GROUNDWATER ROLE IN WORLD WATER RESOURCES: BASICS AND FACTS

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Abstract

Groundwater is the slow part of the back-flow of the continental cycle in the continents and islands, it is associated with a large water volume storage that in many cases makes quantity and quality fluctuations of secondary importance with respect surface water. Groundwater play an important role in the Earth and is essential for many habitats, and at the same time is an important freshwater resource to supply human personal and economical needs. Groundwater is currently well known scientifically and its development is technologically easy and cheap since half century ago. This has been mostly a bottom up 'silent revolution' in hydrology and in water supply that has brought profound changes in many areas of the world, with clear benefits to mankind but also with some serious side effects, mostly due to lack of knowledge and of institutions to adequately and specifically deal with the newly created situations. Groundwater management, and also integrated water resources management, need new and appropriate approaches, which means looking for balance among market forces, institutions and stakeholders' effective participation, in order to deal with problems that are deeply interlinked with land use and that often have to be considered in a 3-D framework.

Palabras clave:

Agua subterránea; gestión; uso intensivo; ciclo del agua

Resumen:

El agua subterránea constituye la parte lenta del ciclo del agua de retorno en continentes e islas. Se asocia con un gran volumen de agua almacenada, lo que en muchos casos hace que las fluctuaciones de la cantidad y de la calidad de la misma sea de importancia secundaria en comparación con lo que sucede con el agua superficial. El agua subterránea juega un importante papel en la Tierra y es esencial para muchos habitats, y al mismo tiempo es un importante recurso de agua dulce para el abastecimiento humano y de sus actividades económicas. Actualmente el agua subterránea es científicamente bien conocida y su obtención es tecnológicamente fácil y barata desde hace medio siglo. Se ha producido una 'revolución silenciosa' en hidrología y abastecimiento de agua, nacida en gran medida desde las bases, que ha producido profundos cambios en muchas áreas del mundo, con claros beneficios para la humanidad pero también con algunos efectos colaterales serios, en su mayor parte debidos a la falta de conocimiento y de instituciones para afrontar adecuada y específicamente las nuevas situaciones. La gestión del agua subterránea, y también de los recursos de agua de forma integral, necesitan métodos nuevos y apropiados, lo que significa utilizar de forma equlibrada las fuerzas del mercado, las instituciones y la participación efectiva de los usuarios, para afrontar problemas que están profundamente interrelacionados con el uso del territorio y que a menudo han de ser considerados en un contexto tridimensional.

Introduction: groundwater and the water cycle.

Continental and island freshwater resources are only a small fraction of total water in the Planet Earth (Shiklomanov, 1993). It constitutes a major part of the back-flow of the hydrological cycle and is fed by precipitation. Part of this water flows on the land surface (overland flow) or its upper shallow layer (interflow), and collects in channels, forming stream flows. But a large fraction of rainfall penetrates into the subsoil and what remains after subtracting the part which returns to the atmosphere as evaporation and plant transpiration, is the recharge to groundwater bodies. This groundwater bodies discharge mostly into rivers, lakes and wetlands, but a fraction may attain directly the sea coast where the discharge is into the sea.

All this is well known and the subject of numerous books (see Llamas and Custodio, 1976) and also is disseminated through small books for non-specialists (Mainardi and Heij, 1991; Price, 1996; López-Geta et al., 2001). There are numerous quantitative studies of water flow and its physico-chemical, chemical, isotopic and biological composition. It is also well known the interrelation and water exchange between surface water bodies and groundwater. They form together an important back-flow of the continental and island hydrological cycle, which is currently the subject of integrated studies. Often in the past only surface water was considered, even if a large part of this surface water was originally groundwater discharge. Integrated consideration of flow and quality of surface and groundwater is a welcome situation for the scientific and technical consideration of freshwater in the World, and for management of water resources for supplying human needs and for preserving natural values. This is the current orientation of UNESCO's VI Phase of the International Hydrological Programme.

But with this welcome integration there is the danger of neglecting the deep differences existing between the behaviour of surface water and groundwater, and simply assuming that in practice groundwater is just an extension of surface water. This unfortunate situation happens more clearly in applied and management grounds than in scientific ones.

Groundwater is commonly taken as the water under the land surface that fully occupies the voids in the ground; this corresponds to the saturated zone, that is below the water-table. Formations containing this groundwater are groundwater bodies, often called aquifers if they are able to yield economically interesting flows to a well, water gallery, tunnel or drain, and aquitards otherwise. Groundwater is often freshwater, with a wide range of characteristics and solute contents, but also there is brackish and saline groundwater, which sometimes represent a large fraction of the subsoil water reserves. Chemical characteristics are an important aspect that depend on precipitation, soil and water-rock interactions (fig. 1).

Surface water is water above the land surface in streams, lakes and wetlands, part of which may be originally groundwater.

