Water Resources in the Anthropocene Age: A Planetary Urgency

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Global environmental change (GEC) is the global change that human activity is causing in the natural systems of our wonderful planet. The international scientific community which is involved in GEC has been calling on, for years, the political and economic world to take action so that our society and our development models may finally start their journey on the road to global sustainability.

In March 2012, London hosted the latest major scientific conference on global change, "Planet under pressure. New knowledge towards solutions" (www.planetunderpresssure2012.net), organized by the leading international scientific organization International Council for Science (ICSU www.icsu.org), and by the Earth System Science Partnership (ESSP, www.essp.org, now transformed in www.futureearth.org), the worldwide partnership that brings together the most authoritative research programmes on global change. About 3000 scientists, academics, and government experts gathered to discuss global change, focusing on the state of the planet's natural systems and on the knowledge we have about the strain caused to them by human activities. Operative proposals were presented that could be urgently implemented to change the direction of the present model of socio-economic development which, up to now, has clearly proved unsustainable for the immediate future. The conference concluded with the statement of a very straightforward "State of the Planet Declaration," clearly outlining the state of health of our natural systems. The declaration was meant to remind us that the research on global change proves that the complex planetary system which, over the centuries, has sustained human well-being and civilizations, is at risk. Without adopting urgent measures, we will have increasing difficulties in facing the threats posed to our vital resources, among them water, which are at the basis of our alimentation and biodiversity. These threats risk to intensify the economic, ecological, and social crises, creating the potential for a global humanitarian emergency. The world's existing interconnected and

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interdependent economic, social, cultural, and political systems are placing a very strong pressure on the natural systems, causing fundamental changes to the Earth as a system and leading human societies beyond the natural "planetary boundaries" within they should act instead.

However, the same interconnection can be used to identify the solutions to these serious problems. Global sustainability must become the basis of our societies.

The declaration recalls that the human impact on the Earth's system can now be compared to the great geological planetary changes, such as those occurring during the ice ages. Consensus has grown on the fact that our planet has entered a new geological era called the "Anthropocene" (originally proposed in 2000 by the Nobel Prize Winner for Chemistry, Paul Crutzen, Crutzen, 2002). In this new era, many processes belonging to the Earth system and to the living "factory" of its ecosystems are now dominated by human activities. Large-scale abrupt changes, identified by the research on past environmental changes, indicate that these sudden changes could also take place in our immediate future. This knowledge has encouraged researchers to try identifying the thresholds (the "tipping points," the critical points, or threshold effects) and the planetary and regional boundaries that, once crossed, could generate environmental and social changes ultimately ungovernable by our societies.

The declaration calls for a fundamental reorientation and reorganization of our international and national institutions to move toward an effective Earth system governance, a concrete commitment to a proposal for sustainable development objectives, such as those for global sustainability, and the recognition of monetary and non-monetary values of common goods, such as ecosystem services and large-scale planetary environments, the oceans, and the atmosphere.

During the conference, the international scientific community dedicated to studies on global change announced the new research program for the next ten years called "Future Earth: Research for Global Sustainability" (www.icsu.org/future-earth, and www.futureearth.org).

The vulnerability of the Earth system to human activities also fully demonstrates the intrinsic vulnerability of our civilization, vis a vis what we have caused to the natural systems and which, inevitably, will have an effect on our well-being and survival. It is now time to change direction and to also modify our established concept of security.

