynamics. Aquifer systems are composed of interrelated subsystems, mainly controlled by the hydrogeological properties of the soil/rock environment, climatic conditions, landscape topography and surface cover. Flow in aquifer systems should be studied with respect to the infiltration rate in recharge areas, transition zone and upward rising groundwater flow in discharge areas. Under natural conditions a steady state or dynamic equilibrium prevails when recharge and discharge rates are in long-term balance. Some aquifer systems form a unitary whole with surface waters while others do not. In this case we consider groundwater that is stored under confining pressures but which, owing to the geological structure, is not coupled to one specific watercourse in a unitary whole to be unrelated confined groundwater.

B. Aquifers characteristics

10. Generally, three types of aquifers (both national and transboundary) should be recognized:

Shallow aquifers — usually occur in fluvial, glacial and eolian deposits and in rock weathered zones, and are mostly unconfined or semi-confined, highly vulnerable because the unsaturated zone is of low thickness and frequently polluted (diffuse pollution of shallow aquifers below arable land is often recorded). They are characterized by active groundwater flushing and a single flow system. Porous permeability and high hydraulic conductivity prevail, particularly in aquifers in fluvial deposits. Short residence time in the order of years and tens of years and low mineralization are their feature. Interface with surface water (discharge of groundwater into streams or ponds, and/or surface water bank filtration from the surface water bodies to adjacent shallow aquifers) is often recorded. However, many shallow aquifers have no direct contact with surface water and discharge through springs. These systems can also be shared by two countries. Low development cost and easy accessibility of groundwater through simple shallow wells has led to the wide exploitation of shallow aquifers by public or domestic water supply wells.

11. *Deeper aquifers* — are of major regional extent, often confined and usually of lower vulnerability. However, many deeper aquifers can be unconfined and can, owing to the permeability of the unsaturated zone, be vulnerable. Owing to geological heterogeneity, the deeper aquifers may consist of a number of laterally and/or vertically interconnected groundwater flow systems of various orders of magnitude. Groundwater in deeper aquifers is renewable, flows at greater distance compared to shallow groundwater systems and discharges into big rivers, lakes, or coastal areas of oceans or seas. Deeper groundwater basins do not often coincide with the surface water catchment areas. In deeper aquifers, temperature, pressure and time and space contact between rock and groundwater gradually increase and groundwater flow velocity decreases. Groundwater in deeper aquifers is tens to hundreds of years old. Many deeper aquifers are shared between two or more countries. Potential conflicts are foreseen for aquifers with their recharge area in one country and discharge area in another country. Interrelationship between shallow and deeper aquifers is observed particularly in regions with highly fractured rocks with fissured permeability.

12. *Fossil aquifers* — can be considered as non-renewable groundwater resources of a very low vulnerability. Fossil waters are not part of the present hydrologic cycle. Major recharge of these aquifers occurred in the last pluvial periods. Under wetter conditions, these aquifers would be renewable. Contamination of fossil confined aquifers is recorded exceptionally only (e.g. in the drilling of deep wells). Chloride-rich, highly mineralized fossil water is usually old; its age may vary from a few thousands to millions of years. Many fossil aquifers are internationally shared between two or more countries. Uncontrolled mining of fossil transboundary aquifers could lead to serious political and diplomatic problems, particularly in water-scarce arid and semi-arid zones.

C. International versus transboundary aquifers

13. In order to develop a uniform terminology it is suggested that one distinguish between international aquifers and transboundary aquifers. An aquifer can be regarded as international if it is part of a system where groundwater interacts with surface water that is at some point intersected by a boundary. In the case of an aquifer and a river that are hydrologically linked, both resources can be intersected by a boundary or only one of the two, making the whole system international in character. Even an aquifer that is located entirely within the territory of one State can be regarded as an international aquifer (that would fall within the scope of the United Nations Convention when the other criteria of the Convention are fulfilled) when it is linked with a body of surface water that is intersected by an international

boundary. A transboundary aquifer is in contrast a groundwater body that is intersected by a boundary itself. Hence, transboundary aquifers could be considered a sub-category of international aquifers. Fossil aquifers need to be transboundary ones in order to be regarded as internationally shared resources, as they are decoupled from all other waters.

D. Transboundary aquifer systems

14. Certain aquifers associated with continuous sedimentary basins can extend uniformly over very large land areas, extending across international boundaries. The key features of transboundary aquifers in general include a natural subsurface path of groundwater flow, intersected by an international boundary. Such water transfers, however slowly, from one side of the boundary to the other (Fig. 2). In many cases, the aquifer might receive the majority of its recharge on one side of the border, while the majority of its discharge would be on the other. It is this feature that requires wise governance and agreement in order to avoid or minimize harmful transboundary impact and, in general, to ensure accommodation of the competing interests of the countries concerned. Activities such as withdrawals of the natural recharge on one side of the boundary could have subtle impact on base flows and wetlands on the other side of the boundary. In most transboundary aquifers these impacts can be widespread and delayed by decades. The same holds true for pollution, both from direct discharges and from land-based activities. Many years may pass before the impacts are detected by monitoring. A worldwide survey of significant transboundary aquifers has recently been initiated under the ISARM initiative (UNESCO, FAO, UNECE & IAH).

