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Re-thinking water scarcity: Can science and technology solve the global water crisis?

Elena Lopez-Gunn and Manuel Ramón Llamas

Abstract

This paper provides examples from the last fifty years of scientific and technological innovations that provide relatively easy, quick and affordable means of addressing key water management issues. Scientific knowledge and technological innovation can help open up previously closed decision-making systems. Four of these tools are discussed in this paper: a) the opportunities afforded by virtual water trade; b) the silent revolution for beneficial use of groundwater; c) salt water desalination; and finally, d) the use of remote sensing and geographic information systems (GIS). Together these advances are changing the options available to address water and food security that have been predominant for centuries in the minds of most water decision-makers.

Keywords: Virtual water, Desalination, Intensive use of groundwater, Water footprint, Water security, Remote sensing, GIS and Internet.

1. Introduction

Despite all the talk of a looming water crisis, should a water crisis occur, the crisis would be felt first and foremost by the poorest sectors of the population, dependent for their livelihoods on rain-fed or irrigated water in arid and semi-arid regions, where 52% of the world's population lives (UNESCO-WWAP, 2006: 338). Yet when the water crisis is discussed in relation to the MDGs the focus tends to be on Target 10 of Goal 1, i.e., to halve the number of people without affordable access to water and sanitation. However, if we were to address key questions in relation to water use through irrigation, by definition we would be focusing on 70% of the world's water use, and in particular in arid and semi-arid areas, where about 40% of the world's irrigated land is located (UNESCO-WWAP, 2006: 263 and 270).[1] Any advances made in irrigation will translate into gains by other sectors — which often have higher economic returns or added value like industry, public water supply and sanitation or environmental services — which at present are not benefiting globally from water captured by irrigation.

This paper looks at recent advances in science and technology to address water 'scarcity'. Although the root cause of 'water scarcity' is mainly due to a crisis of water governance (UN, 2003; Rogers *et al.*, 2006), this paper does not address water governance *per se*, instead it looks at four options which are inexpensive, already available and accessible to highlight options and choices already being taken by different countries to allocate water between competing uses. These latest advances in science and technology can, for example, help address the use of water by irrigation in arid and semi-arid regions of the world in order to help achieve the MDGs, in particular the MDG on combating poverty and hunger.

This paper will also focus on inexpensive and feasible options which currently exist to address the 'looming water crisis', by highlighting recent advances in understanding due to either new data or new perspectives (i.e., the case of virtual water and the silent revolution of groundwater) and technological innovations (like desalination and the use of GIS and remote sensing).

The scope of this paper is to focus on four concrete and key options to address this water 'crisis', which are cheap, feasible and most important, already available; first, it emphasizes the key strategic relevance of virtual water and a country's water footprint, particularly for arid countries; second, it looks at the silent revolution of groundwater use, third, desalination[2]

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[1] However, rain-fed farming represents 82% of cropland and produces only 60% of the world's agricultural production.

[2] Water re-use and rain harvesting are not discussed in this paper, although these are appropriate technologies that can have and are having a certain impact in both agriculture and water and sanitation, mainly in developing countries. We are not dealing with other issues like solar energy, geothermics because — although these are under debate — at present these are not cheap or easily available.

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Table 1. List of Millennium Development Goals

Goal 1: Eradicate extreme poverty and hunger
Goal 2: Achieve universal primary education
Goal 3: Promote gender equality and empower women
Goal 4: Reduce child mortality
Goal 5: Improve maternal health
Goal 6: Combat HIV/AIDS, malaria and other diseases
Goal 7: Ensure environmental sustainability
Goal 8: Develop a Global Partnership for Development

Table 2. Global water and energy in calories for meat, livestock and cereals

	Meat	Livestock	Cereals
Global water use	29%	17%	23%
Global energy use	15%		51%

Source: Modified from Chapagain *et al.* (2005).

Table 3. Comparative table on the amount of water needed to produce 1 unit of specific products

Product	Water (in 1,000 ml) necessary for production
Bottle of beer (250 ml)	75
Glass of milk (200 ml)	200
Bread slice (30 gr.)	40
Cotton T-shirt (500 gr.)	4,100
A4 sheet of paper (80 gr/m^2)	10
Beef hamburger (150 gr)	2,400
Pair of leather shoes	8,000
Beef meat (1 kg)	15,000
Lamb meat (1 kg)	10,000
Cereals (1 kg)	1,500
Chicken meat (1 kg)	6,000

Source: Llamas (2005) from Chapagain and Hoekstra (2004).

and finally — although briefly — the potential of new technologies from the information age, like remote sensing, GIS and internet. The paper discusses these advances in knowledge and technological innovation at the global level which are discussed in depth for the case of Spain in a forthcoming paper.

Some theoretically relevant advances that are currently under discussion are not considered, e.g., biofuels, the genetic engineering to obtain salinity and drought resistant crops, because we have preferred to comment only on factors that are easily available and relatively cheap.

