CHAPTER 4

Can human ingenuity, Science and Technology help solve the world's problems of water and food security?

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ABSTRACT: This chapter argues that advances in human ingenuity (*how we think about problems*), science (*what we know and not know about problems*) and technology (*what we can technically do about problems*) produced in the last decades contribute to *solving* problems of water and food security (or insecurity and associated conflicts), with methods that were unthinkable only two decades ago. This chapter only considers four of these advances. Obviously there are other promising advances but what is presented here refers mainly to those that are cheap and easily available. These are: 1) communication technology (chiefly the Internet) that facilitates, participation, public awareness and education, as well and transparency, which can contribute to reduce corruption; 2) the spectacular increase in virtual water trade due to advances in transportation; 3) desalination thanks to membrane chemical technology that is able to desalt seawater or brackish groundwater or to regenerate waste water at decreasing costs, affordable for many industrial and urban uses; and 4) the silent revolution of irrigation groundwater development that has produced stupendous social and economic benefits although in some countries this has also induced a colossal anarchy and ecological problems. All these aspects are intertwined. However, technology alone will not solve the main water problems. It is necessary to achieve an equilibrium between their utilitarian and symbolic or cultural values. Solutions to water conflicts require considering not only social ethics but also environmental ethics.

Keywords: science policy interface, extended water footprint, virtual water, desalination, groundwater governance, transparency and accountability

> *Paul Polak (2008: 218) writes that, when he returned home tired and discouraged from his trips trying to end poverty through the International Development Enterprises, his two daughters played the theme song of musical The Man of La Mancha.*
> *The main song in this musical is the IMPOSSIBLE DREAM.*
> *This paper argues that impossible dreams are in fact, possible.*

1 INTRODUCTION

Despite current predictions on doom and gloom, this chapter will argue that there is enough knowledge, technology and resources to address many predictions on water and food scarcity. The solutions to global water problems however do not lie in the water arena but rather in policy decisions currently being taken *out of the water box*, in current negotiations over trade, aid, development and energy policies. In this sense this chapter is a follow-up of an article already published (López-Gunn & Llamas, 2008). It was argued that at present there are opportunities in terms of available scientific knowledge and technology that are relatively cheap and accessible to address water problems of around 80 to 90% of the global population. Rogers *et al*. (2006) and Rogers (2008) present similar conclusions.

The chapter is structured in the following way: the section below highlights the key importance of changing the way we *frame the problem*. This in itself can have the highest impact: i.e. innovation in policy making by looking at old problems from a new perspective. The second section focuses on the gap between science and policy by focusing on the gap itself, i.e. on how research and knowledge has be to opened up through processes of inclusion, transparency and accountability. The third and fourth sections then focus on two examples of new ideas (virtual water and the water footprint) that can help re-frame old problems, and how new technologies (desalination) can open up the room for policy manoeuvre (i.e. new water). The final section addresses areas that are often neglected despite their significance (the silent revolution in groundwater uses) and the challenge in bringing them into the spotlight.

In the last two years we have received feedback that have shifted our thinking in ways that we are integrating into this chapter. Feedback to our 2008 paper seems to indicate that we were over-optimistic on the ability of science and technology to solve current global water problems. We believe that we probably did not give enough weight to a third pillar: *thinking out of the (water) box*, i.e. new ways of thinking about seemingly intractable problems. Also a fourth pillar, the fact that decision making is inherently political, and that *rational* decision making based on new evidence is not an automatic and quick process, and knowledge is by-and-of itself not sufficient to trigger change.

In fact, in previous publications one of the authors of this chapter (Llamas & Delli Priscoli, 2001; Delli Priscoli *et al*., 2004; Llamas *et al*., 2009) has long sustained the position that –in order to solve water conflict– it is necessary to achieve an equilibrium between the utilitarian (economic) value of water (i.e. irrigation, production of energy, and others) and the intangible (cultural, social, religious, and other values). This view was also adopted by a working group on the Ethics of Freshwater Uses and approved by the UNESCO Commission on the Ethics of Science and Technology (Selborne, 2001). These guiding principles are particularly relevant for policy making, giving clear directions for decision makers. The *ethics* that should underpin global policy making in the field of water echo other policy debates on the right to water, the right to sanitation, and the right to food, i.e. governments and other actors like corporations have clear *moral* duties and responsibilities *vis a vis* their citizens to provide access to affordable water and food. Water is an economic good, but it also has clear social and cultural values (Delli Priscoli *et al*., 2004). The underlying concept is that science and technology are not by themselves sufficient to solve current water problems. The crux of the potential solutions demands that greater attention is paid to both social and environmental ethics. Social Ethics deals with the relations between human beings, and is reflected in a rights based approach to development (United Nations, 1998), based on human dignity and inalienable rights; meanwhile environmental ethics acknowledges the new capacity of humanity to dramatically alter the environment in ways unprecedented in human history. This links up with new theories on solidarity rights which encompass the right to a healthy environment.

The debate on the positive or negative effects of scientific and technological advances on the future of humanity and nature is alive (as well as on affluence, population growth and other factors). A recent article by Goklany (2009) provides evidence on the general positive impact of advances in technology on human welfare.