IV. Groundwater resources of the world and their use

15. The total amount of groundwater use depends on different factors such as population, climatic and hydrogeological conditions, availability of surface water resources and their degree of contamination. Rapid expansion in groundwater exploitation occurred during 1950-1975 in many industrialized nations and during 1970-1990 in most parts of the developing world. Systematic statistics on abstraction and use are not available, but globally groundwater is estimated to account for about 50 per cent of current potable water supplies, 40 per cent of the demand of self-supplied industry, and 20 per cent of water-use in irrigated agriculture. These proportions vary widely, however, from one country to another. Compared to surface water, groundwater use often brings large economic benefits per unit volume, because of ready local availability, drought reliability and good quality requiring minimal treatment (Burke & Moench, 2000). Water for general household use includes water for drinking, cooking, dishes, laundry and bathing. Today, with a global withdrawal rate of 600-700 km^3/a (Zektser & Margat, UNESCO in press), groundwater is the world’s most extracted raw material, for example, the cornerstone of the Asian green agricultural revolution, providing 70 per cent of piped water supply in the European Union and supporting rural livelihoods across extensive areas of sub-Saharan Africa (S. Foster, WWDR, 2003). In arid and semi-arid regions, where water scarcity is endemic, groundwater plays an immense role in meeting domestic and irrigation demands.

A. Europe

16. Analysis of the available data shows that groundwater is the main source for public water supply in the European countries accounting for more than 70 per cent of the total water resources used for this purpose. Rural populations and small and medium towns rely mainly on groundwater for drinking. In general, more than 90 per cent of big cities and towns are supplied exclusively by groundwater. Groundwater use for industrial water supply represents about 22 per cent of the total withdrawal, including mine-water drainage in some countries (e.g., Germany, France). Extensive groundwater use in industries is characteristic of such countries as Germany, Russia, France and Great Britain.

B. India

17. Groundwater has been used in India since the Vedic times, for over 6,000 years. The irrigation potential created from groundwater has increased from 6.0 million hectares (Mha) in 1951 to 36.0 Mha in 1997. Stress on groundwater resources, also due to increasing water demands, has caused problems related to over-exploitation, such as declining groundwater levels, sea-water intrusion, quality deterioration.

C. China

18. Distribution of groundwater use by sectors in China is as follows: urban residential use 7.4 per cent, urban industrial use 17.5 per cent, rural residential use 12.8 per cent, farmland irrigation 54.3 per cent, rural enterprises and others 8.0 per cent.

D. North America

19. Groundwater represents perhaps less than 5 per cent of Canada’s total water use (van der Leeden and others, 1990); however, more than 6 million people, or about one fifth of the population, rely on groundwater for municipal and domestic use (Environment Canada, 1997). About two thirds of these users live in rural areas, and the rest primarily in smaller municipalities. About 50 per cent of the United States population depends on groundwater for domestic uses. More than 95 per cent of the households that supply their own drinking water rely on groundwater. The use of groundwater in the United States increased steadily from 1950 to 1980, and has declined slightly since 1980, in part in response to more efficient use of water for agricultural and industrial purposes, greater recycling of water and other conservation measures.

E. Central America

20. Groundwater is an important source of potable water throughout much of Mexico and Central America. In Mexico, where desert and semi-arid conditions prevail over two thirds of the country, groundwater is widely used. Groundwater provides most of the domestic, drinking, and industrial water needs of Nicaragua.

Costa Rica, El Salvador, and Guatemala also use substantial groundwater, whereas Belize, Honduras, and Panama are less dependent on groundwater. In most rural areas of Central America, more than 80 per cent of the population is supplied by either private or municipal well systems. Urban areas in Mexico and Central America that use groundwater as their sole or principal source of water supply include Mexico City, Mexico; Guatemala City, Guatemala; Managua, Nicaragua; and San Jose, Costa Rica.

F. South America

21. Based on the latest United Nations estimates, in South America groundwater use is mainly to supply domestic and industrial demands. However, the present use of groundwater is very low, comparatively to the available renewable resources. The region has sufficient water but the availability of safe water is becoming a major socio-economic issue.

G. Africa and Middle East

22. In general groundwater is over-developed in northern Africa, i.e. in the Arab countries, which occupy the semi-arid, arid and hyper-arid belt north of the Sahara. The economy of the region largely depends on groundwater resources. Large aquifers underlie North Africa and the Middle East countries. In these regions several countries share the groundwater resources existing in transboundary aquifer systems. In the humid equatorial and tropical African regions, groundwater is under-developed, because rainfall and surface water is abundant in major rivers and their tributaries. However, countries in these regions have recently realized that provision of safe drinking water to small towns and rural areas can only be guaranteed by utilizing groundwater sources. In the arid and semi-arid region of southern Africa, there is an urgent need to use groundwater for rural water supply. With the exception of the countries of North Africa, and a few countries in western and southern Africa, adequate and reliable information on water use is lacking or scarce in Africa. Lack of rules and national regulations is also an evident problem.

H. Australia

23. The total amount of groundwater used in Australia annually was about 2,460 x 10^6 m^3 in 1983, equivalent to about 14 per cent of the total amount of water used. In Australia, the surficial aquifers are generally the groundwater sources most intensively used for irrigation and for urban and industrial water supplies. The intensive use of groundwater in some areas, especially for irrigation, has led to the over-development of some regional confined aquifers. Groundwater is vital to the pastoral industry (cattle and sheep) throughout large parts of Australia, and the mining industry is also heavily dependent on groundwater.