Continental and island water also includes eventual ice and snow cover and water stored in the biological tissues of plants, and the vadose water or water in the unsaturated zone between land surface and the water-table or upper limit of the saturated zone in the ground. Vadose water is often disregarded but it is very important since the part of infiltration that is not evapotranspirated will be the recharge to groundwater after some time, carrying with it not only the solutes due to rainfall deposition and rock weathering but also those contributed by man's activities on the territory, including contaminants in surface water. The interlinks between surface and groundwater explain that when one of the components is modified the other also is changed, both in quantity and quality, but not in a simple way since there are delayed responses due to water storage in the different parts of the systems, and chemical and biological reactions in the water itself and with the solid materials of the ground. Intensity and rate of these interactions are very different in the various parts of the system, and especially when comparing surface water with groundwater.

Groundwater is hidden to direct observation with the human senses but its existence, movement and quality can be easily noticed, measured, studied, quantified and monitored in groundwater outflows, and the effect groundwater produces can be seen through the physical effects on the ground, such as on electrical conductivity, sound speed and hydrogen nuclear magnetic resonance, and by penetration into the ground with boreholes, drains and mines (galleries and tunnels). Groundwater flow and chemical characteristics can be scientifically described and quantified by means of physical, chemical, nuclear and biological laws and principles, taking into account the lay-out and properties of geological formations and rock characteristics. They can be quantitatively measured by means of experiments, geophysical and hydraulic logging, sampling, and monitoring networks, and the use of numerical models to simulate flow and mass transport.

Groundwater show up on land as water (springs and seeps, river base flow, riparian and coastal discharges, and groundwater-fed lakes, lagoons and wetlands), as vegetation (phreatophyte areas, riparian vegetation belts and seepage patches, and also artificially as irrigated areas with wells and galleries), as land surface changes (subsidence, collapses, some types of landslides) and land deposits (tuffa and travertine, fumarolic deposits).

Groundwater recharge is dominantly an extensive phenomenon affecting a large part of the land surface. Land use changes due to human activity may impact recharge, both increasing or decreasing it, and both improving or deteriorating recharge water quality. A main cause of impact is pollution in rural, urban and industrial areas, and recharge is affected by changes in agriculture, forest cover, erosion, human occupation, climate, surface water use and river channel. The consequences may be storage depletion, dewatering and groundwater level drawdown) or increase (inundation, water logging), or a modificación of fluctuations which affect seasonality.

<u>Role of groundwater</u>

Groundwater is an essential component of geological and biological processes in the Earth, as it is in the continental and island water cycle (Llamas, 1988). Many of the rock-forming processes and geodynamical changes are due to the effect of groundwater which is able to transport large quanties of solutes, dissolve and form minerals, change the rock geothechnical properties and influence volcanism. But must of there processes have developed along million of years and its changes have little effect at human life scale, except for those which refer to land stability and the mobilization of some solutes. They may be modified by groundwater regime changes produced by man's activities.

Also groundwater is essential to many habitats and landscapes (Llamas, 1993; Custodio, 2000), such as those related to phreatophytes and other biological communities which need an easy and permanent supply of water, generally with some stable thermal and chemical characteristics, as happens in groundwater sustained lakes, lagoons, wetlands, riparian areas (groundwater discharge strips) and shallow water table areas (cryptowetlands). Some playa lakes and the associated salt deposits also depend on groundwater contribution. In sea coastal areas the discharge of freshwater and the mixture of fresh and marine water may sustain important habitats both in the land and in off-shore sites.

Groundwater discharge sustain springs and river base flows and thus is an essential contribution to surface water, and for the freshwater resources for human activities that depend on them. This is a traditional use of groundwater after it is discharged into the land surface. But groundwater can be abstracted directly from the aquifers for human use, by means of excavations, wells, boreholes, galleries an drains. Man has used these systems since the earlier times, especially in arid and semiarid times; numerous references can be found in old books, including the Bible, and some of the water works still subsist. The generalized use of groundwater was hindered by difficulties for drilling and for extracting water from the depth, or with the limitation of using gravity-drained groundwater due to the elevation of a far gallery (khanat, foggara), or tapping a confined flowing aquifer. This situation changed dramatically from the mid 19th century, and especially since the mid 20th century. The two main keys for the change have been the drilling rig and the sumergible turbine water pump, jointly with the easy access to energy (oil engines, electric networks). This has been a major revolution which has put at hand reach an almost untapped, extensive, relatively cheap and secure freshwater resource. This has been called a 'silent revolution' (Llamas and Martínez Santos, 2004) since it has been produced mostly by plain people and not by large state organizations; largely private savings have been used, and water development is often outside the costly and complex surface water projects, which need long time to be completed and are prone to failures, miscalculations and sometimes mismanagement of funds when institutions fail.