The noted environmentalist, Lester Brown, wrote in his book *Plan B 4.0* (Brown 2010): "The situation in which we find ourselves pushes us to redefine security in twenty-first century terms. The time when military forces were the prime threat to security has faded into the past. The threats now are climate volatility, spreading water shortages, continuing population growth, spreading hunger and failing states. The challenge is to devise new fiscal priorities that match these new security threats. We are facing issues of near-overwhelming complexity and unprecedented urgency. … We are in a race between natural and political tipping points, but we do not know exactly where nature's tipping points are. Nature determines these. Nature is the timekeeper, but we cannot see the clock. The notion that our civilization is approaching its demise is not an easy concept to grasp or accept. It is difficult to imagine something we have not previously experienced. We hardly have even the vocabulary, much less the experience, to discuss this prospect… Since it is the destruction of the economy's natural supports and disruption of the climatic system that are driving the world to the edge, these are the trends that must be reversed. To do so requires extraordinarily demanding measures, a fast shift away from business as usual… One thing is certain—we are facing greater change than any generation in history. What is not clear is the source of this change. Will we stay with business as usual and enter a period of economic decline and spreading chaos? Or will we quickly reorder priorities, acting at wartime speed to move the world onto an economic path that can sustain civilization?"

1 Water Demand in the Anthropocene

Freshwater is an integral part of the Earth system "machine" and a very important key to understanding the magnitude of this global change. The heating of the Earth's surface due to the increase in greenhouse gases, caused by humans, also changes the water cycles. Many other anthropic factors—the widespread change in land use, the engineering of river beds, irrigation and other water uses, the disappearance of aquatic habitats, pollution—also influence the global water system.

Consequently, there follows the decline in biodiversity and the deterioration of the ecosystems and their resources: Many species risk extinction, while the rainforests, the coral reefs, and the wet zones suffer the devastating effects of human activities. Extreme phenomena, such as flooding and droughts, have increased in intensity and frequency, and the shortages in food and water have become a serious concern for the entire world.

The history of the constant evolution of our planet began about 4.6 billion years ago and has witnessed a series of large-scale geological and biological upheavals. The eras and epochs have reflected these events, taking place on a geological time scale, each marked by extraordinary occurrences that have changed the planet's history, such as the ice ages, the plate tectonics, or the mass extinction of living species. A recent event occurred approximately 11,500 years ago when the retreat of the glaciers made way for the current interglacial period, the Holocene, creating most of the present geological formations, as for example, the potentially arable land, the river deltas, and fluvial deposits. Over the last 10,000 years, our species has been able to enjoy a situation, even with the evolutionary dynamics of the natural systems, of a modest climate and environmental stability which has allowed us to grow and now reach a population of 7 billion.

In the more recent phase of the Holocene, human pressure on the natural systems has become so heavy that it can be compared with the large-scale geological forces that have modified the planet throughout its entire life. From the second half of the twentieth century, the history of the human species has witnessed another important shift: More than a half of the rural population has become urban, supported during the green revolution by an industrial agriculture based on the use of fertilizers and pesticides, intensive irrigation, mechanization, and widespread use of fossil fuels. However, anthropic activities have accelerated and/or intensified many important natural processes, for example, soil erosion, biogeochemical cycles of carbon, nitrogen and phosphorus, the increase in the greenhouse effect, and they have slowed down others, as for example, the quantity of water and sediments that reach the sea via rivers. Although very recent and rapid, as we have already mentioned, this period may represent the beginning of a new geological epoch, the Anthropocene, characterized by the rapid change in the human–ecosystem relationship, and to the extent that humanity could be considered as a global force in itself (Global Water System Project 2012).

The term Anthropocene was introduced to actually underline the growing predominance of humanity in determining GECs and is characterized, among other things, by the growing demand for water and the decrease in its availability. Water use has significantly increased since the advent of the industrial revolution and still even more rapidly over the last four decades. This has caused global changes in river flows (Shiklomanov and Rodda 2003), spatial patterns, and seasonal times for "global water vapor flows" (Gordon et al. 2005). It is estimated that because of water withdrawals, 25 % of the world's river basins dry up before they reach the oceans (Molden et al. 2007).