V. Causes and activities that adversely affect the resource

A. Groundwater quality

24. The value of groundwater lies not only in its widespread occurrence and availability but also in its consistently good quality, which makes it an ideal supply of drinking water. The term "quality of water" refers to the physical, chemical, and biological characteristics of the water as they relate to its intended use. Groundwater also is cleaner than most surface water because the earth materials can often act as natural filters to screen out some bacteria and impurities from the water passing through. Most groundwater contains no suspended particles and practically no bacteria or organic matter. It is usually clear and odourless. Most of the dissolved minerals are rarely harmful to health, are in low concentrations and may give the water a pleasant taste. Recognition of the fact that some of these dissolved substances may be objectionable or even detrimental to health has resulted in the development of drinking water standards. These standards serve as a basis for appraisal of the results of chemical analyses and are based on the presence of objectionable properties or substances (taste, odour, colour, dissolved solids, iron, etc.) and on the presence of substances with adverse physiological effects. A cause of negative impacts is the intensive exploitation of the aquifer. Equilibrium conditions can be disturbed by intensive aquifer exploitation. Intensive use of groundwater can lead to groundwater depletion and groundwater quality degradation.

B. Groundwater pollution

25. In view of the diverse uses of groundwater, it is essential to keep it free from any kind of pollution. While groundwater is less vulnerable to pollution than surface water, the consequences of groundwater pollution last far longer than those of surface water pollution. Pollution of groundwater is not easily noticed and in many instances it is not detected until pollutants actually appear in drinking water supplies, by which time the pollution may have affected a large area. The vulnerability of the aquifer systems to pollutants is dependent on a number of factors, including soil type, characteristics and thickness of materials in the unsaturated zone, depth to groundwater and recharge to the aquifer. Groundwater pollution is a modification of the physical, chemical, and biological properties of groundwater, restricting or preventing its use in a manner for which it had previously been suited. Substances that can pollute groundwater can be divided into substances that occur naturally and substances produced or introduced by human activities (Fig. 3) (Groundwater Pollution, A Zaporozec, UNESCO, 2000).

26. *Naturally occurring* substances causing pollution of groundwater include iron, manganese, toxic elements, and radium. Some of them are quite innocuous, causing only inconveniences, such as iron and manganese. But others may be harmful to human health, e.g. toxic elements (such as arsenic or selenium), fluoride, or radionuclides (radium, radon, and uranium). Arsenic is widely distributed in the environment and is usually found in compounds with sulphates. Arsenic is highly toxic at concentrations above 0.01 mg/l, and high doses cause rapid death.

27. *Polluting substances resulting from human activities* primarily include organic chemicals, pesticides, heavy metals, nitrates, bacteria, and viruses. The type of

groundwater pollution of the greatest concern today — at least in the industrialized countries — is pollution from hazardous chemicals, specifically organic chemicals. Pesticides used in agriculture and forestry are mainly synthetic organic compounds. The term pesticide includes any material (insecticide, herbicide, and fungicide) used to control, destroy, or mitigate insects and weeds. Many of the pesticide constituents are highly toxic, even in minute amounts. Nitrate is the most commonly identifiable pollutant in groundwater in rural areas. Although nitrate is relatively non-toxic, it can cause, under certain conditions, a serious blood disorder in infants. The greatest danger associated with drinking water is that it may be polluted by human excreta and lead to the ingestion of dangerous pathogens. Pollution by infiltration is probably the most common groundwater pollution mechanism. A pollutant released at the surface infiltrates the soil through pore spaces in the soil matrix and moves downward through the unsaturated zone under the force of gravity until the top of the saturated zone (the water table) is reached. After the pollutant enters the saturated zone (an aquifer), it travels in the direction of groundwater flow. Groundwater pollution can also result from the uncontrolled development and abstraction of groundwater. When uncontrolled use of groundwater has significantly exceeded natural rates of aquifer replenishment negative impacts can affect the aquifer systems. Sometimes it can also lead to land subsidence and to the inflow of saline water from deeper geological formations or the sea. Sea-water intrusion is an ever-present threat to groundwater supplies in over-developed coastal aquifers, where under natural conditions fresh groundwater is delicately balanced on top of denser sea water. Often water of poor quality can enter deeper parts of the aquifer from rivers and polluted shallow aquifer systems.

C. Groundwater protection and management

28. Monitoring wells can be installed to discover groundwater pollution from a given activity, detect its extent, and provide advance warning of polluted water approaching important sources of water supply. However, cleanup is difficult and expensive and generally requires long periods of time. Therefore, a major effort should be directed towards preventing pollution from occurring. The cost of groundwater protection through prevention is generally much smaller than the cost of correcting the pollution after it is found. Groundwater resources are vulnerable to human impact particularly in recharge areas, where the hydraulic heads are high and water flow is downward. Important sources of drinking water can be protected by delineating protection zones, in which potentially polluting uses and activities are controlled. Human activities (agriculture, industry, urbanization, deforestation) in the recharge areas should be under control and should be partly or fully restricted by relevant regulations. However, groundwater protection policy should be adequate to different aquifer systems.