This chapter will discuss the following four advances in new ideas, scientific evidence and technology:

a) First, the revolution in Information Technology, which can *democratise* an inherently technical sector and can open up decision making towards deliberative processes in water governance (information, participation, education, accountability and data transparency).
b) Second, how globalization and cheap transport has facilitated virtual water trade. New information and evidence generated by the use of the *extended (economic and hydrologic) water footprint* provides an easily understandable and intuitive tool to showcase options *en route* to Integrated Water Resources Management.

c) Third, thanks to technical advances like membrane technology (Bernat *et al*., this volume), the possibility opens to produce *new water* due to the decreased cost of desalination from seawater, brackish groundwater, or from water reuse from urban and industrial polluted water.
d) Fourth, the recent spectacular increase in groundwater abstraction (according to Shah, 2008) from 100 to 1,000 km^3/yr –occurring in some of the most heavily populated countries in the world– is facilitating fast socio-economic change, thanks to the massive uptake of drilling rigs and turbine pumps. This silent revolution has developed spontaneously, largely due to farmer initiative, in many cases by millions of modest farmers and often outside the planning and control by Water Authorities. There is evidence that this has generated social change, although there are some pending questions over this anarchical model of development.

In relation to the common denominator of the ideas discussed in this chapter, the key criteria is that these are *cheap* and *accessible* in the sense that these are affordable by private individuals, companies or governments and where the pay-off is greater than the cost.

For example, in developed countries investment in desalination and reuse in e.g. coastal areas, can free up water resources for other sectors. In middle income countries, or emerging economies like the BRIC countries (Brazil, Russia, India and China), virtual water trade and the *extended* water footprint can help identify where resources will deliver greater socio-economic welfare. In developing countries, groundwater offers a relatively easily accessible resource that requires small investment, and provides security in the context of e.g. rainfall variability, which is at the root of its silent revolution. Meanwhile issues related to advances in information technology are probably beneficial to all, in terms of data transparency, and these offer the potential to open up decision making processes and thus increase accountability, e.g. of all stakeholders: users, of water authorities, and of businesses (Transparency International, 2008).

2 WATER AND FOOD SECURITY: THINKING OUT OF THE *WATER BOX*

This chapter is mainly concerned with the generally positive influence of the main advances in science and technology to address global water and food security. For the purposes of this chapter, water security and food security are defined as having access to *sufficient, safe, acceptable, physically accessible, and affordable water and food, in the context of sustainable development and livelihoods*. There are differences to the specific way to secure water and food. For example, in the context of *water security* often this has been related to security from damage from extreme events, and linked to the capacity to adapt to these extreme events. Equally, food security also refers not only to the food quantity but also to its nutritious value.

The major driving forces for decision making in relation to water resources allocation and management however are located outside the water arena, i.e. decisions that have the most important effect on water use are often not taken by persons or institutions in Water Authorities. For example, decisions currently taken in the field of agriculture, energy (e.g. bio-fuels) and trade liberalisation are ultimately the key driving forces of water use at both the national and the river basin local level (United Nations, 2009: XIX); and *viceversa*, e.g. the 2008 food crises was also related to factors exogenous to agriculture (Lamo de Espinosa, 2008; 2009). This is exemplified in other chapters in this book, which highlight that the water footprint of any given country is mainly driven by its agricultural policy, since agriculture accounts globally for 70–80% of global water use and 85–95% of global water consumption (United Nations, 2009; Kuylenstierna *et al*., 2008). This number is even higher in arid and semi-arid countries, and in developing countries and emerging economies (including BRIC countries).

Therefore there is a paradox in water policy (like in other policy areas) in the large gap between policy and scientific evidence, and where additional effort is needed to bridge the gap between scientific knowledge, and the world of policy and politics. It is now accepted that the assumption that *good* ideas and new evidence would filter automatically into policy is not guaranteed. Reality is much messier and more complex compared to this *assumed* rational decision making policy process.

The study of the interaction between science and policy is arriving at the same basic conclusion: good ideas can indeed change policy but good ideas by themselves are not always a sufficient condition. A number of factors are at play like: timing, communication and increasingly the role of policy entrepreneurs pushing the idea through. This is a topic previously described in a note by Margaret Catley-Carlson addressed to all the participants which can be read in Botin Foundation website [http://www.fundacionmbotin.org/agua] and as a Postscript in this book (Catley-Carlson, this volume). It was one of the most interesting *hot issues* debated in the Workshop brain storming.

In most countries there seems to be a *communication gap* among persons and/or institutions taking decision that significantly affect the water policy of that country. A good road map of these processes would help to bridge this gap. One of the stumbling blocks is the assumption that the transfer from knowledge to policy is simply a matter of improved communication. However, there is increased realisation that this linear-rational model is at best idealistic, and that *sound science* can in fact fail to have any meaningful policy impacts.

In relation to water policy and scientific knowledge, there are a number of issues in the science/policy interface:

First, the scope of valid knowledge (and its legitimacy) has expanded: different kinds of knowledge (expert, lay, scientific, quantitative and qualitative) are now perceived to fit different purposes.