For example, in the 1990s, the Yellow River in China dried up for long periods of time along its course and at its estuary; huge problems occurred in attempting to conserve the flow of the Murray River in Australia and the Rio Grande on the border between Mexico and the United States; both rivers now experience long periods of drought. In order to meet the ever increasing demand, water is also transported over long distances from one river to another, which can aggravate ecological impacts. Sometimes, this happens on a large scale, as is the case in the "South–North Water Transfer Project" in China (this project plans, by 2050, to divert 44.8 billion cubic meters of water per year from the Yangtze River in the south of China to the Yellow River basin in the north, *ndr*). The reasons underlying this enormous water use (for agricultural, domestic, industrial and energy production purposes) include population growth, economic development, globalization, changes in consumption models and, consequently, in dieting models. An example of the scale of total global anthropic water use lies in plant production that, cumulatively, amounts to about 7000 km^3/year of water. If we include permanent grazing lands, the total evapotranspiration for food production amounts to 15–20,000 km^3/year (Hoff 2009). In order to understand the magnitude of these numbers, this amount corresponds to around the half of the total superficial water discharge of all the rivers on Earth (Hoff 2009). Given the present productivity levels and access to food, a further 5000 km^3/year will be needed to feed the world's population by 2050.

The growing water demand is causing a decrease in quantity, quality, and regularity of the water available for our ecosystems. This, in turn, is resulting in the loss and degradation of ecosystems' biodiversity, which, consequently, diminishes the capacity of those ecosystems to provide the essential services which are necessary to support our societies and life on Earth.

Water scarcity, which can generally be understood as the lack of access to adequate quantities of water for human and environmental use, is acknowledged in many countries as a serious and growing problem. Consequently, "water scarcity" is the term regularly used by the media, in government reports, by NGOs and by international organizations such as the United Nations and the OECD, as well as in academic literature, to highlight the areas where water resources have been subjected to pressure or stress. Therefore, the scientific community is increasingly reminding us of the urgency to act and the need to rapidly intervene to change the direction of our development models that are based on a material and quantitative economic growth. An internationally famous team of scientists, led by Johan Rockström, director of the Stockholm Resilience Center, identified in 2009 the nine thresholds of planetary boundaries (linked to established ecological parameters) which human activities should not step over in order to avoid serious biosphere imbalances. The same scientists confirmed, as well, that in many situations we are already near the "threshold." As evidence increases regarding how, on a global scale, we are facing a water crisis, the global use of freshwater is, obviously, one of the nine planetary boundaries identified (Rockström et al. 2009a, b; Steffen et al. 2015).

The alteration in global water cycles affects biodiversity, food, the health, and the ecological functionality of the ecosystems. For example, changing freshwater habitats may have deep repercussions on fish stocks, on the level of carbon capture and storage, on climate regulation, undermining the resilience of land and water ecosystems.

The deterioration of the global water resources threatens human survival as it determines:

- the loss of soil moisture (also defined as "green" water, being the basis of non-irrigated agriculture), caused by land degradation and deforestation which threatens primary production, carbon capture, and storage;
- exploitation and changes in surface water runoffs (defined as "blue" water), which threatens agricultural and domestic needs;
- the impact on climate regulation caused by the decline in "global water vapor flows" which change local and regional precipitation patterns.

Estimates indicate that 90 % of the world's green water flow is necessary to support vital ecosystem services (Rockström et al. 1999), while 20–50 % of the average annual blue water flow in the catchment basins is necessary to support aquatic ecosystems (Smakhtin 2008).