D. Transboundary groundwater contamination problems

29. Groundwater contamination can occur through infiltration (the downward influx of contaminants), recharge from surface water, direct migration and aquifer interface. Infiltration is the most common source of the contamination of shallow aquifers and unconfined deeper aquifers. Water penetrating downward through the soil and unsaturated zone forms leachate that may contain inorganic or organic

contaminants. When it reaches the saturated zone contaminants spread horizontally in the direction of groundwater flow and vertically owing to gravity. Recharge of polluted surface water into shallow aquifers can occur in losing streams, during flooding and when the groundwater level of the aquifer adjacent to a surface stream is lowered by pumping. Leakages from contamination sources located below the groundwater level (e.g. storage tanks, pipelines, basement of waste disposal sites) migrate directly into groundwater and affect particularly shallow aquifers. Contaminant transport in groundwater systems is a complex process, whose description is not the objective of this report and depends on rock permeability (porous, fissured, karstic), contaminant properties, groundwater chemical composition and processes controlling contaminant migration (advection, mechanical dispersion, molecular diffusion and chemical reactions). Various sources of contamination affect particularly shallow aquifers and unconfined deeper aquifers. Vulnerability of deeper confined aquifers to contamination impact is significantly lower and mostly occurs in recharge areas. However, such aquifers may be contaminated by natural constituents, like fluoride, arsenic, copper, zinc, cadmium and others. Fossil aquifers are not vulnerable to human impacts, however they are often more mineralized and of a higher temperature. Contaminants movement is generally slow, but in fissured rocks and particularly in karst rocks contaminants can move even several metres per day. Contaminants which migrate in the aquifers over the long distance and are sources of contamination of transboundary groundwater are nitrates, oil hydrocarbons and light non-aqueous phase liquids (LNAPLs), heavy metals and radionuclides.

E. Transboundary shallow aquifer contamination problems

30. Several scenarios of contamination of shallow transboundary aquifers exist. Many shallow unconfined aquifers are developed in the fluvial deposits in river valleys and pollution can be transported through groundwater flow from one country to another. Hydraulic gradients between surface water and groundwater control the possibility of bank infiltration of surface water to the adjacent aquifers and vice versa. Stream flow response to precipitation reflects short- and long-term changes in the hydraulic head of surface and groundwater bodies. During long dry periods, surface flow depends almost exclusively on groundwater (base flow conditions) and water quality of the streams reflects the quality of the underlying aquifers. Contamination occurs mostly on the ground surface of fluvial deposits and penetrates to the aquifer. Contaminated groundwater may flow in a shallow aquifer parallel to a river flow, or discharge into river or other surface water body. In both cases contamination originating in the upstream country affects water quality in the downstream country. Such transboundary contamination should be identified by water quality monitoring systems. Seasonal changes in the hydraulic head always have to be considered when a groundwater quality monitoring system is established.

31. However, penetration of contaminated surface water into underlying shallow aquifers may also occur far from the contamination source, where the river is a losing stream and conditions of surface water infiltration set in. Owing to the low attenuation capacity of fluvial deposits (mostly gravel and sands), which are unable to retain or remove the contaminants, shallow aquifers become contaminated long-term. Therefore, to identify water quality in the country borders, monitoring systems of both surface water and groundwater have to be designed. There are many shallow

unconfined aquifers developed in rock weathered zones, in higher fluvial terraces or in eolian deposits that are not directly connected with surface water bodies and discharge frequently in springs. However, such aquifers are often of smaller extent only. Contamination occurs in recharge and vulnerable areas of such aquifers and may be transported along a flow path over a long distance. Contamination is detectable by sampling springs or using shallow monitoring wells. Transboundary contamination should be identified by shallow monitoring wells.

F. Transboundary deeper aquifers contamination problems

32. Deeper confined aquifers may cover hundreds or even thousands of square kilometres. Groundwaters in recharge areas of deeper aquifers are unconfined and vulnerable to contamination. If contamination occurs, it can be transported laterally over a long distance along a flow path under confined aquifer conditions. The lateral movement of contaminants in the aquifer from recharge to discharge area may be accelerated by intensive aquifer exploitation. Contamination of deep confined transboundary aquifers should be identified by deep monitoring wells located in the country borders, which with respect to the contaminant properties have to reach the upper part or the bottom of the aquifer. Because the recharge area of deep confined aquifers in one country may be many times larger than the discharge area in the other country, aquifer depletion may occur, particularly if control measures regarding aquifer exploitation are missing. Deeper aquifers may also be unconfined ones, which renders the transit and recharge zone vulnerable. The downward migration of the contaminants to the aquifer depends on soil properties and the thickness and lithology of the unsaturated zone. In conditions of porous permeability it can take many years before the contamination plume reaches the saturated aquifer. However, in aquifers with fissured permeability and in karst aquifers contaminants can reach the aquifer very fast (days, months). The mechanism of lateral contaminant movement in these aquifers is similar to that in the confined aquifers. Early warning quality monitoring of the unsaturated zone and the upper part of the aquifer supports identification of groundwater pollution problems while they are still at the controllable and manageable stage.

G. Transboundary fossil aquifers contamination problems

33. Fossil aquifers are well protected by the geological environment and are typically of very low vulnerability and their contamination is uncommon. Contaminants can enter fossil aquifers through vertical leakage through the seals around well casings when deep wells are drilled for various purposes (e.g. exploitation wells, deep disposal wells) and the drilling process is not controlled. However, many transboundary aquifers could be affected by depletion, particularly if there is mining and non-renewable groundwater storage is continuously depleted. Comprehensive control over the abstraction of transboundary fossil aquifers is a very desirable and urgent task.

