GROUNDWATER USE AS POTABLE WATER SUPPLY

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Summary

This article begins by recalling that ancient civilizations bloomed not only where water was abundant, but also in barren areas where huge engineering works were built to withdraw groundwater. This is followed by consideration of the human need for water for drinking and domestic use. Today, while water consumption in the developed countries is enormous, in other countries available water is minimal and is used almost entirely for drinking. Drinkable water is a valuable good requiring protection, and the concepts underlying its management and conservation are outlined. The geological, hydrogeological, engineering, sanitary, managerial, and economic properties of supply water are considered, all of them being fundamental to wise management of groundwater resources. Opportunities for real-time control of water volumes are considered, along with the scale and quality of the resources available now and in the future, and the issues involved in dealing with variations in demand.

The article then considers the various characteristics of drinking water, along with the situations in which pollution occurs. The significance of conditions in recharge areas to pollution processes is considered, along with that of the dimensions and depth of aquifers, and the hydrogeological situations near springs or wells. The processes governing diffusion, dispersion, and transport of pollutants in aquifers, and pollutants' abilities to dissolve, spread, and settle over space and time, are explained. The concept

of aquifer vulnerability, particularly regarding the locations of groundwater withdrawal, is analyzed. Some procedures for predicting pollution risks at groundwater withdrawal works are described. Informed and efficient monitoring of aquifers is essential, using mathematical models to help predict the behavior of particular pollutants and thus avoid major problems.

A final section considers the advantages, characteristics, and limits of different withdrawal methods. These fall into two categories: those withdrawing water from springs, and those using wells or infiltration galleries.

1. Water for Drinkable Use

1.1. Water Supply Withdrawal and Conveyance over the Centuries

Water is indispensable for human life, not only for drinking but also for producing food. Water is necessary for the vegetation cycle. Vegetation is the base of the trophic chain: it feeds herbivorous animals that feed carnivores, both in turn finally nourishing humans. The water that is directly used by humans must have specific physical, chemical, and biological characteristics. The amount of water consumed daily by humans varies, depending on individuals and on the availability of water resources. It ranges from several liters to many hundreds of liters per person per day. The amount increases with populations' living standards, and with the rainfall on the territories where they live. An objective of the World Health Organization (WHO) is to ensure that every inhabitant of the planet has access to at least 20 liters of water daily.

Most of the great ancient civilizations developed along great rivers. In the second millennium BC the Babylonian, Sumerian, Hittite, and Assyrian civilizations along the Rivers Tigris and Euphrates constructed imposing works in order to exploit both superficial and subsurface waters. The same is true of Ancient Egypt: Herodotus wrote that "Egypt was the gift of the Nile." At the same time, the first attempts at using "hidden waters" in geological formations took place in the mountainous and barren areas of the Middle East. The Chaldeans' techniques of digging for groundwater, and for withdrawing and conveying it, were particularly advanced and were handed on through successive millennia. Groundwater was always considered precious because it was not exhausted in summer months, when surface waters disappeared.

The search for groundwater soon became a science in countries with warm, barren climates. There is much historical and archaeological evidence for this: from the aqueduct to the swimming pool at Siloe built by King Ezechia in the seventh century BC, to the manuscripts by Polybius (second century BC), to the records of the school of Yazd where the best Iranian hydraulic engineers were educated. Yazd was also served by an aqueduct that carried water from infiltration galleries dug in the mountains. These galleries were widespread throughout the Persian region: known as *kanats*, they are still identifiable today. Starting from the foot of a permeable relief feature, a gallery penetrated an aquifer for kilometers, draining groundwaters. An alignment of vertical wells was sunk along the gallery to facilitate the excavation of galleries between successive wells. Some of these channels remained active for very long periods, and the same technique was used in other regions lacking surface waters. In Saharan Africa

(Libya and Algeria) it was used from the Middle Ages until the Arabic expansion of the sixteenth century, and even until the early twentieth century at the edges of the buttresses of the Hoggar. These channels are locally known as *foggara*, and in the Tonat region alone they have a total length of 1500 km. It is thought that more than 4000 km of *foggara* exist across the Saharan region, many of them still in use.

