WATER INTERACTIONS WITH ENERGY, ENVIRONMENT, FOOD, AND AGRICULTURE

Maria Concepcion Donoso
Environment and Water Sciences, Montevideo, Uruguay

N. M. Vargas
Graduate Research Assistant, Illinois State University, Normal, Illinois, USA

Keywords: Water interactions, energy, environment, food, agriculture, hydroelectric power, tidal and wave power, waterborne diseases, climate change, El Niño, water quality, water quantity, aquatic ecosystems.

Contents

Summary

Water is essential to human development. It is a substantial element of the natural environment, and intrinsically connected with all its interactive processes. Interesting dynamic relations also exist between water supply and water quality, however. These affect key human development activities, including energy generation and agricultural

food production. Agriculture, as well as being crucial to food production, is also the main water-consuming human activity in most regions of the world.

The aim of this article is to discuss water's importance to energy generation, the environment, food, and agriculture. It begins with an analysis of the interrelations between water and the environment. Consideration is given to the relationship between water and human health. Climate change and variability are also discussed, in relation to the environment and water resources. Water's dynamic role in the food production process is then considered. The chapter concludes with a discussion of the interactive issues related to energy and water. Throughout the article, social, economic, and human development factors are emphasized, as well as water's inherent linkage with food and energy production.

1. Water and the Environment

It is known worldwide that water is an especially important natural element because of its interactions with life-related issues, since it is needed to support life. Energy, food, and the environment in general are inseparably related to its presence and quality. Ironically, water is the first natural resource to be affected by poor practice in the production of either energy or food. Finally, water is an "environment" itself, being the support milieu for many ecosystems. As a resource, it is one of the most fragile and sensitive of all to pollution and contamination.

The study of water is known as hydrology, and may be divided into several distinct subdisciplines. Limnology, for example, is the study of freshwater environments, namely lakes and rivers, while oceanography studies the ocean, and its physical and chemical characteristics. Disciplines like these have developed and become more specialized through time, in part reflecting the great importance of water as a component of ecosystems.

Water's mobility allows it to affect land, climate, and weather, which in consequence means that it has enormous influence on the environment. A very clear example of the scale of the interactions between water and the environment is the hydrological cycle: the mass movement of water, powered by the energy of the sun, back and forth between all earth's environmental spheres.

1.1. The Hydrological Cycle

Water is a dynamic element. Changes in its physical state allow it to move from one place to another. The hydrological cycle is the continuous movement of earth's water masses. It may be described simply as follows. Water evaporates from the surface of the oceans, water reservoirs, rivers, and land. Plants also liberate water into the atmosphere through evapotranspiration. Part of this water remains in the atmosphere in the form of clouds or water vapor. A substantial amount eventually falls back to the surface of earth in the form of rain, hail, or snow. Around 75 percent of the water precipitated falls over the oceans and seas, while the rest falls on land. Water can remain trapped in solid state in the polar ice caps, or in glaciers in mountain ranges, for long periods of time. Part of the water that falls over land penetrates the soil. Some of it remains in the upper layers of the soil; some infiltrates deeper layers, where it continues to move both horizontally and vertically. Rainfall over land may flow through streams and rivers back into the oceans or seas, or it may converge within lakes and reservoirs. Water evaporates once more from the surface of these water bodies and streams into the atmosphere, and the cycle begins again. In summary, the hydrological cycle is induced by solar energy, and includes precipitation, infiltration, surface and groundwater flow, evaporation, transpiration, and condensation as basic processes.

The hydrological cycle moves hundreds of thousands of cubic kilometers of water around our planet every year. Some of this movement takes place relatively fast: a drop of water stays in a river for an average of fourteen days, and remains in the atmosphere for about ten days. But these time scales can change considerably when we refer to the dynamics of glaciers, unfolding over centuries, or to the movement of water in some deep, slow moving aquifers, taking place over thousands of years.

As water moves around earth, it modifies the environment, changing the landscape through erosion and sediment deposition, but also affecting the spatial and temporal distribution of nonliving elements and living organisms. At the same time, environmental factors cause changes in the physical and chemical properties of water during its transit from one ecosystem to another. Complex water/environment interactions result from the dynamics of the hydrological cycle.