Currently, starting the 21st century, the availabily and use of freshwater resources has been deeply changed with respect what are considered classical projects and management forms, due to the widespread and often intensive use of groundwater, and the failure of the old rules of control.

Disregarding this new situation may lead to problems and the misuse of an otherwise beneficial and essential freshwater resource. New managerial capabilities and powers are needed, which cannot be an extension of existing ones since the characteristics of groundwater are fully different from that was dominant in the past (surface water). It is clear that groundwater is not a fully new freshwater resource at regional scale, although total available resources may change up to some extent. Its development will have an effect on surface water resources, which is desirable or indesirable in a regional context, but that currently cannot be ignored or disregarded.

Currently groundwater is a key social assest for human supply, health improvement and poverty alleviation (Llamas and Martínez-Cortina, 2002), which needs renewed and intensified attention, new technology and especially-designed managerial capabilities and actions. All this should be in a framework suited to the specific characteristics of groundwater and its relationships with surface water, with the restrictions derived from the integrated consideration of freshwater resources (Llamas, 1999; Sahuquillo, 1991).

Pros and cons of groundwater use

The pros (advantages or positive aspects) and cons (disadvantages or negative aspects) of groundwater use has been discussed in many papers (Llamas et al. 2001; Custodio, 2002; Llamas and Custodio, 2003). They derive from the characteristics of groundwater respect surface water, which are summarised in table 1.

Table 1.- Main differential characteristics of surface water and groundwater in aquifers

Characteristic	Surface (S)	Groundwater (G)	Factor
Flow velocity	fast (cm s^{-1} to m s^{-1})	very slow (<mm d^{-1} to m d^{-1})	10^4-10^5 (S/G)
Water storage	small (mm)	very large (m to tens of m)	10^3-10^5 (G/S)
Mass transport	low/moderate	moderate/high	
Dimensionality	1-D	3-D	
Heterogeneity	small	large	
Turnover time	short (days to weeks)	very long (years to millenniums)	10^3 to 10^5 (G/S)

Groundwater usefulness as a freshwater resource, directly or after treatment (including desalinization) depend on quantity (enough), quality (good), variability and seasonality (small), cost (low), location and accessibility (easy) and readiness for use (technically and administratively easy). Negative consequences of groundwater use, as commented below, should be small, bearable and susceptible of correction, and the results have to be legally attainable.

The pros can be summarized as:

a) Large water storage in the aquifers means small variability of discharge rate and composition, and of groundwater quality and temperature. This is important for supply and use. The water storage allows to meet peaks of demand, solve droughts and deal with emergency situations.
b) Sluggish flow through small voids means enough time for the progress of chemical and biochemical reactions, for the decay of pathogens, virus and short and medium lived radioisotopes, and for damping temperature fluctuations. This is important for water quality preservation and stability, for correcting contamination incidents, and for obtaining clear water, and it makes possible in many cases the safe direct use of the abstracted water for drinking purposes.
c) Abstraction of groundwater may increase recharge by reducing phreatic evaporation, enhancing surface water infiltration, promoting intra-aquifer leakage and enlarging the capture area (catchment).
d) It is needed a small surface area to shelter the abstraction and storage facilities; with respect other water supply sources these facilities may be fractionated into smaller units which are closer to the water demand point due to the extensive character of groundwater; this means much small investment, few territorial problems and security against hazards, human failures and criminal actions.
e) It is possible a fast preliminary evaluation of water resources; the inherent uncertainty may be progressively reduced as development progresses; for planning it is possible to devise robust future scenarios.

The cons can be summarised as:

a) Groundwater development is associated with local and also regional water level drawdown, which means a progressively increased water abstraction cost until there is some stabilisation for a given exploitation rate; this effects the used well, and also other wells and the groundwater cathment. This may mean new investments in wells, pumps and associated facilities. Development is followed with some delay and may imply spring and river base flow reduction, and wetland area decrease.
b) Groundwater development is also associated with progressive changes of water quality due to the displacement of groundwater bodies boundaries –some of which may be saline or may contain high concentrations of undesirable or noxious components (such as Fe, As, F)-, the infiltration of chemically different or contaminated surface water, the intrusion of marine water, the enhanced recharge of polluted water and the modification of groundwater bodies as relative head is modified by abstraction.
c) Decrease in groundwater pressure in pores and fissures, which may produce land surface subsidence in non-consolidated sediments, or an increase in the land surface collapse rate in karstic areas or around poorly constructed wells, especially when fine material is drag along with abstracted water. The increase in groundwater flow velocity may also foster dissolution of soluble rocks such a as halite, gypsum and anhydrite, or of carbonates if there is an excess of CO_2.
d) Impairment of habitats conditions as a consequence of water flow decrease and water quality deterioration, and of landscape and scenic values.

e) Social stress and rejection of groundwater use due to the perception that something undesirable may be happening or is coming, the direct groundwater abstraction costs increase, the consequences of water quality deterioration (new or additional water treatment, enhanced corrosion), the need for early replacement of facilities, the appearance of externalities, the impact on existing water rights (and the associated increased litigation), the more complex management and the introduction of erratic water policies when knowledge is inadequate or they are adopted under pressure.