2. Virtual water and water footprint

Virtual water is the amount of water necessary to produce a good or a service (Allan, 2003; Allan, 2006; Allan, 2007). This is a key advance in addressing the current water crisis because it calculates, fairly accurately, the water embedded in the production of any good or service. For example, 1 kg wheat equals 1,000 kg water (or 1 m^3), whilst 1 kg beef equals 20,000 kg water (or 20 m^3) (UNESCO-WWAP, 2006: 257). This, in turn, provides key new information to policy makers, e.g., Finance or Economic Development departments in poor developing countries, which are ultimately central to decision-making processes on water governance. New information can open up the range of options being considered.

At present, it is calculated that the total global water resources are about 110,000 km^3/year, of which *green water* i.e., water in the soil is calculated at 70,000 km^3/year, whereas blue water i.e., water in rivers and in groundwater accounts for 40,000 km^3/year (UNESCO-WWAP, 2006: 250). Of all global water available (blue and green), Zimmer and Renault (2003) have calculated that the total amount of water needed globally to produce food is 5,200 km^3/yr. This amount is similar in magnitude to the 6,000 km^3 estimated by the United Nations (UN, 2003) as the water needed to produce food for 6,000 million people on the planet. Yet, it is important to remember that the total amount of water in the hydrological cycle is 110,000 Mm^3, and humankind at present uses below 10% of annual rainfall, i.e., of blue and green water.

Out of the 5,200 km^3/yr used to produce food globally, according to Zimmer and Renault (2003), 29% of water is used to produce meat, and 17% to produce meat products.[3] Cereals only account for 23%. However, from the point of view of energy in calories in meat and cereals the situation is quite different; cereals represent 51% of energy value and meat and livestock products only 15%, with the threshold for malnourishment at 2,000 calories/day.

Yet economic and social factors are often the drivers in virtual water trade, through trade in agricultural and processed food products. Estimates on the amount of water required for the production of each good are complex, and are being developed at the moment (Chapagain *et al.*, 2005). Meanwhile estimates on virtual water for food or industrial products are still in their infancy. What is new in the twenty first century is the scale of trade due to increased production through technological advances, and cheap transport — particularly by sea. The cost per tonne of product transported by sea is about 1 to 3 euros per tonne or 0.1 to 0.3 euro cents per kg. It is easier — and cheaper — to transport 1,000 tonnes of wheat, than the 1 million m^3 needed to produce that same wheat (see below Table 4). Thanks to virtual water, many water scarce countries have avoided a crisis, particularly in politically unstable regions like North Africa and the Middle East. The only pre-requisite is that these countries must be rich enough to have the purchasing power needed in international markets (Allan, 2007).

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[3] The calculation for meat and processed livestock products includes animal feed.

Table 4. Average value of some vegetable produce

Product	Average value (US$/tonne)
Wheat	125–150
Barley	134
Corn	125
Tomatoes	856
Horticultural products	757
Sunflower	294
Virgin olive oil	2,036
Coffee	2,118
Fresh grapes	1,160

Source: After Appendix IV in Chapagain and Hoekstra (2004).

There are some data which have to be analyzed further because of their potential implications. For example, it would be useful to further explore the geographical variations in the productivity of virtual water. According to UNESCO-WWAP (2006: 255) the concept of water productivity is now widely accepted as a measure of performance in agricultural water use. This points to the efficiency gains still to be obtained from irrigation. First, while irrigation currently withdraws about 2,300 km^3 of freshwater per year from rivers and aquifers, only 900 km^3 is effectively consumed by crops (UNESCO-WWAP, 2006: 250). Second, strategic choices have to be made by different countries on whether water is used to grow high-value crops, or low-value crops like cereals or alfalfa. i.e., whether to divert water from the production of low-value staple crops to higher-value cash crops such as vegetables, fruit and flowers (UNESCO-WWAP, 2006) (see Table 4).

Knowing the virtual water budgets, together with the economic value of the goods and services of each country, provides interesting information in relation to how green and blue water is used and possible implications for both productive and environmental water uses.

Many countries, particularly in the developing world still have to address questions related to food security, and particularly so in arid and semi-arid regions, where droughts can trigger hunger and also potentially destabilize or even topple governments in power. However, these mass starvations more often have a political origin than a physical cause, as highlighted by Brunel (1989). Food security can often be ensured through either self sufficiency in food production, or a mixture of own production and imports from other countries. This political choice, i.e., whether to opt for self sufficiency or an open trade approach, has substantial implications in terms of potential water savings, water infrastructure, rain-fed agriculture and trade in agricultural products (de Fraiture *et al.*, 2004). Due to their lack of capital, authors like Hofwegen (2004) suggest that their safest bet to ensure food security is to improve the productivity of rain-fed agriculture — or green water as discussed above — since their poverty leaves the choice of building large irrigation infrastructure and/or agricultural trade beyond their reach.

Table 5. Global water footprint of meat and vegetarian diets

Diet	Population	km^3/year (blue + green)
Vegetarian	7.000.10^6	~6,000
Red meat	7.000.10^6	~12,000
Vegetarian	10.000.10^6	~8,000
Red meat	10.000.10^6	~15,000

Source: Llamas (2005a).