There is no doubt that the hydrological cycle has continually been modified by human activities, as well as by major natural events. Since the beginning of history, humans have altered the cycle through the construction of dams, wells, canals, irrigation and drainage systems, and other infrastructural works. Anthropogenic actions not only modify the hydrological cycle but also disturb water/environment interactions, by changing the natural course of water, and by varying the properties of this resource.

1.2. Surface Water and Groundwater

When studying water as a function of ecosystem character, it is important to remember that the chemical species found in water are strongly influenced by the environment in which the water is found, as well as the chemical reactions that occur within it. An important comparison must be drawn between surface water and groundwater. Subsurface water has been filtered by the minerals through which it has drained; surface water, by contrast, is rich in dissolved solids, and bacteria are commonly present in it if it contains high levels of biodegradable organic matter. Groundwater is nowadays of great importance to humans. It is cheap to develop for exploitation because of its widespread occurrence and general natural good quality, and also represents a strategic reserve against catastrophic events (Gibert, Danielopol, and Stanford, 1994). In contrast to surface water, which is exposed to a day/night light alternation, groundwater is in permanent darkness; this situation influences its chemical content. The chemistry of water is also determined by the type of rock which is in contact with the flowing water, flow conditions, and the environmental conditions in general.

1.3. Aquatic Ecosystems

Most water for human consumption is obtained from surface freshwater systems and from groundwater. Surface water occurs generally in streams, lakes, and reservoirs. Some regions are very generously supplied with lakes and streams, particularly those once subjected to ancient glaciation. In certain regions, disappearance of inland waters during the dry season leads to special biological phenomena resulting from its intermittent presence. Inland waters can be divided into lotic environments (running water), which include creeks and rivers, and lentic environments (standing water), including lakes, ponds, swamps, and their various elements (Welch, 1952).

Within a comprehensive study of these water bodies, some important phenomena must be mentioned. Thermal stratification occurs when a surface layer is heated by solar radiation during summer, and “floats” upon deeper layers because of its resulting lower density. Eutrophication is the result of acceleration in the normal rate of reproduction in plants in water bodies, when enhanced nutrient levels lead to increased productivity. When this productivity process is excessive, the decomposition of large amounts of dead algae reduces oxygen levels within water.

Oceans—the largest water bodies on earth, and the largest ecosystems—still offer scientists a whole world to explore and study. They are inhabited by mammals, fish, crustaceans, coral reefs, and millions of marine species. Oceans are important not only as deep seas; coastal areas, including wetlands, estuaries, and mangroves, are also of great scientific and economic importance.

1.4. Water Quality and Health

Water is part of our everyday life. We drink it, use it for cooking and bathing, and feed plants and pets with it. We also use it recreationally: for example, for swimming and many other sports. Above all, however, water is necessary to sustain life. Water has an even greater value for humans because it is also required for sanitation. These are very important reasons for us to monitor water quality and supply carefully.

Because these aspects have been recognized by governments of both developed and developing countries—along with the need for improving hygienic and environmental quality, and the standards of living of their citizens—they are often the object of intensive study, considering not only aims and outcomes but also the costs of achieving them. Governments have to address various issues in dealing with the provision of affordable, reliable, and adequate water supplies and sanitation systems. Sustainable supplies of water and sewerage services depend on a well-maintained and well-operated infrastructure. Population growth and urbanization can be expected to continue, and will need to be considered in planning infrastructure development. Climate change is constantly taking place, with major implications for both water supply and sewerage systems. Education and public awareness programs are necessary to help users appreciate the value of water and sanitation to personal and national health (Kjellen and McGranahan, 1997).

On the other hand, we cannot ignore how directly health is related to water quality. The World Health Organization (WHO) pays special attention to waterborne diseases, and to those caused by poor sanitation. As we will see in this article, water may become extremely polluted by fertilizers, heavy metals, bacteria, and other sources, to the extent that the US Environmental Protection Agency (EPA) and WHO have set strict standards on specific concentrations for elements and compounds present in water for human consumption. WHO estimates that poor environmental quality today contributes to 25 percent of all preventable ill health in the world.