Second, the aim of science/policy interaction cannot be idealised: knowledge can be also used for instrumental reasons, to fit pre-existing policy frames, and be discarded if it does not fit these frames. This situation has occurred throughout history and also in modern times. Scientists who dissent with what is *politically correct* can be ignored or stamped out by hidden or open lobbies (see for instance B. Martin in Newsweek, 1993). The recent debate on climate change, including the stalemate at COP 15, the *climategate*, and the Himalayas glaciers report may be other examples.

Third, issues of relevant timing. In many cases the adoption of new ideas capable of changing policy and shift political inertias can take anything from 10 to 25 years. As the saying goes today's philosophy 20 years later is common sense. This means that scientists should be aware that ideas, scientific advances and technologies currently being developed, could be in operation 10–25 years hence. Other times the uptake of research findings is quick and effective. This is because there are sometimes critical points in time, so called *tipping points* and policy windows which open and when the policy environment is receptive to new ideas and evidence. However, in other cases new research can be uncomfortably ahead of its time, and be *politically inconvenient*, if it does not suit pre-conceived agendas or give answers to pre-conceived problems (Owens *et al.*, 2007).

There are a number of scenarios, e.g. where there is little evidence and no policy, or when there is policy without evidence (Davoudi, 2006), or as in the case of water, where there is evidence in the water field, but most relevant policy decisions lie out of the *water box*. The challenge then is to align science and innovation in water with powerful processes and inertias taking place out of the *water box*. This process of *translation* and *adoption* may be *speeded up* or *fast forwarded*, with scientists acting as policy entrepreneurs (Kingdon, 2003; Jarvis, 2008) or knowledge producers (Catley-Carlson, this volume). As Lorenz (1992: 181) notes, according to Samuel Popkin a *political entrepreneur* is an "innovator who solves collective action problems not by offering selective incentives, but by persuasion and changing beliefs, beliefs about the value of the collective good and expectations about the behaviour of others". According to Schneider & Teske (1992), political entrepreneurs are individuals whose actions produce unexpected results and induce policy changes. Yet not all good ideas and innovations will be taken up, and the challenge is to analyse and understand key factors that increase the chances of an idea being adopted, and anticipate and characterize the likely barriers to enacting new policies and strategies for overcoming these barriers. If one adopts a non-linear and complex model of understanding the interaction between science and policy, i.e. a less purely rational approach to science, this can help identify supposed barriers or constraints which in a *rational* policy frame are often perceived to be in the cultural, social and political arenas. A complex perspective on policy in fact can help perceive these supposed barriers in a different way, to shift our understanding on these supposed barriers to policy change, which in fact can provide early indicators and powerful signals about deeper processes of socio-economic change. Carefully studying the politics of resistance and opposition e.g. to policy change, may assist in bridging knowledge and policy through processes of public engagement (Eden & Tunstall, 2006).

Fourth, influencing policy can happen in different timeframes: in some cases the most powerful impact might be as stated earlier the re-framing of the problem itself, which then makes it more open to *knowledge creep* (Radaelli, 1995) or to *enlightenment* (Weiss, 1977). In other cases a distinction has to be made between research, which might be very useful in the long term, yet it is not very usable in the short term (Owens, 2005), and knowledge. Yet science and policy interaction covers this whole spectrum from immediate impact to the long term re-framing of policy paradigms.

This happy consensus between politics and science however can be difficult, and in fact sometimes undesirable. For example, Malthus's catastrophic predictions or prophecies on the grim future of humanity if population continued to expand have not materialised. In fact, since Malthus time (1766–1834) the world's population has substantially increased by a factor of more than six[1], on track to reach 7,000 million in 2011, only 12 years after reaching 6,000 million in 1999. Virtually all of the growth is in developing countries. Also the growth of the world's youth population (ages 15 to 24) is shifting into the poorest of those countries (Population Reference Bureau's 2009 World Population Data Sheet). Food production –Malthus's main concern– has increased at a higher rhythm than population, and the average food kcal/day per person has increased from 1,700 to 2,500. Equally, since the 1950s, the area of the world under cultivation has increased by roughly 11%, while yields per hectare have increased by 120% (Goklany, 2009; Kuylenstierna *et al*., 2008; CAWMA: Comprehensive Assessment of Water Management in Agriculture, 2007).

Box 1. Examples of increased water productivity in agriculture (*Source*: Allan, 2009).

Farmers as *big water* managers key to increased water productivity.

1) North West Europe:
   Farmers in North West Europe trebled rain-fed wheat yields from 3 to 9 t/ha [t = tonne = 1,000 kg] between 1961 and 1990. This is compared to the yield of 1 t/ha in 1800 using the same volume of water.
2) India and China:
   Indian and Chinese farmers increased wheat, rice and maize production between 1961 and 1990 by 4 and 5 times. Water productivity was not at this level but it was still in the order of three times higher.
3) Vietnam:
   In Vietnam after the end of hostilities in 1975 Vietnamese farmers moved rice yields from 2.5 t/ha to 7 t/ha and increased to double and triple cropping so that some tracts were raising 20 t/ha/yr. Vietnam is now the second rice exporter. It was importing in 1975.
4) Egypt:
   Egypt has increased its wheat yields from 2 t/ha in 1960 to 7 t/ha today and yields and returns to water are still increasing. In the case of Egypt the increased returns have been due to blue water.