The sum of all water (blue and green) and all imported water (i.e., virtual water) required to meet the needs for goods and services for a specific area or collectivity is known as 'water footprint'.[4] This concept was developed by Hoekstra and Hung (2002) and it is used as an indicator of water used by an individual, a collectivity or a country[5] (Hoekstra and Chapagain, 2006). It is now possible to calculate water footprints with acceptable accuracy. For example, about 90% of water needed for total livelihoods survival is for food. A vegetarian diet represents about 800 m^3/year, whereas a red meat diet is equivalent to about 1,500 m^3/year (Table 5).

In the concept of virtual water used by Chapagain *et al.*, (2005) virtual water that is exported is not added. Yet, exports can play a vital role in that country's economy, since it generates the capital that can allow the country to equally import virtual water as other agricultural or industrial products. Therefore, a true water budget for a country should consider both exports and imports of embedded water.

Chapagain *et al.* (2005) calculates that the current total annual global water footprint for humanity is 7,500 Mm^3, although this figure is likely to increase in the coming years. This is a difference of about 1,500 Mm^3 compared to the amount of water used to produce food mentioned above because it also incorporates public water supply and industrial use. In any case, it is important to remember that the total amount of rainfall on the land surface, i.e., the sum of blue and green water is about 115,000 Mm^3. In other words, the water demand from the whole of humanity is well below 10% of annual precipitation. In Llamas (2005a) it was shown that the water footprint of Spain, Italy and the USA is similar — approximately 2,300 m^3/person/yr, whilst India's water footprint is less than 1,000 m^3/person/yr. This is mainly due to the vegetarian diet in India[6] and its lower level of industrialization. Yet consumption preferences change with income and normally people

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[4] This concept is similar to the concept of ecological footprint (Rees, 1996), and more recently carbon footprinting.

[5] It can be defined as the volume necessary for the production of goods and services by one person or group of people.

[6] See Table 1 for amount of water needed to produce 1 kg of cereal vs. 1 tonne of meat.

Table 6. Individual countries water footprint

Country	Water footprint (m^3/person/year)
Spain	2,300
Italy	2,300
USA	2,300
India	1,000
China	700

Source: Various.

consume more meat as their incomes improve. Globally about one-third of all cereals is used for animal feed — a shift away from livestock feeding on natural pastures towards a dependence on cereals.[7] As diets diversify and become healthier and better balanced, the demand for fresh vegetables and fruits increases. Unfortunately, these goods are produced under intensive farming methods, including the use of irrigation for year-round production. The oil crops sector is one of the most dynamic in the world. For example, since the 1970s, oil crops have provided 20% of the increase in caloric intake in developing countries, equally the new push for biofuels is likely to have a knock-on effect on all crops.[8] Equally the predicted rise in biofuels is likely to impact global food prices and compete for water resources.

Food security today is much more related to economic capacity and trade than to physical water scarcity. This shift in perception forces a re-consideration of the main problems of food security aside from pure physical scarcity and technological fixes. The main issues that need to be addressed globally in relation to food security are: the hidden monopolies that currently exist in the World Trade Organization (WTO), the potential threat of political embargoes and the need for domestic social changes to be fulfilled.

As exports grow, there are concerns about the rules of the North American Free Trade Agreement (NAFTA) and the World Trade Organization (WTO). Ramirez Vallejo (2006) argues that it is not sensible to apply pure economic theory to explain virtual water trade. Many factors influence water trade like bilateral trade agreements, direct or indirect subsidies, technological innovation, or the macroeconomic policies of exporting and importing countries. Most virtual water trade is not explicitly or directly motivated by lack of water or food security. In fact, the analysis of food trade shows that most trade occurs between countries that have substantial water resources, indicating clearly that factors other than water drive international food trade (UNESCO-WWAP, 2006).

Trade in virtual water depends largely on WTO rules, which are in the process of being re-drafted. These rules will have important geopolitical consequences, e.g., in terms of power shifts, and some politicians — particularly in developing countries — are uneasy about trade in virtual water since it could lead to increased dependency towards exporting countries or large multinational companies and supermarkets, which in turn could develop monopolies on global food trade. Rogers and Ramirez-Vallejo (2003) have made a forecast of the potential evolution of the virtual water market for the year 2020 in case of market liberalization under the WTO. The dominance of the USA would be even greater under market liberalization scenarios, whilst the role of Latin America would also increase substantially. Yet, for the period 1993–1998, 75% of trade in virtual water was between OECD countries and was mainly driven by economic factors, not by local water scarcity.

A key element in all these future scenarios is the price of blue water, which at present, is generally well below its real cost. Reducing the gap between prices currently charged and the real cost of water — as demanded by the concept of full cost recovery embodied in the European Water Framework Directive, could have a substantial impact on virtual water trade. So called ‘perverse’ subsidies, i.e., those that are bad for the economy and the environment (Myers and Kent, 1998) are however a difficult and widespread problem across the world. These subsidies are difficult to eliminate once granted due to the rent-seeking behaviour of both users and the administration itself, which develop clientelistic relationships. For example, according to Allan (2007) American agriculture is over-producing strategic food commodities whilst not reflecting the fiscal impacts of subsidies in their export prices. Thus, global trade in virtual water is much more dependent on global trade policy than national water policy aimed at increased irrigation. Authors like Williams (2004) believe that the concept of virtual water is useful to help re-define agricultural policy framed in the wider context of food security and global food trade.

