WATER RESOURCES QUALITY AND SUPPLY

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Keywords: irrigation, water resources, water quality, water supply, surface water, groundwater, desalination, irrigation technology, water redistribution, irrigation sewage, water abstraction hydrodevices

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Summary

This article looks at the state of the art in irrigation and considers the quantity and quality of the water required by agriculture as determined by soil characteristics and external factors such as fertilizers, pesticides, and municipal and industrial wastewater. The volume of water available from surface and groundwater sources may be increased by desalinization of brackish and sea water, and treated recycled water. Mineral salts, sodium, toxic elements, and temperature affect the quality of the water used for crops. Water taken from agricultural, municipal and industrial areas, ranches, or springs will have greater or lesser concentrations of material affecting quality and usability. This article examines the forms in which runoff from irrigated areas can affect the environment, as well as means that can effectively reduce these effects. Grower training and good farming practices are more important than treatment. An overview is given of the infrastructure needed to use water efficiently in agriculture, the importance of planning and legislating water use in the entire watershed, and of the environmental impact of irrigated areas and the corresponding infrastructure.

1. Surface (Rivers, Lakes, Reservoirs) and Subsurface Water for Irrigation

Agriculture is the single largest consumer of water in almost all countries, demanding more than 80% of the volume produced. Since 1950, the area receiving irrigation has tripled to approximately 2.75 million km^2. Nearly half of all the world's food is produced on the 18% of irrigated cropland. However, it is calculated that in the year 2030, world population will be 8 100 million and therefore it will be necessary to increase food production. This can be accomplished in three ways: by increasing the productivity of plots, the agricultural area, or the number of crops each year.

An FAO study estimates that by the year 2030, water consumption will increase by only 12%, from 1840 km^3 currently used to 2060 km^3 for that year. This is because it is predicted that irrigation efficiency will improve. In the rush to increase and extend the land receiving irrigation, little attention has been paid to the environmental impact of these changes and to the efficiency with which these systems operate. Optimizing current irrigation systems may provide more rewards than adding new areas with low efficiencies.

Water loss from the channels connecting dams and wells to plots is high. Worldwide, irrigation system efficiency averages 37%. Water lost on the plot does not contribute to production and the salts, fertilizers, pesticides, and toxic elements it picks up lowers its quality. As such, the problem is not simply a shortage of hydraulic resources, but in many cases poor management.

During the twentieth-century, some arid and semi-arid countries have used wastewater, treated and untreated, to irrigate crops. The water used in agriculture should be of at least a minimum quality, which should be provided through treatment, to ensure the health of workers and consumers.

In 1980, the volume of wastewater generated worldwide reached 1 870 km^3 and at the end of the twentieth century it was 2 300 km^3. Household wastewater carries organic matter and nutrients causing eutrophication of water bodies and their excessive growth with algae, microorganisms, plankton, and bentonic life. This exuberant growth depletes the oxygen in the water which is essential to fish and other life.

In most countries, there are simply not enough domestic wastewater treatment systems. Where they do exist, the resulting sludge, which requires specialized treatment, is often taken to surface refuse areas from which it slowly returns by way of the sewerage systems.

The pollutants in industrial wastewater vary widely in their characteristics, depending on the nature of the processes. Some 5 million chemical compounds have been identified and 45 000 more are registered each year. Unfortunately many of these substances reach water bodies untreated, polluting the water and affecting users downstream. Some pollutants affect public health, producing long-term toxic effects through exposure to low doses. To cite just a few, cadmium, lead, arsenic, and selenium are often found at unacceptably high levels downstream of large metalworking plants. Phenols (used in the manufacture of pharmaceuticals, dyes, explosives, herbicides, insecticides, and disinfectants), and substances used in the processing of textiles and leather goods appear frequently in the list of compounds observed in monitoring programs for lakes and rivers.

Non-point pollution, seen in surface runoff from cities and farms or related to filtration to aquifers located under irrigated farmlands, poses problems more difficult to solve than those related to point source pollution. Non-point pollution is much harder to monitor and control because it often arises from large areas and occurs after storms. Agriculture plays an important role in this case because poor water and soil management practices result in salt accumulation and soil erosion. In addition, fertilizers, herbicides, and insecticides are often used to excess. Poor management of animal wastes adds bacteria, viruses, and organic matter to the surface runoff, to the detriment of urban and agricultural users downstream.

The subsoil is another source of water for irrigation and other uses. However, groundwater is poorly distributed. Aquifers have been depleted by extracting more than can be replaced through recharge, and polluted through recharge with poor-quality water carried down from the surface where agricultural, urban and industrial centers are located. When the aquifer is near the coastline, salt intrusion may result from overexploitation.

Technology will surely play an important role in the solution of agricultural problems: for example the use of optimization techniques, new methods to apply the correct amount of water to crops, and new varieties of plants that can use groundwater with high salt concentrations. Economical and precise devices provide data for soil and weather studies, make it possible to assign adequate volumes of water, aid in weather predictions to anticipate the effects of flooding and droughts, and give planners time to program preventative measures, when possible. The measurement of the volumes of water delivered to growers is a challenge that researchers and developers of equipment have accepted. The data from these devices helps improve the efficiency of catchment, conveyance, and distribution systems by detecting losses through filtration and working with automated channel control systems. New application systems, such as surge, deficit, and reuse methods, make better use of the water that reaches farms. The information available from satellite images assists in efficient water use, and there is new technology for urban and periurban agriculture. However, biotechnology will lead to deep analysis arising from its technical, economical, social and ethical implications. (See *Technology for Irrigation*.)