From this point of view, it is interesting to reproduce most of the written statement of A. Allan (2009) on occasion of the Workshop:

> "Farmers are the main water managers and they manage the big water –that is the water used in agriculture which is more than 80% of all water in the world's economies of which 70% is

[1] [http://belfercenter.ksg.harvard.edu/publication/1734/dont_count_out_malthus.html].

green water. If farmers were to double water productivity –that is double returns to water– they would make a very important contribution to global water security. [In fact] more than any other community.

Yet farmers compete with the environment for water more than any other community, because of their key role in managing *big water*. Therefore we need to understand what motivates farmers. Society needs to value what they do more than it has until now. We need to encourage farmers to further increase water productivity and at the same time be environmentally aware. In addition to the above, consumption and international trade asymmetries need to be understood and where necessary remedied."

Malthus's oversight was to ignore human ingenuity and its capacity to solve problems. For instance, one hundred years ago the typical yield in staple food (e.g. wheat) was about 1,500 kg/ha/yr. Today in industrialized countries yields are around 8,000 kg/ha/yr, whilst in most developing countries, it is about 3,000 kg/ha/yr (Goklany, 2009; Kuylenstierna *et al*., 2008).There is no reason to believe that human ingenuity to cope with new problems in water, food and other issues is now finished. Nevertheless, as The Economist (1997, December 20th) pointed out, there will be always forecasters of scarcity, the so called *limits to growth debate*: "they are invariably wrong but they think that being wrong proves them right". As the Director of the World Water Week wrote "the natural resources are limited but human ingenuity is boundless".

There are different opinions on whether it would be possible to feed the 3,000 million human beings who will probably inhabit earth within half a century. To cope with this problem different solutions are proposed but these are mainly classified in three groups:

a) An increase arable land in rain-fed agriculture.
b) An increase in irrigated land.
c) To increase agricultural productivity per m^3 of green or blue water used.

For instance, according to CAWMA (2007), the additional necessary food could be obtained if productivity in developing countries increased by about 30% from their current productivity; this also requires an increase in irrigated surface which will demand an additional 500 km^3/yr of blue water. However, Kuylenstierna *et al*. (2008) present a more optimistic perspective, because they consider that technology improvements are sufficient to cope with the increasing need for food due to a higher standard of life and population growth. Statement by Allan (2009) on occasion of the Workshop is quite hopeful.

Goklany (2009) shows that the situation is just the opposite: for example, the variation in life expectancy in the last hundred years has increased substantially in all the countries (industrialized and developing), which many authors consider as one of the best indicators for social well-being. These ideas are in close agreement with those presented decades ago by Simon (1996) and Clark (1968).

3 BRIDGING THE GAP BETWEEN SCIENCE AND POLICY: TRANSPARENCY IN DECISION MAKING AND THE ROLE OF THE INTERNET

The previous sections highlighted that more attention has to be given to the *gap* between policy and science and innovation. This gap sits mainly between the political economy of water and the scientific and technical contexts. There is an increased tension to open up decision making processes to society, and the potential powerful role (rarely realized in practice) of *meaningful* processes of participation, accountability and transparency. The call for greater civil society participation is redundantly mentioned in most documents on water governance, starting with the Dublin Principles (United Nations, 2009; CAWMA, 2007; Transparency International, 2008; Salman Salman, 2004). The Dublin Principles which *instituted* public participation as one of the cornerstones for water policy was re-instated in Agenda 21 and Rio. Nevertheless, the achievement of this goal, as adopted in Article 14 of the EU Water Framework Directive, is far from being a reality in most EU

Member States. The situation outside of the EU and the USA is possibly even more fraught with problems.

The onset of many social movements and contestation of key issues in relation to water (e.g. dams, human right to water, Doha round) is possibly a proxy indicator of the exclusion of different perspectives and types of knowledge and opinion. The challenge therefore for participation is to move beyond rhetoric, and this is where democratising knowledge, through science and innovation itself can contribute.

For example, Transparency International (2008) estimated that up to a 25% of the funds theoretically used for water infrastructures are lost in bribes and other types of corruption. Although the correlation between transparency and less corruption is still not fully proven, what is clear is that there is increased evidence between the link between transparency and economic growth. This relates to addressing the problem of information asymmetry, which is a classic example of market failure. Transparency is a core component of the so called second generation institutional reform, and it is increasingly associated with better socioeconomic development, as well as with higher competitiveness and lower corruption, which ultimately can improve policy outcomes (Bellver & Kaufmann, 2005). Transparency for example, can facilitate participation and collective action by stakeholders. Transparency is at the heart of water governance and a fair allocation to users and sound incentives for efficient water use (WEF, 2008). The authors of this chapter are currently involved in a project with Transparency International (Spanish chapter) to develop transparency indicators on water management that will be applied to all river basins in Spain.