The pros can be linked to benefits of groundwater exploitation and the cons to costs. Benefits and costs are both direct (directly related to groundwater development) and indirect or externalities, which are an additional consequence of groundwater development. The difference between benefits and costs is the net benefit (it is a net cost if negative), and there are different values depending on which benefit and costs terms are included, and how subsidies and taxes are included. Conceptually a groundwater development is economically sustainable in itself if there some net benefit, but the result is different for a given development in which only direct costs, subsidies and taxes are included, than for the social value for the whole aquifer system in which externalities have to be added. Some externalities are difficult to quantify and even to identify when the results of groundwater exploitation are delayed. Obtaining a maximum net social benefit is a goal for sustainable use of a resource, especially when part of the storage is to be depleted; to attain this environmental taxation is needed.

Uncertainty and delayed effects

The analysis of aquifer intensive development has to consider two important behaviours: uncertainty and transient evolution.

Uncertainty in the quantification of hydrological variables and parameters is inherent to all natural processes and is shared by surface water hydrology and groundwater hydrology, although with different aspects. Uncertainty is due to measurement errors, indirect observation of groundwater, the stochastic component of rainfall and stream flow –even if this affects much less groundwater than surface water– the unavoidable simplifications of the conceptual model and the possible deviations due to knowledge failures or inadequacies in the model, and modification of aquifer parametres along time due to changes of land and water use, climate, and aquifer development.

Actions and decision-making has to be carried out under uncertainty conditions. The high water storage in aquifers make initial deviations to be bearable and offers the opportunity for the progressive reduction of uncertainty as groundwater development progresses, provided there is an adequate and sufficient monitoring, and studies are being carried out to increase the knowledge by using the increasing information. Otherwise persistent deviations may progressively worsen a situation that was initially considered as good, and this may include some difficult-to-redress consequences such as soil salinization and alkalinisation, sea water intrusion or land surface subsidence.

The large water storage associated to aquifers means that the effect of external stresses develops slowly and softly. This leads to a long transient evolution. Hydraulic changes last a time measurable by $\tau = \alpha L^2 S T^{-1}$ (Custodio, 1993; 2002a; Llamas and Custodio, 2003) in which L is aquifer dimension, T aquifer transmissivity, S the aquifer storage coefficient, and α a coefficient which depends on geometry and the degree of completeness of the process. This means months to many years. Chemical and isotopic changes mean displacement of water fronts at a velocity of $v = kim^{-1}$, in which k is hydraulic conductivity, i is current hydraulic gradient and m is dynamic porosity. This means years to centuries in horizontal directions and weeks to years in the vertical direction. Uncased, long-screened or multi-screened wells produce water mixtures which vary along time.

The long transient behaviour of aquifers after some stress is imposed means that an evolution that may be qualified as negative or undesirable, does not necessarily implies that groundwater abstraction exceeds recharge, but just the evolution towards a new steady situation. This makes that what is often quantified as 'overexploitation' is only a natural evolution in a framework that does not take into account aquifer behaviour, and which uses erroneously initial conditions as comparison levels instead of the final ones (Custodio 1993; 2002a). This may be the cause of losing development opportunities and the associated net benefits, or contrarily a non-sustainable development. In any case the evolution may go unnoticed in the short-term, especially in large, low diffusivity ($T.S^{-1}$) aquifers.

Managerial and social aspects of groundwater intensive development

Evaluating aquifer development has been the subject of numerous studies which have resulted in different concepts. The oldest one is 'safe yield', starting in the 1920's (Meinzer 1920) in the dry Western United States, and applied widely (Bear and Levin, 1967, ASCE, 1961; Todd, 1958; Young, 1970); safe yield refers to the water that can be abstracted without producing undesirable results and reflects the point of view of groundwater developers; it is not defined what is an undesirable effect, and originally many externalities and deterioration of Nature were not included. Recently the poorly defined concept of 'over-exploitation' (Custodio, 2002a, Llamas, 1992; Hernández-Mora et al., 2001; Margat, 1992; Collin and Margat 1993) is being widely used to mainly point out the negative aspects of groundwater development but without expliciting the benefits. This is why it is proposed the use of 'intensive groundwater development', which includes the analysis of the situation but without involving an evaluation of the consecuences (Llamas and Custodio 2002; 2003). Here it is considered that the development of groundwater -or aquifer use- is intensive if as a consequence the natural flow and chemical characteristics are significantly changed.