1.5. Climate Variability and Water Resources

Among the various events related to climate variability, perhaps the most well advertised (rather than well-known) event in the western hemisphere is the El Niño/Southern Oscillation (ENSO). El Niño is the term used to describe a phenomenon which starts with the surface warming of an area of the eastern Pacific close to the Equator, and whose effects spread over most of the world (Donoso and Adames, 2000). There are, in fact other definitions for El Niño. However, they all agree that it is an anomalous warming of surface water that accompanies a slackening of westward-flowing equatorial trade winds, and that it returns around Christmas time, lasting around twelve to eighteen months (Glantz, 1996). In the past century, the worst El Niños occurred in 1982–3 and 1997–8. The latter event was blamed for extreme rainfall and flooding in some regions of the Americas. Peru, Ecuador, and Colombia, among other countries, were very badly affected by this process, which some scientists call an "anomaly" and others refer to as "a natural event." This particular El Niño was also held responsible for severe droughts in northeast Brazil, and in the southern part of Africa and Indonesia. The impacts of El Niño events on national economies are worst for the poorest sector of the population, namely farmers and indigenous groups (Donoso, et al., 2001). Events like this show how alteration of water characteristics arising from large-scale changes in the global environment can affect the overall character of ecosystems at a continental scale.

Scientists have recently begun to try to see if there is a relationship between global warming and El Niño events. In this regard, a multinational panel of scientists known as the Intergovernmental Panel on Climate Change (IPCC) states, in one of its reports, that the 1990 to mid-1995 persistent warm-phase of the El Niño was unusual in the context of the last 120 years (IPCC, 1996). This suggests it to be strongly related to surface temperature increases.

1.6. Climate Change and Water Resources

An important natural phenomenon is happening right now in the earth's atmosphere. Several gases, known as greenhouse gases, trap infrared radiation from the earth's surface, preventing it from cooling too much when the sun is not shining. The overall process is known as the "Greenhouse Effect." Some greenhouse gases: carbon dioxide, nitrogen oxide, and methane (CH_4) are produced naturally, while others, such as CFCs, are of human origin. Today, however, anthropogenic activities like the burning of fossil fuels are causing the atmospheric concentrations of these gases to increase. Scientists have blamed this phenomenon for the present increase in the earth's temperature, predicting that this process will continue; ultimately this may have catastrophic consequences for life on the planet, through the various effects on global climate change (Broecker, 1997).

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 to assess the environmental and socio-economic impacts of climate change, and to formulate response strategies (IPCC, 1996) based on the available scientific information. In 1990, the IPCC completed the First Assessment Report. This presented several important findings, including the fact that carbon dioxide is the most important contributor to anthropogenic forcing of climate change, along with other observations that suggest “a discernible human influence on global climate.”

Scientists believe that global heat (energy) distribution patterns will change, and the climate will be directly affected by it. A temperature increase does not only involve extreme temperatures—although this by itself is a great problem—but also involves a range of related processes. Scientists have established that precipitation has increased over land in the Northern Hemisphere, and also that global sea level has risen by 10–25 cm over the past 100 years. The IPCC has also developed a range of scenarios of future trends, including: an average sea level rise as a result of thermal expansion of the oceans and melting of glaciers and ice-sheets; a reduction in the strength of the North Atlantic thermohaline circulation and a widespread reduction in diurnal range of temperature; and a more vigorous hydrological cycle. These may lead to more severe droughts and/or floods in some places, and/or less severe droughts and floods in others. In turn, these changes may cause shifts in the competitive balance among plant and animal species, and changes in their geographic ranges (IPCC, 1996).

The indirect effects of climate change on aquatic ecosystems are clear. Estuaries, for example, may be dramatically affected: excess precipitation leading to a change in river discharge may alter the amount of sediments brought into the estuaries in a more drastic way, since sediment transport rate is related to water flow (Eisma, 1995). Additionally, climate change may affect rates of weathering. Moreover, it is important to remember that stream flow, groundwater flow, and lake levels also respond to changes in precipitation and evapotranspiration. Under hotter and drier scenarios, lower runoff and greater evaporation would reduce stream base flows, and could result in periodic drying of some perennial headwater streams (Watson, Zinyowera, and Moss, 1996).