Finally, some regions in the world live in conditions of extreme poverty, on less than US$ 1 per day. In these countries the majority of the population is rural and depends on subsistence farming; virtual water or importing food without giving due consideration to the staple diet of the country and to the potential impact on local agricultural markets could do more harm than good. The combination of high production costs due to lack of technology and the potential flooding by cheap and often subsidized products from global trade could substantially harm local subsistence markets.

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[7] On a positive note, meat demand has been shifting towards poultry, with the world consuming more poultry meat than bovine meat, which is positive for water footprints, since poultry has a much better conversion rate of cereals into meat (two to one) than cattle.

[8] Livestock production globally accounts for some 40% of the gross total value of agricultural production, and its role is continually growing as consumers adopt a diet richer in meat and dairy products.

3. The silent revolution: The intensive use of groundwater

In terms of re-considering physical water scarcity and the need to question 'technological fixes' largely spearheaded by central or national government, the next great advance is the silent revolution — groundwater use. The silent revolution has happened in the last half century in practically all arid or semi-arid regions across the world. A first wave took place in California, Italy, Mexico and Spain followed by a second wave in Asia, with a large part of India and the North China plains to parts of the Middle East and North Africa (Shah *et al.*, 2007). It is called a revolution because it has led to dramatic changes in water use and food policy in these regions. It is also called 'silent' because it has been mainly undertaken by millions of small farmers, with little control and planning on the part of the government administration (Fornés *et al.*, 2005; Llamas and Martínez-Santos, 2005b; Llamas, 2006b). It is estimated that global groundwater abstraction rose from a base level of 100–150 Mm^3 in 1950 to about 950–1,000 Mm^3 in 2000. In turn farmers abstract 900 Mm^3 of water to generate $210–230 billion, with a gross productivity of about $0.23–26 per m^3 abstracted (Shah *et al.*, 2007: 396).

The strategic importance of groundwater can be fully appreciated when considering specific data; globally 25% of global irrigation depends on groundwater, although in arid and semi arid areas this percentage goes up to 60% of irrigated agriculture. In terms of hectares the official number is estimated at 69 m ha, although other studies indicate that the actual figure might be closer to 100 m ha (from 30 m ha in 1950) (Shah *et al.*, 2007; UNESCO-WWAP, 2006). What is also highly relevant is that most of this land and 80% of groundwater abstracted is in some of the most heavily populated countries in the world like Bangladesh, Pakistan, India and China; or otherwise economically crucial for global food trade, like the United States.

Considering that by 2030, over 60% of the population will live in urban areas, claiming an increasing share of water abstraction (UNESCO-WWAP, 2006: 254) it is crucial to appreciate the role of groundwater in public water supply. It is estimated that groundwater systems globally provide 25 to 40% of the world's drinking water (Morris *et al.*, 2003). Another estimate calculates that more than half the world's population relies on groundwater for its drinking water supply (Coughanowr, 1994). In 2004 more than 2 billion people relied on groundwater for their daily supply (Kemper, 2004). In terms of scale, groundwater is crucially important in the world's mega cities and hundreds of other major cities which make significant use of groundwater (Foster *et al.*, 1998). In Europe for example, a substantial part of the population depends on groundwater for public water supply. Finally, groundwater is a useful back up in water supply gaps during long dry seasons and droughts, offering drought resilience. Managed aquifer recharge, shallow groundwater management, and rain water harvesting and recharge can, in fact, provide more resilient (and safe) drinking water systems in water short communities, especially relevant in the context of climate change.

The main reason for the huge explosion in the use of groundwater resources is technological innovation. The introduction of increasingly cheap tube well and mechanical pump technology and its wide availability has facilitated a social revolution in the use of groundwater, which has produced great socio-economic benefits (see Plate 1) (Giordano and Villholth, 2007). This is probably because of the autonomy and empowerment groundwater offers since it can be developed by individual farmers or small groups. Although operating costs might be higher (due to e.g., electricity costs), initial capital investment is much lower per irrigated hectare. Users can pump groundwater when needed, with precise application (e.g., when crops need water most), which can greatly increase yields (UNESCO-WWAP, 2007). Groundwater has been vital to yield and production increases, and in turn, has helped to reduce rural poverty (Moench, 2003). Intensive groundwater use has allowed rural communities to undergo a social transition thanks to improved farm incomes, the education of a younger generation and the migration of most of the family to nearby cities. This is, for example, evident in the Middle East where permanent shifts have occurred (Allan, 2006), and in South Asia where there are flexible and diverse adaptive part-time modes of rural–urban interaction.

There is some evidence that groundwater in fact promotes greater interpersonal, intergender, interclass and more spatial equity than surface water use (Shah *et al.*, 2007: 396). This is particularly the case in the use of shallow groundwater wells. It is estimated that groundwater is critical to the livelihoods and food security of approximately 1.2–1.5 billion rural households in the poorest regions in Asia and Africa (Shah *et al.*, 2007).