Currently sustainability is an often used concept that was defined in the so called Bruntland WCDE, 1987) report. It is a global concept that later on has been applied to very different sectorial situations.

Aquifer development sustainability may be a goal, but often it is not since what is the subject of sustainability is Nature values preservation and the guaranteed supply of human needs.This has to be considered in the framework of integrated freshwater resources in the area –a more or less large one, depending on circumstances– and taking into account that water needs, technology, scientific achievements, social perception and socio-economic and political constraints change along time, in such a way that scenarios one decade ahead are only approximate, two decades ahead one only indicative and half a century ahead are fully speculative.

Aquifer exploitation and intensive exploitation may be sustainable or not, depending on circumstances; the same situation may lead to different evaluations depending on how these circumstances change. In this respect, the concept of safe yield may be unsustainable (Sophocleous, 1997; 2000; Bredehoeft, 1997), since some externalities are not considered.

The discussion and development of aquifer overexploitation reality and of aquifer intensive use benefits and problems have been developed in international meetings and the related publications (Candela et al., 1991; Simmers et al., 1993; Llamas and Custodio, 2003; Sahuquillo et al., 2004). The idea of groundwater being one more example of the tragedy of the commons (Aguilera, 1991), although supported by some economists and environmentalists, and which probably reflects the early stages of development, is no real since there are control mechanisms (Custodio, 2003), as above commented. This seems true even for complex situations, such as coastal aquifers, in which loss of value due to mixing with saline water of marine origin is a danger (Custodio and Bruggeman, 1982; Custodio, 2002), but may be controlled if things are correctly done. Coastal aquifers are important infrastructural pieces for groundwater supply.

The value of an aquifer as an economical asset is seldom considered, as it also happens to many natural elements which perform an important role as infrastructures. Their value can be assessed from the actualized cost of the cheapest alternative facility and construction performing the same or very similar role. This is rarely found in reports and environmental impact studies; this does not mean that this is the correct way of reporting and evaluating things, but a serious oblivion. A very preliminary evaluation of the value of the small (80km^2) Llobregat lower valley and delta aquifer role as a water supply source and back-up for emergencies and dry periods may be reckoned at 500 million euros (Custodio et al., 2001), at least.

Groundwater intensive development needs control to preserve the net social benefit and avoiding unsustainable situations. This means limiting and compensating the negative consequences.

To some extent the sole market forces may lead to a sustainable result in the long term, but it is not sure, and some unbearable social stress and damage may be unavoidable (Custodio, 1989). Existing experience in large areas tend to show that there are conflicts (Foster, 1993), but they appear as bearable, although there is still limited knowledge and fully documented cases are scarce. The increasing water costs tend to reduce water abstraction and even groundwater level depth. A slow and smooth water abstraction reduction, which is favoured by the high aquifer groundwater storage, tend to i) increase groundwater use efficiency; ii) wipe out marginal uses; iii) favour the constitution of stakeholders' associations, and iv) improve water management. Opposed to these positive effects, some negative consequences are: a) social stress, from mild to intense; b) the possible reduction or elimination of some socially interesting developments; c) the early decommissioning of existing investments and facilities, and d) some environmental damage, from mild to serious. The introduction of subsidies to try to compensate for some of the damage; although they may be good in the short term, in the medium and long term they introduce a distortion that may enhance negative results without improving the net benefit.

Institutions to manage groundwater development are needed to improve the situation, provided they do not eliminate the favourable effects of some market forces. The role and power of institutions cover a wide range of possibilities, but in any case they must be properly staffed and have to have the capability and ability to carry out the job, at local level but also with a global or at least regional, vision of water resources problems. Their work need adequate and realistic legislation and guidelines, and a clear understanding of the real capacity to address complex territorial issues.

Institutions of a reasonable size and staffing cannot effectively control what happens in the territory; this can be much better done by local people, especially those who have some interest in groundwater. Stakeholders, to be effective in upholding their interests, and to be an element in groundwater management, need to be organised in groundwater users' associations (Aragonés et al., 1996; Hernández-Mora and Llamas, 2001). Their role and power is variable although they should participate and cooperate in groundwater management. But unrestricted user's associations tend to keep what they have already and thus they may introduce too much restrictions to aquifer development and may be reluctant to improvements. This is part of the wicked problems of water management (Freeman, 2000).

In any case it is needed some kind of balance between market forces, institutions and users' associations. This depends on local hydrogeological, social and legal circumstances. Still there is little experience. The objective is sustainability in general, and of freshwater availability in particular. The goal is not necessarily a groundwater abstraction reduction –as is often proposed– but a rational use. In intensively exploited aquifers below and surrounding urban areas the groundwater table recovery after abstraction reduction –or abandoning by diverse causes– may produce undesirable water-logging of some areas, increased drainage needs of fields, uplift of structures by underpressure and water chemical changes due to dissolution of oxidized minerals in previously dewatered zones.