Climate change, and its impact on water resources, will intensify already-stressful competition between different water users in many regions. New and innovative technologies are expected to improve the quality of water, and reduce demand among major users. However, societies’ increased demands for comfort may increase demand for water, and increase contamination levels in this, and other, natural resources. Changing weather patterns might elevate water demands for agriculture and industrial practices. In addition, the ongoing increase of the world’s population, added to the changes in water-use habits, will increase the need for freshwater. This may cause social unrest and environmental problems, especially in regions where water resources are already under stress. Therefore, the social consequences of climate change can and will modify the interactions between water and the environment.

1.7. Other Threats Linked to Water Resources

Acid rain is the result of dissolution of sulfur dioxide and nitrogen oxides in the atmosphere. Although rain is naturally acid, the presence of sulfuric and nitric acids causes its pH value to become very low, creating various adverse effects on the environment where it falls. The principal sources of sulfur dioxide are coal and oil combustion, and smelting; internal combustion engines, residential and commercial furnaces, and industrial and electric utility boilers are the major sources of nitrogen oxide emissions (Brasseur, Orlando, and Tyndall, 1999).

Acid rain represents a threat to water bodies upon which precipitation falls. The capacity of lakes may become exhausted, and pH levels may drop dramatically, so that aquatic life may be seriously impaired. Acid rain also damages vegetation, and human constructions like buildings and statues.

2. Water and Food: Agriculture

Water is the prime substance needed for agricultural production. It is also an “environment” in its own right, nurturing thousands of species that humans use for food. It may become polluted, however, as a consequence of different practices related to food production, especially in agriculture. Water in oceans, rivers, lakes, and aquifers may be affected. Moreover excess water, and shortages due to floods and droughts, may lead to agricultural harvest losses, and the drowning or dehydration of edible species.

Today’s world population is around 6 billion people. In order to understand and help satisfy the feeding requirements of this number of inhabitants, world specialists in agencies such as the Food and Agriculture Organization (FAO) carry out comparative studies of world resources and requirements. In these studies, agriculture is taken to be a primary source for food. One of these studies estimated that around 800 million people in the developing world do not have enough to eat (FAO, 2000, a and b). In the World Food Summit of 1999, it was agreed to attempt a 50 percent reduction in this number by the year 2015. Although identification of these needs was itself a positive step, more detailed analysis has shown that momentum is too slow, and progress too uneven, for this goal to be achieved (FAO, 2000 c). There is no single prescription for fighting hunger: policies and strategies must address both the causes and effects of food insecurity, in order to build an appropriate framework for concrete actions. In the meantime, scientists are engaged in research programs and projects to assess the interactions between water quality and supply and agriculture.

-
-
-

Bibliography

Autoridad Nacional del Ambiente (ANAM). 1999. *Informe Ambiental 1999*. Panama. [Comprehensive diagnostic study of the condition of the environment in Panama for the year 1999, in Spanish.]

Broecker, W. S. 1997. Will our Ride into the Greenhouse Future be a Smooth One? *GSA Today*, Vol. 7, No. 5, pp. 1–7. [Provides analysis on possible future greenhouse gas emissions.]

Brasseur, G. P.; Orlando, J. J.; Tyndall, G. S. (eds.) 1999. *Atmospheric Chemistry and Global Change*. New York, Oxford University Press. [Provides useful overview on the interrelations between atmospheric chemistry and climate change.]

Cooper, C. M.; Lipe, W. M. 1992. Water Quality and Agriculture: Mississippi Experiences. *Journal of Soil and Water Conservation*, May–June, pp 220–3. [This provides data on water pollution from agriculture.]

Donoso, M. C.; Adames, A. 2000. *The Panama Canal watershed: Physical process and human dimension*. V. George Kovacs Colloquium. 22 pp. Paris, IAMS and UNESCO. [Presents a physical and socio-economic overview of the Panama Canal. The impacts of climate variability on the Canal's operation are presented.]