Groundwater provides flexible, on demand, irrigation to support vibrant wealth-creating agriculture (Shah *et al.*, 2007: 395). In India it has allowed 'small' irrigation to truly revolutionise agriculture in the country. This has been achieved mainly through the abstraction of 200 Mm^3/yr, from about 20 million wells to irrigate about 50 million hectares, i.e., 60% of the land (Shah, 2005). In a recent report of the World Bank, this situation has been described as a 'quiet revolution' (Briscoe, 2005). These efforts have been mainly undertaken and financed by small farmers or small municipalities, and the pattern extends to most of South East Asia, including Pakistan and Bangladesh (Shah *et al.*, 2006). In extremely poor countries, with less than 1$/per capita/per day, — where 500 million people live — the NGO International Development Enterprise (or IDE) created in the last 20 years a simple pedal operated pump (Polak, 2005), which has allowed these areas to evolve in a relatively short space of time to a diesel or electric pump.

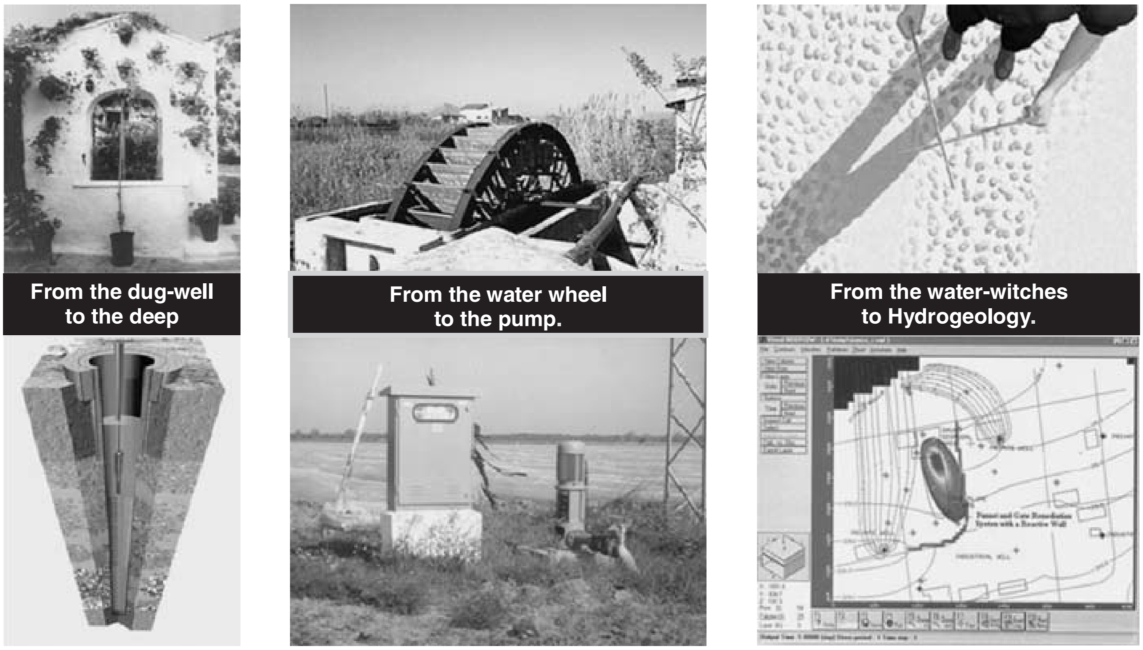

Plate 1. Technological changes generating a silent groundwater revolution.

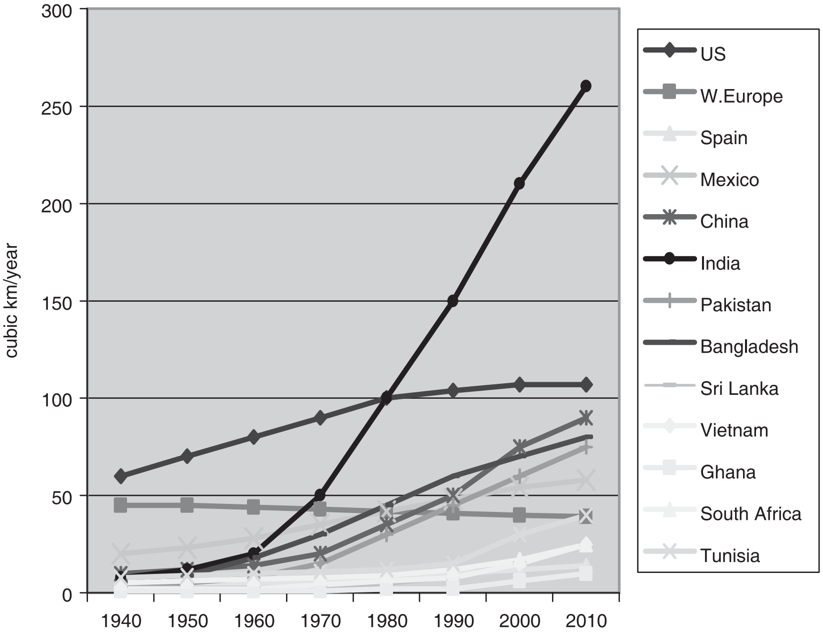

Figure 1. Growth in groundwater use in selected countries (author's estimates).
Source: Shah (2004).