In many cases these galleries also advanced into plain areas in order to transport water without evaporation losses. In desert areas the scarcity of water is such that there is a need to utilize not only the aquifers within permeable mountain rocks but also the subsurface waters present in the ground capillary zone, and the nocturnal condensation of atmospheric humidity. By simply digging a hole between the dunes of the Sahara it is possible, by the following morning, to find a veil of water on the bottom sufficient to quench the thirst of one person.

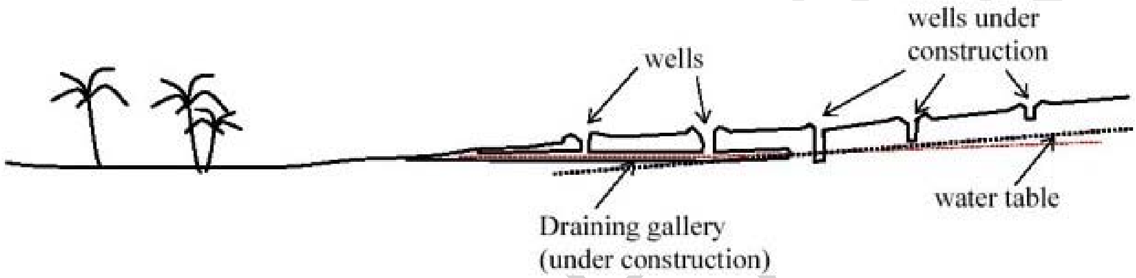

Figure 1. A *kanat* under construction

In Europe the Roman era saw widespread construction of aqueducts to carry water from mountain springs to cities located in plain areas. Long arched viaducts carried very gently-sloping channels that conveyed water great distances over hills and valleys. The same technique was used in Arab-dominated areas in the Middle Ages until the nineteenth century. Since then, pressurized pipes have been used increasingly for water supply.

1.2. Quality Requirements for Drinking Water

The amount of water necessary for human survival varies with climatic conditions but is in the order of several liters each day, when considering both drinking water and that consumed within solid foods. Greater amounts are used for other essential human functions, like personal hygiene or various domestic uses. Some uses, such as for watering gardens and powering decorative fountains, are non-essential but also contribute significantly to people's quality of life. Social and economic development tends to reduce the difference between drinking water and that for domestic and other utility applications. In situations where a community's livelihood depends on an activity that requires great amounts of water, this second type of water may become even more precious than drinking water. *Per capita* water consumption tends to increase over time with improvements in living standards. In order to not waste natural water resources it is wise to reserve water of better quality for drinking and use inferior water for other uses. Water distribution can be implemented using dual networks, separating drinking water from that for other domestic uses and reusing water after wastewater treatment.

Water requirements for drinkable and domestic use increase also with the size of an inhabited center: they may vary between 20 L p^{-1} s^{-1} (liters per person per day) for small cities, to 500 or more than 1000 L p^{-1} s^{-1} for large ones. Water consumption in cities varies with the seasons, during the week, and also during each day. The number of residents of a city can vary, due to fluctuating population. This is particularly evident in tourist areas, or in cities where there are many commuting workers. In these cases water requirements for human use can sometimes rise to double or triple the average level. The increase of population worldwide and progressive increases in living standards are leading to steadily rising demands for water. Many international and national laws and directives have established the importance of ensuring potable water supplies as a priority over those for other uses. These laws have also defined water quality standards, the principles of protecting natural water systems, and the need for sustainable exploitation of the natural resource. Criteria for different uses that are observed widely include:

- use of top-quality water for only drinking, and use of inferior water for other domestic and utility needs;
- reduction of water consumption by applying appropriate technologies and discouraging wasteful human use; and
- use, where possible, of recycled wastewater that has been subjected to appropriate physical, chemical, and biological treatments.