VI. Practices of States with regard to national management of groundwater

34. Groundwater resources management has to balance the exploitation of a complex resource (in terms of quantity, quality and surface water interactions) with increasing demands for water and the attitudes of land users who can pose a threat to resource availability and quality. Both in common law and in civil law countries, land ownership used to attract all resources above and below the land. However, in response to growing pressure on high-quality reserves from increasing demand, groundwater has been increasingly brought within the scope of legislation regulating the extraction and use of the resource. Also, the threat posed to the quality of groundwater has attracted legislation regulating direct and indirect discharges and preventing and abating groundwater pollution. In many countries, groundwater is protected through the enactment of a basic water law that covers all water resources. Specific provisions for groundwater may be included within this or may be added at a later time. This approach has been followed in Finland, Italy, Israel, Poland, Spain, the United Kingdom and the United States of America. In other countries, including France, the Netherlands, Romania and Turkey, groundwater protection has evolved through the adoption of a wide range of regulations dealing with specific aspects of groundwater, such as extraction rates, well depth and environmental protection. Primary jurisdiction for groundwater protection may be centralized at the national level, as in Mexico and Egypt, or may be largely delegated to states or provinces, as in the United States, India and China. In cases where this jurisdiction is delegated, the central Government typically retains authority over certain aspects, such as minimum water quality standards, to ensure consistency. One of the key components of effective groundwater management is the establishment of a central agency with responsibility for the implementation of groundwater legislation. A wide variety of regulatory and non-regulatory mechanisms have been developed to protect groundwater resources from over-extraction and from pollution.

VII. Preliminary survey of shared aquifers under pressure from cross-border pumping or from cross-border pollution

35. *Sonora-Arizona Border Area* of Mexico and USA (partly covered by agreement (Minute 242 of 1973, of the Mexico-USA International Boundary and Water Commission (IBWC)). This area concerns the Yuma Mesa aquifer and belongs hydrologically to the Lower Colorado River basin, but the tension is about the pumping of groundwater.

Hueco Bolson Aquifer (USA (Texas)-Mexico (Chihuahua)) (no agreement).

Mimbres Aquifer (USA (New Mexico)-Mexico (Chihuahua)) (no agreement).

Generally at least 15 transboundary aquifers at the US-Mexican border (no agreement except for Minute 242 on the Yuma Mesa).

Araba-Arava Groundwater Area (Israel and Jordan) covered by the 1994 Treaty of Peace between Israel and Jordan. It could be a case of cooperation. The real tension between Israel and Jordan is about surface water (Jordan River and Yarmouk).

Mountain Aquifer (Israel and Palestine) (a case of actual conflict) (Israeli-Palestinian Interim Agreement on the West Bank and the Gaza Strip, 28 September

1995. The Agreement establishes a joint commission; however, it does not solve the conflict over water, which was supposed to be discussed in the final negotiations).

Disi Aquifer (Jordan and Saudi Arabia) (no agreement).

Regional Basalt Aquifer System (Jordan-Syria). Technical cooperation was developed by United Nations-Economic and Social Commission for Western Asia (ESCWA) and the German Federal Institute for Geosciences and Natural Resources (BGR) between the two countries to establish information regarding the sustainable development of groundwater resources; the outputs were the establishment of a geological map of the aquifer, and the study of the prevailing hydrogeological conditions. At the urging of ESCWA, a memorandum of understanding was signed by Syria, and will be signed by Jordan for further cooperation regarding the aquifer.

Nubian Sandstone Aquifer System (NSAS) (Egypt, Libya, Chad, Sudan). Agreement establishing a NSAS Authority (date uncertain) and two agreements made during 2000 governing access to, and use of, the aquifer database and model (on file with FAO).

Systhème Aquifère du Sahara Septentrional (SASS) (Algeria, Libya, Tunisia) (no agreement, but joint decision setting up an arrangement for tri-partite consultation on the updating and management of the aquifer database and model) (on file with FAO).

Continental Terminal Aquifer (Gambia and Senegal) (no agreement).

Guaraní Aquifer (Argentina, Brazil, Paraguay, Uruguay) (no agreement, but a Global Environment Facility (GEF) project in progress. The main objective of the project is to prepare and implement a common institutional framework for managing and preserving the aquifer. The project agreement provides for a Steering Committee of representatives of the four countries (and one from the South American Common Market (MERCOSUR))).

Eighty-nine transboundary aquifers in Europe have been surveyed and recorded by the UN/ECE Task Force on Monitoring and Assessment set up under the 1992 UN/ECE Convention on the Protection and Use of Transboundary Watercourses and Lakes (in the *Inventory of Transboundary Groundwaters*, Lelystad, September 1999, p. 181-283 (copy on file with FAO)). Of these, however, it is not known at this time how many are under actual or foreseeable pressure from extraction or pollution.