Without an equivalent progress in their implementation, the value of international declarations to solve drinking water and malnourishment decreases as the number of declarations increase. The effect of their overall impact and eventual legitimacy wilts if it is not matched by their effectiveness and implementation. For example, paying lip service to participation can in fact backfire and be seen as hypocritical, eventually losing value and meaning. Capacity building, participation, bottom-up initiatives, the empowerment of women, transparency, accountability, and so on can become once more elements of social engineering, if these are not translated into results and real change to people on the ground.

The use of Internet and of GIS (Geographic Information System) can be a great aid to achieve the goals of transparency and participation, and may even indirectly be a great means to fight corruption in the water sector. Technology can now provide the means at a relatively affordable prize to provide better monitoring and data collection and transparency. Reform and change is inherently a political, negotiated process with potential winners and losers when, for example, water is subject to being re-allocated between e.g. agricultural and urban users. Data transparency can be a catalyst against the inherent resistance or inertia in the system against change. For example, transparency can shed light on false or inaccurate pre-conceptions on cost and benefits, identify data and knowledge gaps, and help shift to other criteria like e.g. cost effectiveness and full cost recovery (as demanded in Europe by the EU Water Framework Directive).

The case of virtual water is a case in hand, e.g. the *true* cost and benefits of physically transferring water resources, *vs*. the cost effectiveness of transferring virtual water. For example, the farmer lobby has proved very successful framing of what is *politically correct*, and in political terms the farming lobby is a feared enemy by any government having to tackle the re-allocation of water resources e.g. from agriculture to other uses. Transparency can help to assess trade-offs (water accounting, social and environmental impacts) and open up decision making through sharing information and knowledge in a more equitable way.

Policy making is a messy process with many drivers in constant flux, therefore new information has to be constantly produced and updated to help steer direction, and in the particular case of water, achieve the idealised model of adaptive management. For example, the problem of managing expectations in public consultation processes. As Catley-Carlson (this volume) points out: "Consultation is dangerous unless there is a consultation strategy –in terms of a realistic assessment of the key stakeholders". Here science and innovation can help democratise decision making processes, whilst encapsulating the complexity of the issues at hand, the use for example of techniques like Participatory Bayesian networks, participatory modeling and participatory GIS have provided powerful new tools for decision support (Zorrilla, 2009). New accounting tools like the water footprint can also help shift debates, e.g. by questioning established assumptions, e.g. in the case of Spain on the economic productivity of water by different uses (Garrido *et al.*, 2010).

4 VIRTUAL WATER TRADE AND THE WATER FOOTPRINT

For current global water use, agriculture is the key sector not only for food security but also for water security, since about 85 to 90% of all (blue and green) water consumed by humans is used for agricultural activities (Hoekstra & Chapagain, 2008). In this context, there are some areas which – due to a combination of geographic location, population pressure, and rapid economic growth – face key decisions in relation to water: Indus-Ganges, Northern China Plain, and the North America High Plains, also called *hot spots*.

The volume of water consumed by evapotranspiration in agriculture seems to be in the order of 7,000 km^3/yr (CAWMA, 2007; Hoekstra, 2009). A study by FAO-IFAD indicates that there are 1,500 million hectare (Mha) of cultivated land. Out of this 1,500 Mha, about 300 Mha are irrigated cropland. Out of this 7,000 km^3/yr, around 80% is used domestically (inside the country where the agricultural goods are produced) (Hoekstra & Chapagain, 2008). From this, 20% of virtual water traded in food only about 15–16% according to Yang & Zehnder (2008), is imported by arid and semiarid countries. In other words, it seems that the virtual water traded to solve water and food security is smaller than 4% of the total amount of water consumed currently in the planet to feed the 7,000 million persons who inhabit it. However, Liu *et al.* (2009) consider that the previous numbers are too high and that the real consumptive use is significantly smaller.

Nevertheless, this small percentage is very important to solve the problems in a good number of arid and semiarid countries. One typical example is the MENA (Middle East and North Africa region) where the volume of virtual water imported is greater than the Nile river average annual stream flow (Yang *et al.*, 2007; Kuylenstierna *et al.*, 2008). Increasingly more *water-poor* countries will be looking outside their borders to secure access to virtual water, or in some cases, for land to grow their food, as is the case e.g. with Saudi Arabia currently in the process of buying land in Sudan (Cotula *et al.*, 2009).

Virtual water trade has advantages and disadvantages. For example, it could be argued that the current land grab is an unintended consequence of the increased awareness on the key strategic role of virtual water. Equally, there is increased awareness of the potential *blue* water savings from international food trade for *water poor* countries. Overall the estimate on global water savings due to trade is around 300–500 km^3 (Hoekstra & Chapagain, 2008). This is between 4–8% of the total global agricultural footprint (around 7,000 km^3/yr). On the other hand, the cascade of errors in many estimations of evapotranspirative consumption (scale factor, type of soil ignored, and others) is probably much greater than 5%. Therefore, we have to be very cautious on the relevance or scale of global water savings due to virtual water trade. The main advantage might be that virtual water trade could represent strategically significant outside options for intensively developed river basins. This is a way to secure access to additional (virtual) water resources, thus keeping real green and blue water for key uses like public water supply and e.g. high added value industrial uses like solar thermal energy. For instance, preliminary assessments indicate that in Spain the economic productivity for water in thermo solar is between 100 and 200 greater that the economic productivity of water for irrigation for cereals or cotton (Garrido *et al.*, 2010). It seems obvious that cereals and cotton can be imported from other water rich countries and would be therefore meaningless to prioritize water uses for irrigation over thermo solar production.