Meanwhile, in mid-range countries, a potential initial solution will be the intensive use of groundwater (Llamas, 2005b; Allan, 2007).

Therefore groundwater is a key resource often underestimated in global water budgets in helping meet the Millennium Development Goal on poverty and malnutrition. This is mainly due to its affordability, and low abstraction cost even without 'perverse' energy subsidies. Abstraction costs usually vary between 0.02–0.20 US$/m^3. It has allowed significantly 'more crops and jobs per drop' than in-surface water irrigation systems, which in turn has helped the socio-economic transition necessary for other sectors in the economy to take off. Meanwhile in developed countries, more concerned with the green agenda than the brown agenda of environmental issues, the motto is changing to 'more cash and nature per drop' in the context of EU's Common Agricultural Policy. It is important however to note the cash generated per hectare in different contexts, for example, in Spain 60,000 euros/ha can be produced whereas in India, production concentrates on staple foods like cereals and rice, i.e., subsistence farming. However, there is no reason why the pattern adopted in Spain and other countries would not be adopted in the future by countries like India or China, which have shown a spectacular growth in the last decades.

Yet the main threat to the silent revolution is not physical scarcity once again, but lack of water governance. Often regulatory frameworks have lagged behind the quick take off of groundwater use (Wegerich, 2006). Even if regulatory frameworks existed or were developed, their implementation has often been ineffective in controlling and rationalizing groundwater use (Koundouri, 2004). Most regulators have limited understanding and poor data on groundwater situation and value (Llamas, 2003). It is difficult to say if groundwater governance is better in arid or semi-arid countries where groundwater is privately owned (for example, California, Texas, India, or Chile) or in countries where it is public dominion (for example, Mexico, Libya, and Spain).

In the course of this revolution there have been some significant casualties, mainly environmental. The use of groundwater is so economically salient, that often serious external environmental impacts have been ignored. It is easier for the authorities to turn a blind eye to its chaotic and irrational management due to its key strategic economic importance for agriculture, public water supply and industrial use.

This attitude, which has tended to ignore or disregard groundwater use in water planning, has been called 'hydroschizophrenia', where groundwater management was considered as totally separate from surface water, thus practically ignoring the concept of the hydrological cycle. The dominant view extended to the majority of the public is the 'hydromyth' that groundwater is a fragile resource (López-Gunn and Llamas, 2000; Custodio, 2002). Paraphrasing Hamlet: the main strategy adopted is to perceive groundwater as 'frailty, frailty, thy name is groundwater'. Yet this conveniently ignores its widespread use and its enormous socio-economic significance, thus evading the public duty of regulating a key strategic common pool resource.

Groundwater is now a key political issue in many areas of the world due to its strategic socio-economic significance for both irrigation and public water supply and increasingly its competing rival uses like industry or mining. Yet in many countries monitoring of groundwater use has been minimal, with most government and water agencies taking little or no action to assess and control groundwater use.

4. Desalination: Potential and limitations

Desalination is one of the most obvious technological advances in relation to access to 'new' water resources. Desalination is used mainly in arid and semi-arid areas either located inland where the only available water source is saline or brackish groundwater, or in coastal areas. Globally, about 50% of global desalination takes place in the Gulf, followed by North America (16%), Europe (13%), Asia (11%) Africa (5%) and the Caribbean (3%), whilst South America and Australia each accounted for about 1% of the global desalination volume in 2002 according to the International Desalination Association (UNESCO-WWAP, 2006). However, these trends are changing, with other countries considering desalination, particularly for public water supply like China, Mexico, Turkey and North Africa (Global Water Intelligence, 2007). In terms of the uses for desalinated water, municipalities are the largest users (63%), followed by industry use (25%). Additionally — and in view of climate change — desalination is often a key strategic option for many island environments. In terms of future uses, the IDA predicts new demands for desalination for recreation and tourism, the military, and irrigated agriculture (UNESCO-WWAP, 2006).

Technologically, in recent years there has been progress thanks to chemical engineering in membrane technology (Reverse Osmosis) (Service, 2006). This has allowed the removal of all impurities from water at a reasonable (and decreasing) cost to meet the increased demands of water-short areas. According to the UNESCO-WWAP (2006), the contracted capacity of desalination plants is 34.2 million m^3/day converting principally seawater (59%) and brackish water (23%).

The main reason for the increased consideration of desalination is that the cost of producing desalinated water has fallen dramatically in the past two decades. Equally, according to Voutchkov (2007) the cost of water production worldwide (from rivers, lakes and aquifers) has increased by 50% to 100% mainly due to limited availability, water quality degradation and more stringent drinking water regulations. During the same time costs for reverse osmosis desalination decreased by 50% to 100% as a result of breakthroughs in technology, energy use, engineering innovation and economies of scale. This means desalination is increasingly becoming an 'affordable' technology, since the energy cost to desalinize one cubic meter of sea water has decreased from almost 20 kwh to less than 4 kwh for a large desalination plant in full-time operation. This is generally the case with no hidden subsidies. The energy consumed to drive the conversion is a significant part of the cost and ranges from 4 to 15 kWh/m^3 depending on factors such as the technique used, the production rate of the facility, and the quality of the equipment. (UNESCO-WWAP, 2006: 150). The cost of desalinated water is about US$ 0.5/m^3 for large plants working almost continuously. The price is lower if desalinating brackish groundwater, where costs decrease to US\$ 0.10–0.20/m^3. In most cases this cost is affordable for urban water supply in cities near the coast and also for irrigating cash crops.