VIII. Social, economic and environmental aspects of the management of non-connected groundwaters: special focus on non-renewable groundwater

A. General

36. Water resources are of two types: flows and stocks. The use of flows does not affect future availability, while the use of stocks does. Fossil groundwater represents, by definition, a stock resource. Management of flow resources represents generally a straightforward application of marginal analysis. Stock resources, on the other hand, like any physical capital, have the characteristic that its optimal use requires considering future impacts (as risks or utilitarian values) of current

decisions. Considering non-connected or unrelated groundwaters as a combination resource with conjunctive characteristics, the connection with flow resources is closer to the hydrogeological realities. However the conjunctive aspects of water make its management more complex and this is probably one reason why this has developed into a principal question of discussion. In a neo-classical paradigm the goal of water resources management is to maximize the (short and long-run) value of the water resources to society. However, the neo-classical paradigm has increasingly given way to alternatives, such as the political, evolutionary, institutional and economic paradigm, with greater recognition of evolutionary processes and the prevailing political economy, which in reality governs decisions on the allocation of resources in society. Fossil groundwater resources contained in confined aquifers can be large regional systems shared by two or more countries. Fossil water appears as directly measurable and contained in a receptacle and should therefore be subject to appropriation and regulated at law like any other owned object. However, this is a simplified picture and the measurable and contained in a receptacle aspects do not accommodate the complex and uncertain hydrogeological, social, economic and political long-term impacts characterized by high risk and uncertainty related to change of climatic and environmental conditions. So far, hydrologists and lawyers have, in fact, few tools to incorporate future uncertainties. This shortcoming requires mechanisms for enhanced participation and communication and enhanced attention to social and environmental water demands. The political will to accommodate uncertainty and incorporate escape clauses and to provide for shared risks already at the moment of negotiating international water agreements has, however, proven to be limited and there is therefore a call for alternative mechanisms for conflict prevention and resolution.

B. Non-connected groundwater resources: risk combined with scientific and policy uncertainty

37. While not, at least not directly, connected to modern annual recharge, fossil groundwaters are generally confined, over-pressured and often artesian. The risk of human-induced abuse coincides with that for annually recharged, connected groundwaters and include not only inappropriate water and other drilling, casing and capping practices, over-abstraction and inter-aquifer contamination but also impacts of changing land use, its consequences for recharge, pressure salinization and water quality. While non-connected groundwaters are less vulnerable to point- and non-point-source pollution, sudden expansion and waste discharges from abstraction of partly fossil water could have wide negative (water pollution, salinization and water-logging) and positive (increase in the available water resource, reduced evaporation losses) environmental impacts. Similar to the exploitation of other stock natural resources the practices of transboundary agreement therefore seem to represent one important tool for the joint management and use of transboundary non-connected groundwater.

C. Ethical versus scientific standards

38. While utilization of fossil groundwater had long been labelled as non-sustainable, the rigid attitude based on the rigid hydrogeological safe yield concept has recently become relaxed and the permissible level of exploitation is no longer a

fixed but a relative term related to social, economic and environmental values. It is becoming increasingly recognized that most standards in water and natural resources management are ethical, as the earlier dominance of scientific and utilitarian standards could deviate from and confuse politically agreed and ethically based intentions as expressed by legislators and the public.

IX. Conclusions

39. The presentation of groundwater resources in general has shown that

- Transboundary aquifers (be they shallow unconfined, semiconfined, confined) can be connected with international surface water systems.
- However, there may be cases where transboundary aquifers are not connected with international surface water systems.
- Shallow aquifers are generally more vulnerable (easily exploited and contaminated) than deeper aquifers but all aquifers (confined, unconfined) are vulnerable in their recharge areas.
- Fossil aquifers, decoupled from contemporary recharge, need to be treated as a non-renewable resource and planned for accordingly.
- Aquifers need to be periodically assessed and monitored, if they are to be managed and allocated in an equitable fashion.
- Groundwater development policies need to consider conjunctive use of groundwater and surface water, impacts to dependent ecosystems, coordination with land use planning and links to social policy and cultural practice.

40. The vulnerability of groundwater, especially fossil groundwater, to depletion and pollution calls for the development of norms of international law that contain stricter standards of use and pollution prevention than those applied to surface waters.

Annex I

Terminology used in this report

Aquifer: Permeable water-bearing geological formation capable of producing exploitable quantities of water

Confined aquifer: Aquifer overlain and underlain by an impervious or almost impervious formation and in which the groundwater is stored under a confining pressure

Unconfined aquifer: An aquifer that has a water table at atmospheric pressure and is open to recharge

Fossil groundwater: Groundwater that is not replenished at all or has a negligible rate of recharge and may be considered non-renewable

Groundwater: Any water existing below the ground surface

Groundwater resources: Volume of groundwater that can be used during a given time from a given volume of terrain or water body

Groundwater table: The upper limit of the saturated zone where pore water pressure equals atmospheric pressure

Groundwater vulnerability: An intrinsic property of a groundwater system that depends on the sensitivity of that system to human and/or natural impacts

International groundwater: Groundwater that is either intersected by an international boundary or that is part of a system of surface and groundwaters, parts of which are located in different States

Recharge: Replenishment of groundwater from downward percolation of rainfall and surface water to the water table

Surface water: Water that flows over or is stored on the ground surface

Transboundary groundwater: Groundwater that is intersected by an international boundary. It is a subcategory of international groundwater

Unsaturated zone: Part of ground below land surface in which the pore and fissures contain air and water

Annex II

Case studies

A. Practice of States in groundwater management and cases of adverse effects on groundwater and their causes. Examples from the Middle East: Jordan, Syria and Lebanon

Groundwater resources

Located in an arid and semi-arid zone, the countries of the Middle East have limited surface water and rely on their groundwater resources.