Groundwater management decisions are taken among a set of possible actions or solutions to a situation with boundancies that may be different depending on the point of view and other related circumstances. There is no a unique optimal solution. Often the decision is the result of economical and socio-political trade-offs. These decisions may change –and often should change– along time since the framework under which they have been taken – water needs, scientific knowledge, technology, social context, public perception – evolve progressively.

As has been said before, groundwater problems and solutions cannot be addressed on a local scale, but a the scale of interacting water resources among them and with land use, and the economic and social environment integrated in a region. Decisions and solutions should consider, further to what has been said, the cultural and religious values and constraints, the political circumstances and conditions and the need for formation and information of managers, decision-markers, media and the population. There is an ethic dimension (Llamas, 2001; delli Priscoli and Llamas, 2001; Custodio, 2001) and a wise use of private and public property (John-Paul II, 1991).

Management decisions have not to be limited by results that in the short term or local context may appear as undesirable. A rational aquifer use may include as alternatives some freshwater depletion and groundwater mining (Margat and Saad, 1982; Lloyd, 1997: Custodio, 2003), as may happen in coastal areas and in arid lands, if such circumstances are known, actualized costs are internalized and plans for the future include provisions for new economic activities such as those that with less water or more expensive water but providing at least similar employment opportunities and improved economical output. Development should maximize the social benefit (Howe, 1987; Young, 1993).

Groundwater mining is a concept in which the non-renewability of groundwater reserves is emphasized. This happens when abstraction rate is greater or much greater than recharge, or freshwater reserves are continuously depleted since the aquifer is emptied or existing groundwater is replaced by groundwater of a different quality.

<u>Actions to approach the sustainable, intensive use of groundwater</u>

Actions to be included in a water plan to approach the sustainable intensive use of groundwater include:

a) The progressive improvement of aquifer system behaviour and making the results available to all interested groups
b) Informing interested persons and groups on the role and value of aquifers.
c) Reinforcing institutions, providing trained people and a working structure
d) Drafting and enacting realistic and applicable laws and rules.
e) Involving groundwater stakeholders into groundwater management.
f) Promoting the constitution and participation of groundwater users' associations and sharing management responsibilities with them.
g) Inserting local water problems into a wide framework with an integrated point of view, but that clearly differenciates the very distinct characteristics of the diverse water cycle components
h) Provide and operate an adequate groundwater monitoring network that considers the relevant variables in a 3-D framework of flow and mass transport, making the information obtained available to all interest parties and in an understandable form
i) Having a representative and democratic water forum or assembly for free discussion, setting up new ideas and solving conflicts.
j) Introducing taxation to correct externalities, to pay the management costs, to improve groundwater use in the integrated framework, to try to maximize social net benefits and to foster water related activities oriented to preserve the territory and the landscape.

k) Progressively reducing and cancelling subsidies that disturb the efficient use of water resources and foster inadequate water uses.
l) Producing realistic probable future scenarios of groundwater development, groundwater use and social conditions in order to back water planning.

European legal tools for groundwater management

The European Union, making use of the provisions of the Treaty supporting it, has produced Directives on water, and also on groundwater, to assure a coordinate compensated and compatible economical development of the member States, which include environment protection as a common goal. Following the subsidiarity principle (Areilza, 1996) the legislation and rules to develop the principles and provisions of the Directives correspond to the State Members, and inside them to the Regions according with the States' legislation (Fig. 2).

The most recent piece of European legislation on water is the Water Framework Directive (WFD) (2000/60EC, ECOJ 22 Dec 2000) which deals with surface water, groundwater, coastal water and water related ecosystems and wetlands. It contains goals, definitions, obligations of member States, studies to be carried out, measures to be undertaken, deadlines and annexes with details.

It considers previous directives dealing partially or totally with groundwater:
- 91/676/EC, on nitrates (it remains in force)
- 95/57/EC, on pesticides
- 981/83/EC, on drinking water
- 80/68/EC, on groundwater protection from pollution (to be repealed after 13 years).

The WFD stresses the integrated use of water resources, their strategic values, the good chemical quality objectives and the environmental protection. The application to groundwater in Spain has been the subject of a recent meeting (IAH-GE, 2003).

The groundwater goals of the WFD can be sumarized as follows:
- Progressive reduction of groundwater contamination
- Halting new contamination and reversing deterioration trends.
- Defining protected areas, mainly for water for human consumption
- Knowing the quantitive and qualitative status of groundwater through:
  * attaining the abstraction –recharge equilibrium.
  * monitoring
  * compliance with norms for protected areas.
- Preserving and obtaining good status of groundwater
- Avoiding and limiting the introduction of contaminants
- Adopting specific measures regarding hazardous components.