Donoso, M. C.; Vargas, C.; Leaman, K.; Castillero, M.; Martinez, D.; Nakayama, M. 2001. Panama Canal Case Study: Impacts and Responses to the 1997–98 El Niño Event. In: M. Glantz (ed.) *Once Burned, Twice Shy?* pp. 147–58. Japan, United Nations University. [Comprehensive presentation and analysis of the impacts of the 1997-1998 El Niño event in different countries worldwide.]

Dugas, W.; Bland W.; Arkin, G. 1985. Evapotranspiration Measurement from Different-Sized Lysimeters. In: *Advances in Evapotranspiration*, pp. 208–15. Proceedings of the American Society of Agricultural Engineers. USA. [Provides information on how to determine evapotranspiration using different types of Lysimeter.]

Edwards, L. H.; Chilingar, G. V.; Riekell, H. H.; Fertl, W. H. (eds.) 1982. *Handbook of Geothermal Energy*. Houston, Tex., Gulf Publishing. [Basic source.]

Energy Educators of Ontario. 1993. *Energy Fact Sheet.* http://www.iclei.org/efacts/hydroele.htm. [Interesting information on water-power related issues.]

Environmental Protection Agency (EPA), Office of Water. 2000. *Drinking Water: Past, Present, and Future.* http://www.epa.gov/safewater/consumer/dwppf.pdf. [Comprehensive analysis on the state and problems related to water resources for human consumption.]

——. 2001. *Current Drinking Water Standards*. http:// www.epa.gov/OGWD/mcl.html. [Basic source.]

Eisma, D. (ed.) 1995. *Climate Change. Impact on Coastal Habitation*. Fla., Lewis. [Analyzes and presents case studies of the impact of climate change on coastal habitation, mostly in Florida.]

Food and Agriculture Organization of the United Nations (FAO). 2000a. *The State of Insecurity in the World.* http://www.fao.org/FOCUS/E/SOFI/home-e.htm. [Presents food security as one of the main causes of social unrest and insecurity.]

——. 2000b. *Meeting the Challenge*. http://www.fao.org/ FOCUS/E/SOFI/way-e.htm. [Analyzes the challenges posed to nations by food security issues.]

——. 2000c. *Undernourishment Around the World.* http:// www.fao.org/FOCUS/E/SOFI/under-e.htm. [Essay on the problems related to food scarcity around the world.]

Gibert, J.; Danielopol D.; Stanford, J. A. (eds.) 1994. *Groundwater Ecology*. Academic Press. [Basic Source.]

Glantz, M. H, 1996. *Currents of Change. El Niño's Impact on Climate and Society*. Cambridge, University Press. [Basic source.]

Herrero, M. A.; Sadi, G.; Maldonado, V.; Flores, M.; Orlando, A.; Carbo, L. 1999. *Groundwater Management and Agricultural Production Systems in Buenos Aires, Argentina. Proceedings of the II Water Meeting. IICA. June 1999, Montevideo, Uruguay*. http://www.iica.org.uy.

Intergovernmental Panel on Climate Change (IPCC). 1996. *Climate Change 1995: The Science of Climate Change.* Cambridge and New York, Cambridge University Press. [Technical contribution of Working Group I to the Second Assessment Report for the Intergovernmental Panel on Climate Change.]

Kjellen, M.; McGranahan, G. 1997. *Urban Water: Towards Health and Sustainability*. Stockholm Environment Institute. [Comprehensive and informative publication.]

Likens, G. E.; Bormann, F. H.; Johnson, N. M.; Fisher, D. W.; Pierce, R. S. 1970. Effects of Forest Cutting and Herbicide Treatment on Nutrient Budgets in the Hubbard Brook Watershed-ecosystem. *Ecological Monographs*, Vol. 40, No. 1, pp. 23–47. [A classical long-term ecological study of the interrelationships between ecosystem character and the quality and quantity of the water within them.]

Ministerio de Salud (MINSA). 2000. *Situación Nacional de Salud, Enero del 2000.* Panama, Dirección Nacional de Políticas de Salud. [General information and statistics on health indicators for the Republic of Panama (in Spanish).]