At present, desalination is mainly an option considered in arid and semi-arid areas, and particularly in wealthy regions like parts of Australia and California. In the case of Australia, the policy adopted is one of 'security through diversity' (McCann, 2007). The desalination market is currently estimated at US\$ 150 million a year and according to the private sector predicted to expand by 35% per year for the next four years. These predictions are likely since about 85% of the population in Australia lives on the coast and the other 152 municipalities have a small population. Furthermore, plans for desalinated water are being revised upwards. For example, the Gold coast plans for 50 ml/day by 2050 have now been revised to 125 ml/day on a request from Queensland state government, to cover the water needs of Brisbane and south east of Queensland. Sidney has also issued a tender for a plant in the 250 ml/day range (Degremont/Veolia). Meanwhile, in the USA, population in the state of California is set to increase from 36.5 to 48 million requiring a possible 4 Mm^3/day new water to be put into supply. The California Department of Water Resources established a US\$ 50 million desalination plant programme in 2004 aimed at assisting water utilities across the state in implementing brackish water and seawater desalination projects.[9] By 2020 most southern Californian water utilities are planning to supply 10 to 20% of their water from the ocean. However, a recent study by the Pacific Institute (Cooley *et al.*, 2006) gives some note for caution. For example, the desalination plant in the city of Santa Barbara is being decommissioned for economic reasons.

Meanwhile in the United Kingdom, not traditionally perceived as a water scarce country, due to the heavy concentration of population in the south east, a private water company has invested £300 million (US\$ 539 million) in a reverse osmosis plant to treat water from the tidal estuary of the River Thames to serve 900,000 customers in London, producing up to 150,000 m^3/day for the public water supply (UNESCO-WWAP, 2006).[10]

In developing countries like China, Turkey and Mexico there is growing interest in desalination. For example, in China the lack of access to traditional water sources is making desalination an option. This is the case, for example, in coastal north China where four coastal provinces, which account for 25% of China's GDP, have an estimated demand gap of 16.5 to 25.5 billion m^3/yr by 2010. In addition, new tight regulatory controls on groundwater abstraction and the use of surface water are forcing consideration of other water supply options. At present the interest is mainly for industrial purposes, but by 2010–2015 when convergence between cost of desalination and municipal water tariffs is likely to happen, there will also be interest for the public water supply. At present the installed capacity is 380,000 m^3/day, yet the forecast for 2012–2015 is 2.5 Mm^3/day (Global Water Intelligence, 2007).

The reason why desalination has been discussed in this paper is because it is a technology that is already providing solutions to urban water supply in coastal areas, where much of the world's population currently live and many more millions are likely to live in the coming years. It is also a technology that could be used for irrigation of high value crops, thus freeing up other cheaper water resources for such uses as the public water supply of the poorest sectors of the population, which cannot afford to pay for desalination, and for small scale irrigation schemes.

5. The role of GIS and the internet in increasing transparency and participation

Possibly one of the most important problems in water conflicts is the illusory accuracy of data, and in many cases as the saying goes: 'Half-truths are worse than open lies'. Yet advances in the use of the internet, GIS and remote sensing can increase transparency and increase participation of multiple users. This in turn can facilitate monitoring and control a classic sign of 'healthy' water management systems, which makes water managers and users mutually accountable. Rapid developments in communication technologies can help record and disseminate experience, and strengthen social learning in decision-making processes, through information, knowledge and stakeholders participation (UNESCO-WWAP, 2006: 336). The application of satellite information and modeling can have a substantial impact on water resources monitoring in lower-income countries.

Generally transparency and availability of water data is scarce. Key data where information tends to be lacking or is most inaccurate are on the one hand, irrigated area and types of crops and on the other, inventories of groundwater uses and rights. Yet relatively new technologies like remote sensing can help provide these data in a fast and affordable way. An additional advantage in the use of GIS and remote sensing is that it can facilitate the increased participation of different water users and stakeholders at different levels. For example, there is already a case in Bolivia where the use of a GIS-based programme allowed comparison of the efficiency of water allocation of customary uses *vis-à-vis* proposed allocation arrangements based on formalising water rights. This use of GIS in effect highlighted that the existing process was not less efficient that the proposed changes.

GIS, internet and remote sensing can encourage increased government transparency and make information accessible to civil society at large. This is because GIS and

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[9] The first round of the programme in 2005 awarded \$24.5 million to 24 different desalination projects. The second round awarded \$21.5 million grants to 23 projects in June 2006 — Applied, research, pilot testing implementation of demonstrations and full scale desalination projects.

[10] At present plans for this desalination plant are pending approval by the London Authority (Stuart Orr, personal communication)

internet allow elaboration and dissemination of data to the general public with a relatively small investment. Information transparency can prevent corruption, clientelism and inertia, whilst taking decisions that sometimes are politically difficult yet necessary. It brings about deliberative democracy in water management, essential to achieving sound water governance (Innes and Booher, 2000; Lowndess *et al.*, 2001; Bulkeley and Mol, 2003).