The application to groundwater involve new concepts and a deep effort to inventory a complex and variable situation. I order to better define the framework a (Doughter) Ground water Directive is being drafted, to be enacted by the end of year 2003.

Conclusions

Groundwater play an important role in natural processes and in Nature, and is also a very valuable source for freshwater to supply human needs, from drinkings proposes to economic activities. Their enormous potential can be currently realized due to dramatic technological improvements in drilling and pumping elements, and sound scientific advances. This has produced a 'silent revolution' which started half a century ago and currently is changing the way of poverty alleviation. But this is poorly known, reluctantly accepted by decision–makers and water managers, incomprehensibly neglected by many engineers and does not attract the attention of media but for highlight, exaggerate and misjudge the side effects of these new developments. Groundwater development, even if intensive – with significant changes in groundwater flow and mass transport processes – produces benefits to Society but there are also some inherent drawbacks and mismanagement and abusive situations. This is partly due to the poor and often negative attitude of some managers, social forces and mass media, but also to the lack of enough experience and the insufficient diffusion of existing knowledge. All this is resoluble if there is the will. Solutions are a combination of free market forces, adequate institutions and stakeholders' participation, in a framework that considers local attitudes and social and religious orientations.

Makind cannot neglect groundwater potential as a freshwater resource and economic asset in a globalized world with scarce freshwater resources and poverty, and decission-marking cannot turn the blind eye on groundwater development since most of it is produced bottom up, in an almost unstopable form; mismanagement only means increased problems and a loss and waste of social and economic benefits.

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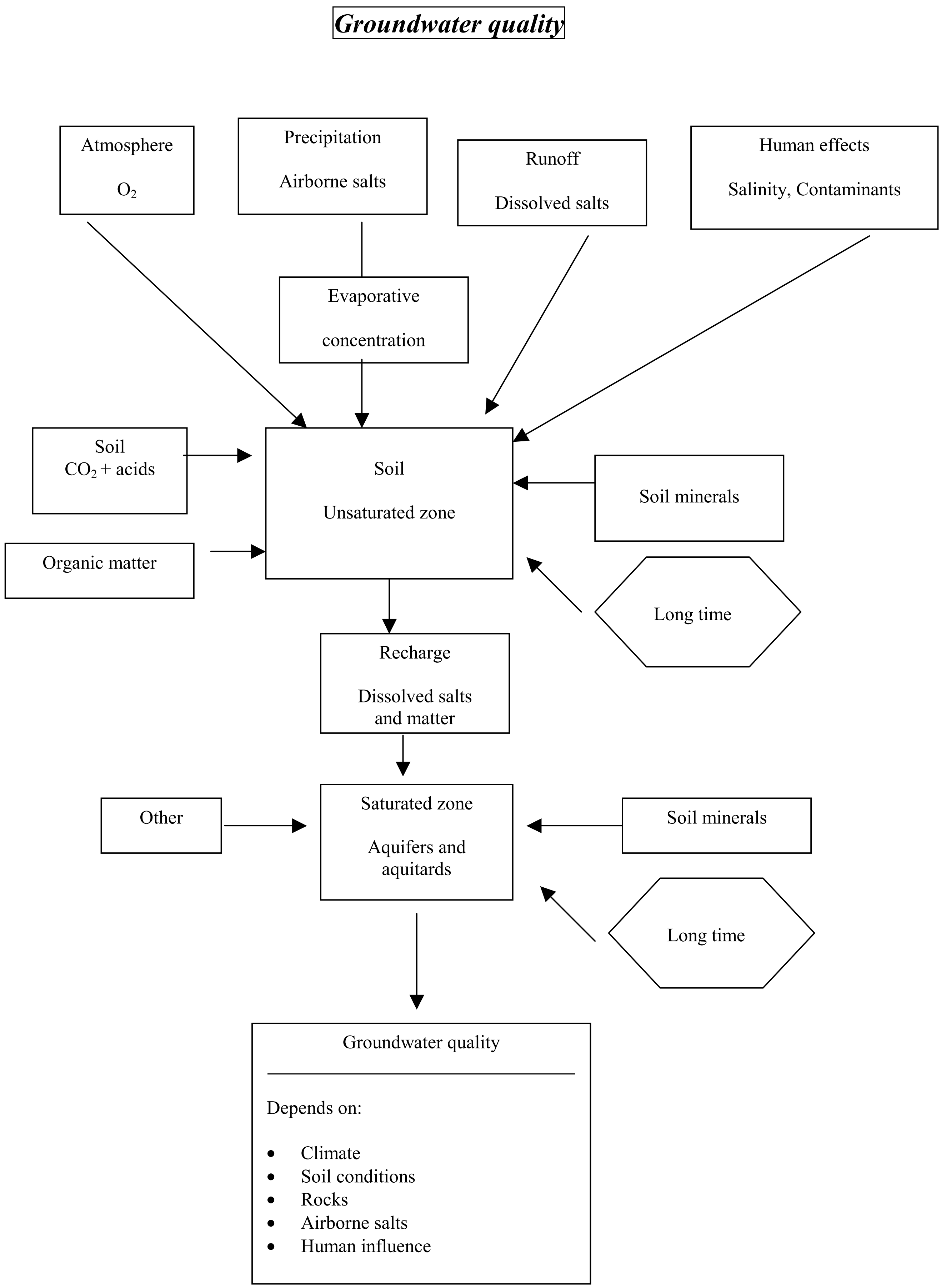