However, this raises some key issues related to regulatory structures on both national and global food trade, as well as national and global regional structures in order to adapt them and make them resilient to these fast changes in trade and land ownership. Trade has the potential to help countries manage water security in a globalised world system. However, the global trade system is outdated and in need of deep reform (WEF, 2008). In the context of the current stall in World Trade Organization (WTO) negotiations, and the growth in bilateral negotiations, questions are centred on how food trade fits into inherently political decisions. If water scarcity or its increased opportunity cost is internalised into global trade structures, there are some key areas that should be addressed: e.g. could food and fibre international trade be regulated by policies derived from virtual water? Is livestock a sector that merits special attention due to changes in diet, and its implications in terms of increased water demand? Should regulation be introduced on clean and dirty energy and incorporated in the goods that are traded internationally? Would there be additional problems if virtual water and dirty and clean energy are used to design international trade policies?

There are also some pertinent questions raised on whether implications are different if this trade refers to *domestic trade* (e.g. India and China) compared to *global trade*. To achieve the potential global water savings from trade, it is important to consider that water has not traditionally been a direct determining factor for trade, as compared to other production factors like land, labour, or capital.

Global food trade is not driven by-an-large by water scarcity. For example, if Canada imports bananas or flowers from Central America, it is not because Canada is water scarce, in fact Canada is one of the most global *water rich* countries in terms of water resources. International commodity trade mainly depends on factors such as availability of land, labour, technology, the costs of engaging in trade, national food policies and international trade agreements. In this sense, what was previously mentioned is a logical development: and just a small amount of international virtual water trade is due to water scarcity. However, some countries like Saudi Arabia as a *cash rich*, *water poor* country have taken the policy decision to secure food and water from outside their border (see above). Meanwhile other *water poor* countries will be unable to adopt this strategy because they are *cash poor*. This is also the case for some countries of the MENA region (Yang *et al.*, 2007) and in other countries (Yang & Zehnder, 2008; Liu *et al.*, 2009). Preconditions for trade are a minimum of wealth in terms of GNP and a fair trading system. The virtual water *trade* is fraught with diverse problems and possibly the most urgent is the lack of fair international trade regulations, and where attempts to solve this impasse by the WTO have failed up to now. The main obstacle seems to be the position adopted by some industrialized countries.

Another key associated topic to the regulatory reform of the current trade system is the issue of perverse incentives and in particular the current subsidy structure in agriculture by most OECD countries. This probably deserves deeper analysis because of some media grabbing *moral hazards* in current European subsidies to agriculture, where e.g. it appears that each cow receives about 1 US$ per day, which is higher than the income of more than 1,000 million human beings (Development Policy Forum, 2009). In the context of recent large subsidies to other sectors (e.g. the bail-out of the financial system and banks), key questions need to be posed on what are the principles that define which subsidies are permissible and which are detrimental. The WTO agreements on subsidies and countervailing measures have established a legal definition of subsidy. However, in reality there is no clear over arching consensus and analytical framework to help evaluate the use of public budgets, in relation to subsidies to energy (electricity), subsidies to agricultural prices, and cross subsidies, e.g. for public water supply or to water infrastructure.

The analysis of the flare up of the price of staple food two years ago has already identified a number of drivers (biofuels, speculation by some food international corporations, oil price increase, lack of enough storage for staple foods, economic and financial crisis, and others) (Lamo de Espinosa, 2008; 2009; Paarlberg, 2008a; 2008b). One of the main potential reasons is that millions of people in BRIC countries are starting to eat meat, and this will drive cereals prices up for the long run. Therefore, the issue of incentives (and subsidies) –in the context of regulatory reform for trade liberalization– is the key complementary side to trade, and questions on the criteria used to assess the *kindness* of subsidies. For example, do subsidies lock in inappropriate technologies; lead to inefficient use of water, or remove incentives to invest on infrastructures? It is also necessary to identify where, how and when to reduce perverse incentives (including subsidies), and where subsidies are in fact needed.

A number of authors (Falkenmark & Rockström, 2004) consider that rain-fed agriculture should play a more important role in providing food for a growing world population. Nevertheless, some authors call attention to the issue of rainfall variability, which increasingly is perceived as more urgently pressing in terms of adaptation in the short term than climate change itself. This is because addressing variability is a win-win strategy since adapting to rainfall variability is a good adaptation measure to prepare for the much larger variability range of potential climate change. However, this variability in the production of staple foods is not global since up to now droughts have been regional; a *global drought* has never occurred. It may be appropriate to assess the global staple food storage capacity because lack of storage might have been one of the key factors that explains the increase in the prices of staple food two years ago.