Remote sensing, GIS and the internet are cheap, available tools that can play a crucial role in order to achieve a participatory management. The incorporation of methods and techniques such as GIS, remote sensing and other quantitative, digital or statistical forms of data can provide a vehicle for increased participation. This is particularly the case with new trends towards participatory GIS research or so called Public Participation GIS (PPGIS) with its capacity to empower by incorporating diverse forms of local knowledge. GIS is particularly powerful because of its visualization potential, and its ability to communicate complex data in a user friendly, accessible format. It also opens up decision-making since it can force a dialogue between different types of knowledge, namely rationalist, expert or scientific, which is often granted greater legitimacy and other more localised, grounded and experiential knowledge. In this case, the process itself can become as important as the end product itself (i.e., GIS maps) since in the production of GIS maps a dialogue can occur e.g., with marginalised sectors of society. Through collaborative efforts, it can help transform certain political or institutional cultures. PPGIS can help make transparent the constant process of negotiation and knowledge production that is often obscured in expert systems, and which are then often distrusted by those it is supposed to benefit (Elwood, 2006). There are still some questions on the digital divide i.e., the uneven distribution worldwide of communications technology and access to, and use of information, although hardware and software costs are dropping increasingly.

Whereas it was once difficult to map a community, it is now relatively easy with the use of satellite imagery and geographic information systems. In today's market, satellite images are no longer expensive. This development, coupled with a UN-HABITAT programme to provide GIS capability in up to 1,000 cities globally, makes it feasible to bring this technology to local authorities. The use of GIS by local authorities, commonplace in high-income countries, provides a basis for collecting the kinds of spatial information needed for pro-poor governance (UNESCO-WWAP, 2006).

6. Conclusion

This paper has shown that there are already two politically silent events, virtual water and groundwater, which are helping to prevent the often quoted 'water crisis'. Both are politically silent yet are allowing countries, particularly in arid and semi-arid regions, to sidestep the problem of water scarcity. However, this paper has also highlighted that these 'revolutions' generated thanks to scientific and technological innovation should not occur in a vacuum and it is the responsibility of states and other actors to carefully assess their full potential and limitations.

It seems clear that the introduction of key concepts like virtual water and the water footprint have generated new ways of looking at old problems, like the traditional concept of food and water security, and the concern that humanity will shortly be 'water-stressed'. Trade in virtual water constitutes a key element in helping to eliminate or at least soften the global water crisis. However, it is not a panacea. Methods must be further developed, data have to be improved and the side effects or unintended consequences — economic, social, geopolitical and ecological — better studied.

Most solutions proposed at present for the 'water crisis' are 'hydrocentric' based on the watershed (Brichieri-Colombi, 2004). However, as it was discussed above decisions on the type of crop or on food trade would have a much higher impact than any decisions to build new large water infrastructure and improvements in irrigation efficiency. This leads towards a re-definition of the unit of analysis away from a pure watershed towards the concept of the 'problemshed' — as defined by Allan (2006). That is, taking into account that globally approximately 70% of water is used for agriculture, the decisions on which crops are grown (and their embedded water use), and which foods are imported as virtual water, have a substantial impact on the country's or catchment's water budget. Equally, ignoring the huge boom in groundwater use can only lead to the mismanagement of a key strategic resource that has already been instrumental in lifting millions of people out of poverty, in line with the MDGs. Desalination, although still out of reach for poor countries, is increasingly becoming affordable to wealthy farmers and large mega cities, thus freeing up other traditional water resources like groundwater for other sectors. Last but not least, the revolution in information technology (internet, GIS and remote sensing) can bring much needed transparency and accountability to a sector that has been traditionally mired by its problem of water being a natural monopoly and what this entails (Stalgren, 2006).

The current competition over water resources requires innovative solutions to old problems. This translates into a portfolio of appropriate solutions to specific problems, instead of the old mentality where one size fits all, i.e., where water infrastructure was *'the'* solution to *'the'* problem of water scarcity. Science and technological innovation already offer cheap, accessible options to areas under so-called 'water-stress', but like any advancement in technology and knowledge it has to be grounded in the equitable and efficient allocation of water.

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Corrigenda

In *Natural Resources Forum* 32 (2008), 228–239, ‘Re-thinking water scarcity: Can science and technology solve the global water crisis?’ by Elena Lopez-Gunn and Manuel Ramón Llamas:

Page 229, column 1, line 5: ‘110,000 Mm^3’ should have been ‘110,000 km^3’.

Page 230, column 2, paragraph 4: ‘7,500 Mm^3’, ‘1,500 Mm^3’ and ‘115,000 Mm^3’ should have been ‘7,500 km^3’, ‘1,500 km^3’ and ‘115,000 km^3’ respectively.

Page 232; column 1, paragraph 1: ‘950–1000 Mm^3’, ‘900 Mm^3’ and ‘200 Mm^3’ should have been ‘950–1000 km^3’, ‘900 km^3’ and ‘200 km^3’ respectively.