The inexorable increase in water demand to produce food, to supply industries, urban and rural populations, has resulted in an increasing freshwater scarcity in many parts of the world. In fact, while the erosion of the Earth's productive surface stratum began with the first farming of wheat and barley, the trend in lowering the groundwater levels is historically more recent, since the technology required to pump water from underground aquifers is only a few decades old. The wells gradually dry up and the depletion of groundwater aquifers occurs where there is the habit to pump excessive quantities of water. An increasing number of rivers are drying up for long periods before reaching the sea. In many areas, groundwater is pumped at rates that exceed the groundwater replenishment capacity, with the result that the groundwater levels are rapidly dropping in at least 20 countries, including India, China, and the United States. The three most populated countries in the world where half of the world's cereal crops are grown (Brown 2011). Consequently, it is relatively clear how water shortage can turn into food shortage, taking into consideration the data that show how, for example, 40 % of the world's wheat harvest originates from irrigated lands. A World Bank study shows that 175 million people in India are fed thanks to over-exploited groundwater, while in China we are speaking of more than 130 million people (Brown 2004).

As Werner Aeschbach-Hertig and Gleeson (2012) recall, humanity, today, also intensively uses so-called fossil water (the underground water accumulated throughout the Earth's geological history, scarcely conditioned by the surface water cycles and, therefore, with a very slow renewability rate). As these academics demonstrated, there is a widespread depletion of fossil water reservoirs, particularly in regions of high fossil water use for irrigation purposes in China, India, and the United States. The situation is especially serious as it does not only concern the withdrawal-renewability deficit from surface water. The rapid increase in evapotranspiration should be also taken into account, which is augmented by climate change, growing anthropic pressures and by the various impacts on agricultural activities.

Climatic changes also threaten food security. There is a threshold where the increase in temperatures represents a problem for agricultural production. Every increase of 1 during the growing season can imply, for farmers, a decrease of 10 % in wheat, rice, and maize harvests. From 1970 until today, the planet's average surface temperature has increased by more than 0.7 °C (IPCC 2007). Increasingly more often, governments, societies, and communities have become worried about the future availability and sustainability of water resources. Over the last 20 years, researchers have developed a number of parameters and indicators to describe and map the geography of global water scarcity. These include, for example, the ratio between the human population and the renewable water systems (Falkenmark 1989), the ratio between water withdrawals and renewable supply, and they contribute to documenting the spread of water scarcity over time.

Meeting the demand of a world population that is growing every year by about 80 million people has become increasingly more difficult. If the reduction in food consumption, driven by the present serious economic crisis, is a new situation for many countries in the world, for many others further sacrifices are not possible. Food is the "Achille's heel" of our societies and risks becoming an important factor of instability, also politically. To avoid a collapse, also from an environmental viewpoint, societies as a whole need to mobilize. No one can afford to be merely a spectator any more (Brown 2012).

2 Water Resource Management

Water resources and their management, up to today, have been approached on a local, or even catchment basin level. Only recently has it been recognized that water resources are, at the same time, subject to and an integral part of global change and globalization. The idea of a global water system with interdependent social and ecological elements has only been recently established (Alcamo et al. 2008).

In 2010, in the scientific journal "Nature" (Vorosmarty et al. 2010) a very interesting study was presented which documents how almost 80 % of the human population, or 5.6 billion people (out of the 7 billion that now live on our planet), live in areas where there exists a high risk concerning water supply security and the state of health of the biodiversity of freshwater habitats. This involves ecosystems highly threatened by pollution, dam construction, the presence of invasive species, coastal habitat transformation, etc. The study is the first which correlates the factors threatening water supply security for humans to the state of health of the biodiversity of the ecosystems which provide water. It clearly shows the need and urgency for a careful and coordinated management of the water demand of human society, preserving and guaranteeing the services which the freshwater ecosystems provide for our well-being and survival. The stress factors that threaten freshwater ecosystems jeopardize the security of water reserves for human use and 65 % of the world's river habitats are now classified at risk—from moderate to very high. This affects the survival of thousands of aquatic species. The main rivers under threat are in India, Europe, the Middle East, Southeast Asian countries, and the United States. Only a small fraction of the world's rivers appear to be not significantly compromised by human activities, as can be seen, for example, in some remote areas of the Amazon River and the Congo Basin.