Fig 1.- Schematic chart indicating how groundwater gets its chemical composition.

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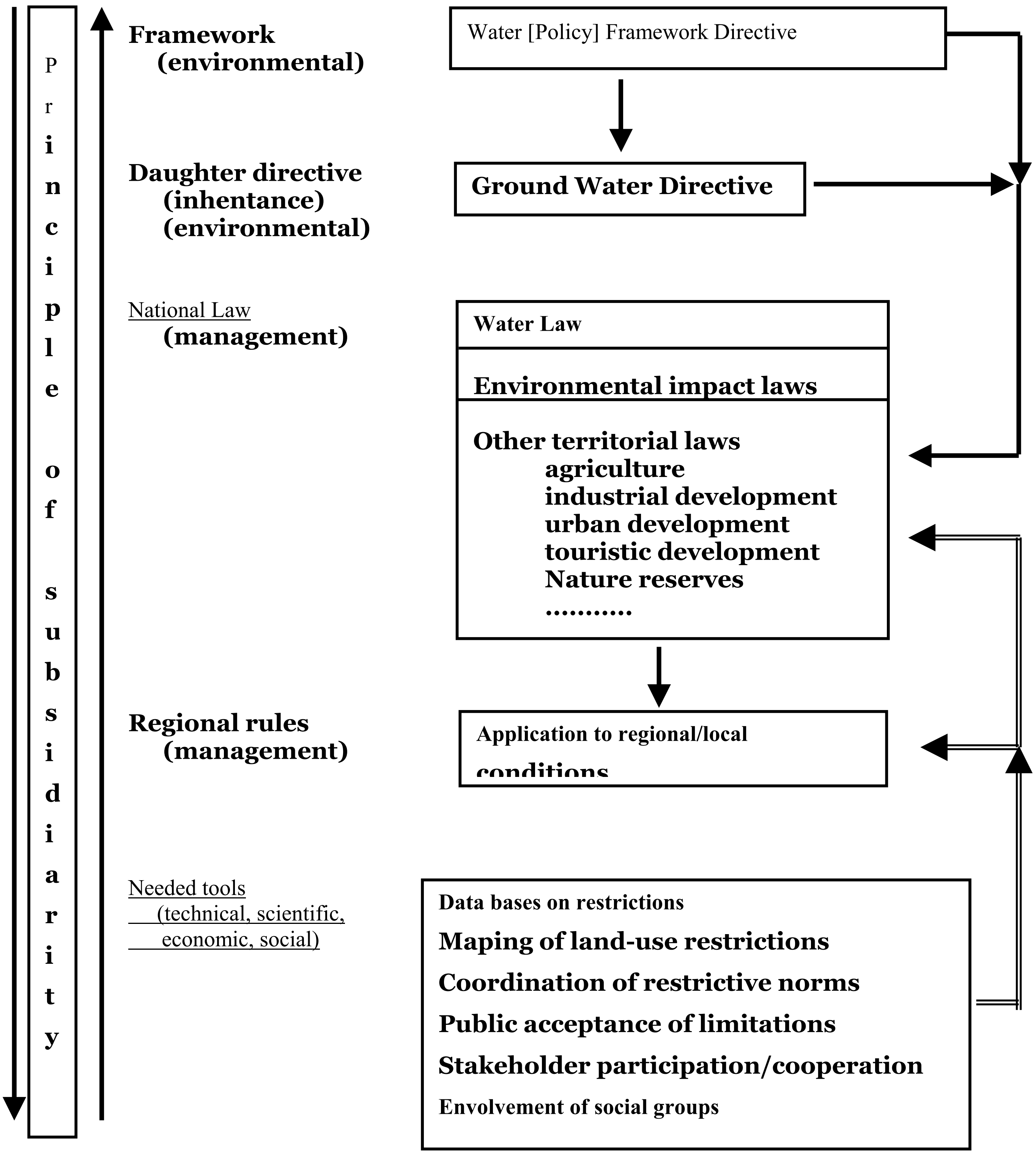

Fig 2.- Groundwater and the European Union Directives on water.