National Oceanic and Atmospheric Administration (NOAA). 2001. *Commercial Fisheries*. http://www.noaa.gov/ fisheries.html. [Basic source.]

Rochester University. 1995. *Cornell Lake Source Cooling Project*. http://www.energy.rochester.edu. [Description of the study of the deep-water source cooling system at the Cornell Lake.]

Rocks, L.; Runyon, R. P. 1972. *The Energy Crisis*. New York, Crown. [Analyzes the causes and effects of the energy crisis.]

Tamminga, S. 1996. A Review on Environmental Impacts of Nutritional Strategies in Ruminants. *Journal of Animal Science, Vol.* 74, No. 3, pp. 112–24. [Presents an innovative way to introduce nutrients management in animal production systems.]

The National Fisheries Institute (NFI) 2000. *Data and Information*. http://www.nfi.org/industry.html. [General statistical and other information on the fishing industry in the USA.]

United Nations Environment Programme (UNEP). 1998. *Handbook on Methods for Climate Change, Impact Assessment and Adaptation Strategies.* Version 2.0, October 1998. [Presents methods for determining climate change impact assessments and establishing adaptation strategies.]

Watson, R. T.; Zinyowera, M. C.; Moss, R. H. (eds.) 1996. *Climate Change 1995: Impacts Adaptations, and Mitigation of Climate Change: Scientific Technical Analyses.* Cambridge and New York, Cambridge University Press. [Technical contribution of Working Group II to the Second Assessment Report for the Intergovernmental Panel on Climate Change (IPCC).]

Welch, P. 1952. *Limnology*. 2nd edn. New York, McGraw Hill. [Respected, although now slightly dated, textbook.]

World Bank. 2001. *The Little Green Book.* International Bank for Reconstruction and Development/World Bank. Washington, D.C., World Bank. [A succinct collection of information from the World Development Indicators 2001.]

Biographical Sketches

Maria Donoso. Prof. Maria Concepcion Donoso is Director, Water Center for the Humid Tropics of Latin America and the Caribbean (CATHALAC), with headquarters in the Republic of Panama. Her research and professional interests are in air/sea/ land interaction processes, and in climate change impacts on the natural environment (especially water resources) and society. She is actively involved in many relevant activities in the Americas. Recently, she served as the Co-ordinator of the Regional Consultation of the Caribbean and Central America Vision on Water, Life, and the Environment for the Twenty-First Century, and as a member of the Global Environmental Facility (GEF) Overall Performance International Team of Experts. Presently, she is a member of the Inter-American Water Resources Network Executive Council, and serves in the Central America Technical Advisory Committee of the Global Water Partnership. Among her most recent relevant publications are *Tropical Intraseasonal and Longer-period Variability of Precipitation in the Isthmus of Panama* (American Institute of Hydrology, 2001: co-author Dr K. Leaman), and *The Panama Canal: impacts and responses to the 1997-98 El Niño event* (United Nations University, 2001: published in collaboration with C. Vargas, K. Leaman and M. Nakayama).

Nara Mirei Vargas was born on April 11 1979, and obtained her B.Sc. in Environmental Science in July 2001 at Florida Institute of Technology, Melbourne, Florida, USA. She is currently pursuing a Master's degree in Environmental Health and Safety at Illinois State University, and is expecting to graduate in May 2003. At Illinois State University (August 2001–present) she is a graduate assistant for the Health

Sciences Department, being a teaching assistant for the undergraduate course "Environmental Health in the twenty-first Century", and a research assistant for the project "Pilot-scale Constructed Wetland for Metal Detoxification." At the Water Center for the Humid Tropics of Latin America and the Caribbean (CATHALAC), Panama, she was Research Assistant for the Project "Multi-objective study of climate variability for impact mitigation in the trade convergence climate complex" (Summer 2000 internship). She was also Assistant to the Third Inter-American Dialogue on Integrated Water Resources Management, 1999, for the Inter-American Water Resources Network (IWRN). In 1999 she undertook a summer internship as research assistant for the Trade Convergence Climate Complex Network, for CATHALAC, Panama.