Of the three countries presented, Jordan has very limited water resources (among the lowest in the world on a per capita basis), and most of it consists of groundwater, in renewable and non-renewable aquifers. Thirteen groundwater basins have been identified, among them two are non-renewable (Al-Jafer and the Disi aquifer which is shared with Saudi Arabia) and two (other than the Disi) are shared (one with Syria and one with Israel (Wadi Araba)).

As for Syria, the country counts seven major surface water basins (of which six are main international rivers like the Tigris and Euphrates) where seven General Directorates are assigned responsibilities. No reliable data is available on groundwater availability and quality. In some of the hydrological basins, groundwater is more important than in others, and some of it is renewable and some of it is not.

In Lebanon, 65 per cent of the country is composed of a karstic soil, which favours fast water infiltration. However, only part of this water is stored, some of it reappears as surface water (springs), the rest flows underground to the sea or to neighbouring countries.

Groundwater regulations

In all three countries water is part of the public domain (Syria and Lebanon) or State owned (Jordan). Therefore, the pumping and use of groundwater is regulated through a law or a by-law. Well drilling is subject to a permit, which also specifies the volume of water that can be extracted and its use. In Jordan, the Ministry of Water and Irrigation has also developed a groundwater management policy, which sets out the Government's policy and intentions concerning groundwater management aiming at the development of the resource, its protection, management and measures needed to bring the annual abstractions from the various renewable aquifers to a sustainable rate for each.

Groundwater use

As in most other countries in the Middle East, agriculture is the largest consumer of water. Between 75 and 80 per cent of the water resources in Jordan, Lebanon and Syria are used for irrigation and rely heavily on groundwater.

In Syria, 60 per cent of all irrigated areas are currently irrigated by groundwater, through wells privately owned and developed. In spite of the by-law regulating the use of groundwater in agriculture and subjecting well-drilling to a permit, almost 50 per cent of the total number of wells in the country are illegal, leading to severe overdraft and pollution problems. Extraction often exceeds recharge, therefore water level declines are occurring in several basins, having major impacts on surface sources, such as spring flows. In the coastal area, groundwater is suffering from sea-water intrusion owing to the overdraft. Mining of non-renewable resources is particularly evident in some of the basins.

In Jordan, the situation is very similar. Privately managed farms in the highlands are irrigated by groundwater from private wells. Highlands irrigation expanded from 3,000 ha in 1976 to an estimated 33,000 ha today and accounts for about 60 per cent of groundwater use. Another 5,000 ha is irrigated by non-renewable groundwater in the Disi area. Groundwater extraction exceeds the safe yield, leading to significant water level decline and salinity increase, drying up of springs and reduced water level and water quality. Enforcement of the by-law regulating groundwater control is also poor. Even if they have been drilled with a permit, most of the wells do not respect the allowed quantity of water to be pumped (broken meters) or the pumping depth.

In Lebanon, most of the wells are drilled illegally. Overpumping has led to the same problems mentioned above for Syria and Jordan. In the Beka'a valley, the water table has declined from two meters in 1952 to 160 m today.

B. Case study: The Nubian Sandstone Aquifer System

The Nubian Sandstone Aquifer System (NSAS) occupies a great portion of the arid Eastern Sahara in Northeast Africa (Fig. 1). It is shared among four countries: Chad, Egypt, Libya and Sudan. The NSAS study covers an approximate area of 2.2 million km^2. The groundwater in storage in the Nubian Sandstone Aquifers is huge; it is estimated at 457,000 km^3. The aquifer system is a transboundary, deep, confined aquifer system containing non-renewable groundwater resources.

Over the past three decades, Egypt, Libya and Sudan have made separate attempts to develop the Nubian sandstone aquifers and the overlying arid lands. Since the early seventies, the three countries have expressed their interest in regional cooperation in studying and developing these shared resources. They agreed to form a joint authority to study and develop the Nubian sandstone aquifer systems and also agreed to seek international technical assistance to establish a regional project in order to develop a regional strategy for the utilization of the Nubian sandstone aquifer system.

In order to assure the sustainable development and continued regional cooperation for the proper management of the Nubian sandstone aquifer, it was deemed imperative to share the information, monitor the aquifer regionally, and exchange updated information on the behaviour of that shared resource. Therefore, the national coordinators of the four countries signed two agreements in October 2000 that were endorsed later on by the joint authority in January 2001.