Climate change will be mainly mediated through water, i.e. most climate change impacts are related to water (sea-level rise, rainfall variability, melting of glaciers, river flow and groundwater recharge, availability of water for crops production, frequency and magnitude of floods and droughts, . . .). Water management is therefore key in adaptation to both climate variability and climate change and to amplifying the resilience of the global economy (López-Gunn, 2009). Innovation which incorporates both cutting edge research and scientific and technological advances as well as indigenous/local knowledge on e.g. good husbandry of green and blue water management, e.g. age-old techniques like terracing, fallow periods, etc. represent valid and valuable traditional knowledge. Recycling this knowledge can be a relatively cheap investment with potential high pay offs. For example, the European Union could consider the potential for incorporating green water credits, i.e. a mechanism to transfer cash to rural people in return for water management activities that determine the supply of all fresh water at source – activities that are presently unrecognised and un-rewarded. Direct payment could enable better management of the resource[2] in rural development policy (Dent & Kauffman, 2007; Dent & Kauffman, 2008), and their linkage with payments for environmental services. In addition, green water credits might become increasingly seen as part of climate justice demanded by African countries and which have to be incorporated into the reform of foreign and development policies in the EU. Both these examples highlight how green water credits and payments for environmental services are intimately linked with the need to reform agricultural policies like the Common Agricultural Policy, away from price support, and towards rural diversification and land use and good husbandry policies.

Many predictions or assessments state the need for more water or arable land to cope with the extra food needed for the growing world population (2,000 or 3,000 million persons within 25 to 50 years). These consider that the agricultural productivity of staple foods in developing and/or emerging countries will continue to be small in comparison with productivity in industrialized countries. For example, today the yield of rainfed cereal across humid Europe might be up to 8–10 t/ha, but in developing countries productivity is assumed to rarely reach one third of this amount. This is equivalent to assuming that most farmers in the Third World are not going to have access to technology, institutions, transportation, markets, or are incapable of innovating. Yet data on the yearly economic growth (8 to 10%) in a good number of developing countries, like India and China, seems to reject such a pessimistic assumption. As was previously mentioned, the papers by Goklany (2009) and Kuylenstierna *et al*. (2008) in addition to the communication of Prof. Allan (2009) supports the idea of a potential increase in agricultural productivity in the near future based on previous precedents in now developed countries. To conclude this section, virtual water and the water footprint, represent a new take on an old idea (embedded water and comparative advantage). It shows that increasing the hydrological and economic productivity of water used for agriculture offers an entry point for relatively simple, but high impact changes in national and global water policy (WEF, 2008). The extended water footprint may become a good tool to achieve Integrated Water Resources Management (IWRM). Furthermore, in many countries like Spain it may facilitate the transition from the motto ***more crops and jobs per drop*** to the new motto ***more cash and care of nature per drop*** as required by the EU Water Framework Directive.

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[2] [http://www.isric.org/UK/About+ISRIC/Projects/Current+Projects/Green+Water+Credits.htm].

5 NEW AND RECYCLED WATER: DESALINATION AND REUSE[3]

The global water footprint at the moment is mainly agricultural (i.e. about 90%), and this is likely to decrease in the coming thirty to fifty years (WEF, 2008). Therefore there are key questions related to this transition in the global economy, towards a service based global economy and the re-allocation between sectors on the existing water resources and uses. In this changing global water scenario, certain areas and sectors become particularly crucial. For example, at present more than half the world's population lives in urban areas, and of these, about a third are located in coastal areas. This opens a number of opportunities, e.g. related to desalination and reuse of urban waste water for agricultural uses. Economies of scale exist, however there remain some constraining factors like access to financial resources and the cost of energy. Recent events related to lack of water resources for urban water supply, e.g. due to drought in cities like Barcelona, Atlanta and Istanbul are highlighting the problems of guaranteeing water supply and of making these cities water secure. This will be reflected in the political decisions on trade-offs, for example, whether to e.g. transfer water resources physically, opt for desalination or instead for re-allocation between existing dominant uses (mainly agriculture). All these options have pros and cons and require a great dose of transparency and education to the public at large. For example, transparency on prices paid per m^3, and the willingness to pay by different economic sectors (e.g. agriculture *vs*. urban users) and whether desalination plants fulfill their projections (e.g. time span before they operate at full capacity). However, reallocation of water used to irrigate low value crops to new water demands like public water supply may be the best way of solving water supply problems in the ever growing cities. This, of course, requires that the staple food supply for developing countries is guaranteed through better international regulation of food trade.

There is little doubt about the relevance of recent advances in chemical Engineering to provide *new water*[4]. Nevertheless, in Spain and other countries the clear advantages of this *new water* technology have to be assessed realistically, to dispel the possibility that sometimes this potential might have been overstated for political or other reasons. There is also the potential for water reuse. However data in this area are not easily accessible or detailed enough (including costs), to be able to assess easily the scale and full potential of reuse in terms of timing, possibilities, costs e.g. based on sewage systems in operation[5].

In addition, there is dispersed data at the global and national level on the current uses, costs and prices of desalinated sea water, desalinated brackish groundwater and reused waste water. In some specific local circumstances desalination may be a useful solution. This could be the case for example in the Middle East, where thanks to advances in desalination, water does not have

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[3] This topic will be dealt with in detail by other participants at the Workshop. Therefore, here we only comment on some general aspects.