In this sense, groundwater appears highly suitable for drinking, being of high quality by comparison with surface waters. Its quality is also less variable over time, and it is less vulnerable to pollution.

1.3. Planning and Management of Groundwater Allocated for Human Use

Groundwater used for domestic and civic purposes must be controlled, managed, and protected, from the aquifer to the consumer. These operations are carried out in successive phases that address:

- geological, hydrogeological, and hydro-geochemical aspects;
- engineering and sanitary aspects of withdrawal works, conveyance, storage in tanks, purification and distribution networks, and the collection, purification, and recycling/drainage of wastewater;
- economic and managerial aspects of withdrawal services, distribution, and treatment.

Correct planning of a groundwater supply system must account for all these aspects, identifying constructional and managerial solutions that are most suitable for the prevailing social, economic, and environmental conditions.

A system for potable water supply is made up of facilities intended to serve for a period of some decades; by their nature, they are seldom adaptable to uses and circumstances other than those foreseen by the original design. From the standpoint of the social, economic, and cultural dynamics of the new millennium, it is increasingly obvious that “real-time” management of water-supply systems must be preferred over the planning methods of the twentieth century. With a real-time outlook, plans and actions are adapted, step-by-step where necessary, to attain long-term strategic objectives—which include ensuring that a viable water supply remains to meet the needs of the next generation. This involves conserving less-renewable water resource elements and protecting them from possible pollution processes.

The basis of a managerial system of this type is familiarity with all the geochemical, hydrogeological, social, economic, and technological parameters of the system. Monitoring networks must therefore be interconnected with databases at a management center. These data must be manageable with the help of geographical information systems (GIS).

Many mathematical models may be used for simulating, predicting, and managing the behavior of water supply systems. They include deterministic, stochastic, and probabilistic models, the generation of synthetic series, and the use of uncertainty theory, neural networks, and cellular automata. A broad-based comparative analysis leading to the choice of optimal solutions follows to the procedures of scenarios generation in different evolutionary ambient. This is based on social, economic, and environmental cost–benefit analyses, which call for monetarization of the various social and environmental parameters and benefits. In making choices between alternative solutions it is recommended that suitable decision support systems (DSS), using ordering criteria for the alternatives that best reflect the various issues arising from management of groundwater resources, are used.

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Bibliography

Food and Agriculture Organisation (FAO) (1990). *New Approach to Energy Planning for Sustainable Rural Development*. FAO Environmental Energy Papers 12. Rome.

Food and Agriculture Organisation (FAO) (1995). *Methodology for Water Policy Review and Reform*. Water Reports n.6, Rome.

Maidment D.R. ed. (1992). *Handbook of Hydrology*. McGraw-Hill.

Mays. L.W. ed. (1996). *Water Resources Handbook*. McGraw-Hill.

Maksimovic C., Calomino F. and Snoxsell J. eds. (1996). *Water Supply Systems: New Technologies*. NATO-ASI series. Berlin, Springler.

Biographical Sketches

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Stefano Pagliara was born in 1962 in Pontedera (Italy); after graduation in civil engineering at the University of Pisa, he obtained a Ph.D. at the S. Anna School for University Studies and Doctoral Research in 1994. He has been Fullbright Awardee (United States Government) in 1996/1997 and was STA (Science and Technology Awardee: Japanese Government) in 1997, and has conducted post-doctoral research in the United States and Japan. He has been in charge of management and control of major rivers for the Regione Toscana, Italy. He is active in hydraulic construction work, and has experience in the hydraulic processes of inundation. He has published more than 80 scientific articles, mainly on experimental hydraulic applications, hydraulic construction works, and hydrology. He is currently Professor of Hydraulic Construction at the University of Pisa.