The WWF, in agreement with the international scientific community, has stressed for years how it is no longer possible to refer to human water security as something unconnected to the value of ecosystems' biodiversity, from which it originates. Practically almost all of humanity lives near a water source, either at the end of a water pipe or in proximity of a river. We need water to survive, to grow crops, to generate electricity, and to produce the goods for our daily use. Though less than 1 % of the world's water resources is available, that quantity must satisfy both human and environmental needs, the two being inseparable. The key issue, therefore, is to guarantee sufficient water of adequate quality to the humanity, preventing the destruction of the basic ecosystems necessary for its supply, such as rivers, lakes, and groundwater.

Today, the services provided to the economy and human society by freshwater ecosystems, including the supply of water, are exploited well over their sustainable levels. This was clearly shown by the "Millennium Ecosystem Assessment," the international study published in 2005 and sponsored by the UNO, on the state of health of the planet's ecosystems and their future (www.maweb.org).

Furthermore, it is forecasted that water resource demand, the so-called human water footprint (www.waterfootprint.org), is continuing to increase in many parts of the world. The main impacts of the human water footprint on the freshwater ecosystems derive from the increase in river fragmentation, in excessive water withdrawal, and from pollution. In addition to that, the looming impacts of current climate change could exacerbate the situation (WWF 2012).

The chain reaction on the global scale of water scarcity was fully understood from the moment the methods of water footprint calculation highlighted how much countries and economies depend on the trade in virtual water embedded in all our food and services (from a cup of coffee to a cotton T-shirt, or a steak), but never taken into account in any economic evaluation.

The growing demand for water and hydro-electric energy, along with the attempts to control flooding and to improve river navigation, have led to the construction of dams and other infrastructures, such as locks, underwater dams, and levees along most of the world's large rivers. In total, out of the 177 rivers of more than 1000 km in length, only 64 flow freely without being hindered by dams or other barriers, as shown in a WWF study published in 2006 ("Free-flowing rivers – Economic luxury or ecological necessity?", www.panda.org). A water infrastructure can result in benefits, but it can also deeply impact the freshwater ecosystems and populations that depend on the services provided by those ecosystems. Dams alter river flows, changing the quantity, the times, and the quality of the water that flows downstream. Moreover, larger dams can totally interrupt the ecological linkages between the upstream and downstream habitats, creating serious problems, for example, to migratory fish species.

The most recent research calculates that dam construction has a negative impact on the life and existence of about 500 million people.

The economic and financial crisis is strongly hitting many countries worldwide. The climate change and ecosystem crisis is doing exactly the same with even more serious repercussions as it is incredibly difficult to rebalance the ecological deficit which we have caused. The consequences of climate change and of the overexploitation of the natural resources, such as forests, agricultural land, fish species, and freshwater, will impact differently in different parts of the world. Some regions will suffer more than others, but in the long term no area of the world will be able to protect itself or avoid these negative consequences. Ultimately, energy food and water suppliers will be those most at risk. Similar to the financial crisis, which had been forecasted for many years beforehand, but had gone unheeded, the same is happening for climate change and environmental deterioration. Why then, despite the many warnings, has little or nothing been done? The environment is now in a much worse state compared to 50 years ago, its evolution being dominated by human activities. This is occurring notwithstanding the increasingly detailed and numerous studies that have clearly shown how our societies are on a collision course with nature. Environmental issues regularly end up at the top of the list of priority questions in opinion polls, but any real action is still a long way off. Therefore, it has become increasingly important to establish economies based on the efficient use of our resources, through a tax system that transfers the revenues of current taxation on employment into strategies toward a sound utilization of resources and sound pollution control, and on clear guidelines and objectives for global sustainability.

Adopting the family of "footprint" indicators (ecological footprint, carbon footprint, water footprint, material footprint, etc.) could be very useful in contributing to better transparency for consumers. However, above all, there is an extreme necessity to act and to change the direction of our social and economic development models. Inaction does nothing but aggravate the solution to the problems.

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