2. Regulation and Territorial Redistribution of River Flow

Poor water distribution has caused serious problems. An excess of humidity in the tropics limits agricultural activity, and floods threaten crops. The main challenge is to create technology to drain the plots. Water scarcity in arid and semi-arid regions emphasizes optimum use of the resource through efficient irrigation technology (see *Technology for Irrigation*), laws and regulations, grower training, and in many countries, the reuse of municipal or agricultural wastewater. High-yield crops may receive water that has been desalinated from the ocean (see *Desalination of Water*, and *Sewage*) or aquifers with high salt levels.

The problem is magnified when other users compete with growers for water. Cities, industries, fish farms, and electricity generating plants demand large volumes of water. Regulation of use and redistribution is important in creating a balance among these demands.

The watershed is the natural place to plan for efficient water use and to evaluate the results. Cities, industries, hydroelectric plants, irrigation districts, and fish farms must survive side by side. The water needs of each user are clearly seen, as are the benefits that each can receive through fair and equal distribution. Although some measures might bring about small water savings for some users, the savings might be large for others, and even prevent or reduce the risk of pollution or over-exploitation of the resource. Efficient use in the watershed is complex given the number of objectives and the numerous solutions. To deal with this variety, logical procedures have evolved to rationally eliminate options until only the most viable remain. Each watershed must adopt its own laws, standards, and regulations to redistribute the water using the appropriate infrastructure, which might include diversion and storage dams, aqueducts, pumping systems, distribution and irrigation systems, and other structures that serve to ensure efficient water use. In this context, the environment may be improved or protected through low-pollution systems and wastewater treatment plants. A user that is often forgotten is the environment. The ecological flow to protected areas or reserves must be set apart (see *Dimensions of Sustainable Development*). Problems of this nature do not always have a local solution, but might require the participation of the region, the nation, and of other nations, and perhaps the importation of water from neighboring watersheds.

The FAO estimates that 130 developing countries must provide irrigation to 152 000 km^2, modernize 120 000 km^2, install drainage and water control systems in 70 000 km^2, and carry out small-scale conservation projects in 100 000 km^2. These changes will lead to competition among industrial and municipal users, fish farms, and electricity generating plants. Fair and rational laws and systems for charging for water, and public participation, can provide the basis for adequate distribution among these varied demands.

3. Resources of Groundwater

Approximately 14% of the world's sweet water (60 million km^3) is concentrated in aquifers. Only 7 million km^3 can be extracted, of which 40% is destined for agriculture. When the water passes through the upper soil layers it is subject to a series of forces, the intensity of which determine how it interacts with the soil particles. Some of the water is retained by non-capillary forces (that is, the electrical attraction between the soil particles and the water molecules), and this water is not available to plants because the suction created by the roots is smaller than the electrical attraction. Capillary forces (also known as surface tension) hold another portion of the water in the soil. This water is available to plants because the suction developed by the roots is greater than the strength of the capillary forces. Finally, yet another portion of the water descends, in response to gravity, to the aquifers. Two commonly used terms arise from these observations. "Field capacity" is the maximum amount of capillary water the soil can hold. The "permanent wilting point" is the lower limit of capillary water when plant roots can no longer extract water. When a plant takes water from the soil, it returns the water to the atmosphere in the form of vapor, and this is known as "evapotranspiration." This water, which satisfies the plant's needs, is also called "consumptive use."

Groundwater quality depends on factors such as the geological formations through which it flows and that surround the aquifer, and the quality of the recharge water, which is in turn affected by the source, including rain, irrigated plots, municipalities and industries, or the sea through intrusion (see *Requirements of Irrigation Water*, and *Chemical and Heat Regimes*). Point and non-point pollution has dimmed the potential of groundwater as a source for irrigation. Municipal and industrial discharges are an important source of pollutants. The toxic compounds found in industrial wastewater are readily identified in groundwater. Other sources of pollutants are the leachates from refuse sites, and filtrates that carry nitrogen, phosphorus, salts, heavy metals, and plant nutrients from farms that use agrochemicals at greater than recommended doses (see *Irrigation and Disposal Water, their Purification and Utilization*). The literature contains numerous reports concerning the presence of heavy metals in groundwater. Proximity to the coast represents a risk to aquifers. Salt water might intrude when the volume of groundwater extracted is so large that the normal direction of flow from land to sea is inverted. In this case, the levels of salt, sodium, boron, bicarbonate, and toxic ions should be monitored to ensure that they do not exceed the limits established for proper crop growth.

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Biographical Sketches

Felipe Ignacio Arreguín-Cortés has a Master's and Doctorate in Hydraulics, Postgraduate Studies Division, Engineering Faculty, National Autonomous University of Mexico (UNAM). His professional experience includes: Engineering Institute, UNAM, Postgraduate Studies Division, Engineering Faculty, UNAM, the United Nations Organization and the Mexican Institute of Water Technology.

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