Figure 1
Hydrogeological Cycle

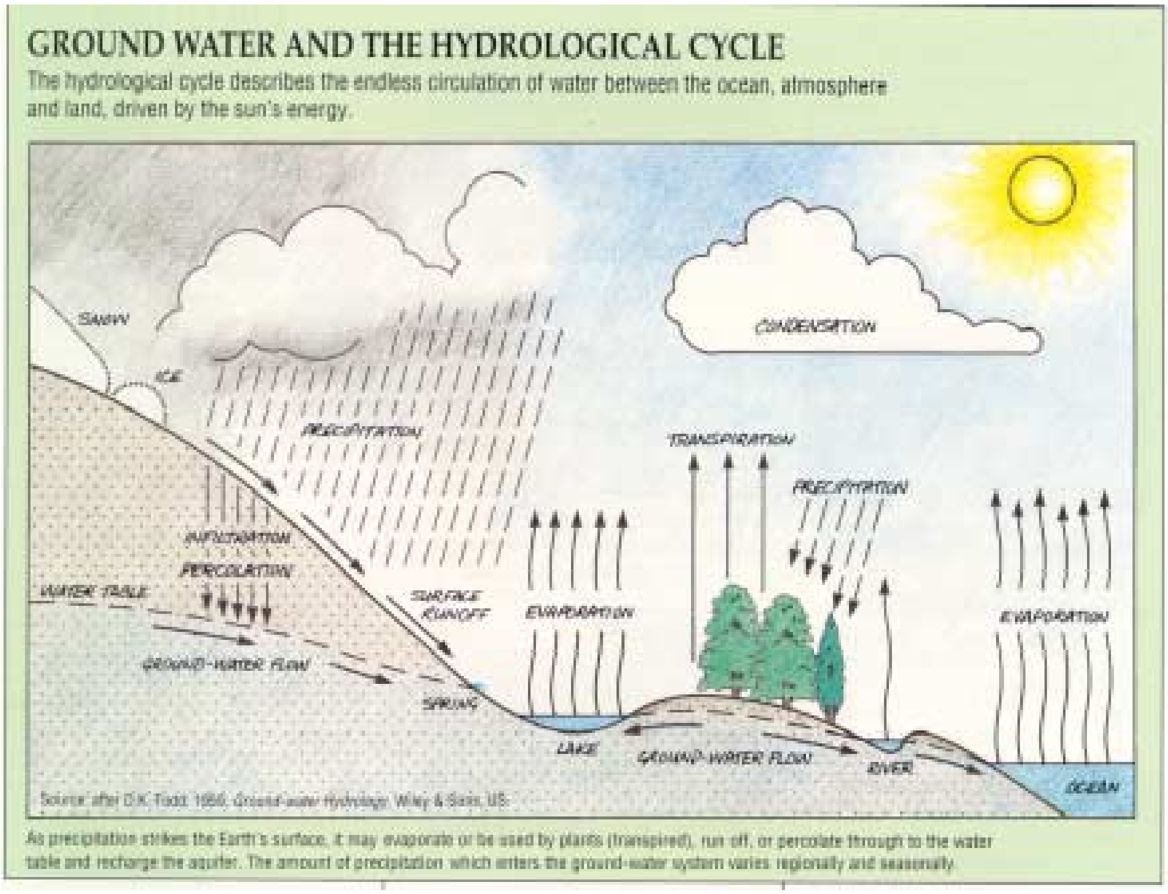

Figure 2
Transboundary Flow (ISARM Framework Document, 2001)

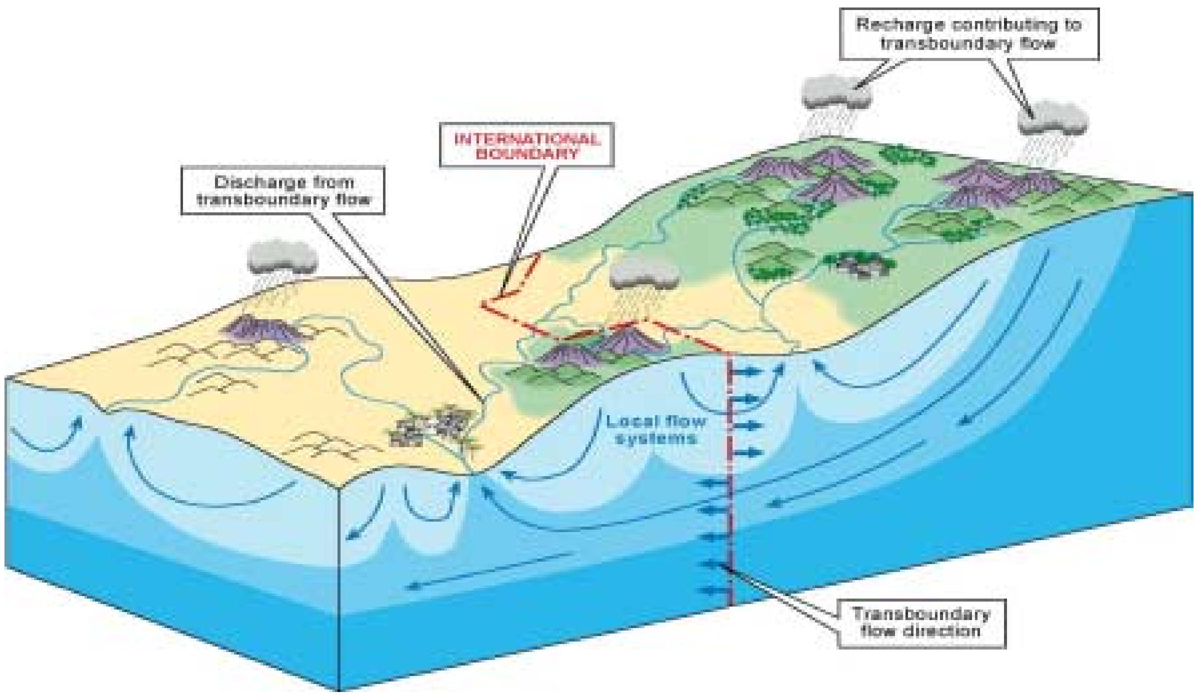

Figure 3
Groundwater Pollution (Groundwater Pollution, A Zaporozec, UNESCO, 2000)