[4] *New Water* refers to "additional volumes of fresh water that can be introduced to the hydrological cycle, through various means" such as desalination, wastewater reuse, or bulk importation of fresh water (Phillips *et al*., 2008: 11).

[5] Water harvesting, supplemental irrigation, managed aquifer recharge, field water conservation and deficit irrigation offer relatively low-cost technologies that can have real impacts at the local scale. For example, the decentralized recharge movement was an almost spontaneous response to India's groundwater depletion to help water tables rebound to pre-development levels at the end of the monsoon season in pockets of intensive use (Polak, 2008). This is an example of the contrast in perception between *popular hydrogeology* and formal *hydrogeology*, e.g. scientists argue hard rock have too little storage and advocate recharge, meanwhile the prolific growth of recharge structures is based on the value people attach to a check dam even if these wells would only provide 1,000 m^3. This 1,000 m^3 is nevertheless crucial for livelihoods irrigation in times of delayed rain. However, it seems important to obtain better data on the practical relevance of these methods in countries with a medium or high economic standard. Possibly, the real significance in the water balance of the country is irrelevant, but they can be vital in specific points in time, and furthermore can contribute to create a better public awareness on the duty of care for nature. At a bigger scale, new ideas like virtual water trade and the extended water footprint can offer better national and global strategic water policy choices in water allocation.

to be a cause for conflict between Israel and Palestine. The fact that discourses on water conflict continue despite available options highlights that water can become an excuse or smokescreen for other conflicts. The main conflict over water centers on a volume of water that is less than 400 Mm^3/yr of groundwater in the Judean aquifer. Today the cost of this volume as desalinated seawater is less than US$ 300 millions per year. This is significantly less than 1% of the GDP of Israel's (Llamas, 2008). Provided there is political will, water can be a *positive sum outcome*. This becomes obvious when one can show through a theoretical economic model, like WAS (Fisher & Huber-Lee, 2008) that water is mainly valuable where it is scarce. In fact, the generation of *new water* in terms of quantity is a trivial amount for governments. As Fisher & Huber-Lee (2008: xiv) stress: "thinking about water values rather than water quantities can lead to useful and surprising results".

6 DEEP BLUE WATER: GROUNDWATER DEVELOPMENT SILENT REVOLUTION[6]

Groundwater is the largest volume of global freshwater resources in this planet, and yet it is largely invisible for civil society and in the mind of many water planners. Yet in the last half century groundwater use has increased ten times –from 100×10^3 Mm^3/yr to more than $1,000 \times 10^3$ Mm^3/yr (Shah, 2008). This spectacular increase has been generally undertaken by millions of modest farmers, a true example of human innovation and initiative. Yet it has been undertaken with scarce or no planning and control by conventional governmental water authorities, and the scale of this silent revolution are now becoming more startling thanks to new technologies.

This silent revolution has produced large economic and social benefits, particularly since it has been an emergent, spontaneous process that has enabled socioeconomic transition and change (Llamas & Custodio, 2003; Shah, 2008; Mukherji *et al.*, 2009a; Giordano & Villholth, 2007). Groundwater irrigation is considered by many as a driver for important social changes. However, it is less clear –since it is a relatively new global phenomenon (half a century of groundwater irrigation compared to 5,000 years of surface water irrigation)– what the long term consequences of this intensive groundwater use might be. What is clear however is that there can be and have been substantial environmental externalities to this groundwater growth model, which some authors think might follow the boom and bust model of mining and non-renewable resource use (Hotelling rule[7]). There is increased awareness on the scale of ecological impacts, such as the problems created by overdraft of aquifers in Southwest and Central USA, China, India, Australia, Spain, Mexico. Nevertheless, it is appropriate to know that this concern has grown especially among experts in surface water resources who usually are non-experts in groundwater hydrology. As a matter of fact the UNESCO World Commission on the Ethics of Science and Technology (COMEST), published a report (Selborne, 2001) that gives recommendations on this issue[8].

Nevertheless, we are not aware of practically any case where the ecological, economic and political externalities caused by the use of non-renewable groundwater have been analyzed in adequate detail from multiple perspectives. In general the concept of sustainability has been defined as ecological impacts, the emphasis predominant in a Northern and Central European approach, which only takes socio-economic aspects as a secondary aspect. The WFD of the European Union is

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[6] This topic is dealt in detail in other chapters in the book, therefore we will only emphasize some aspects.
[7] Hotelling's rule is a 1931 economic model of non-renewable resource management by Harold Hotelling. It shows that the efficient exploitation of a non-renewable and non-augmentable resource would, under otherwise stable economic conditions, lead to a depletion of the resource. The rule states that this would lead to a net price or *Hotelling rent* for it that rose annually at a rate equal to the rate of interest, reflecting the increasing scarcity of the resources (http://en.wikipedia.org/wiki/Non-renewable_resource).
[8] This report is largely based on a previous monograph by Llamas & Delli Priscolli (2001).

the epitome of this perspective. This is rather narrow and sometimes highly unrealistic when looking at the reality of what is happening e.g. in developing countries. This was already commented by the UNESCO Working Group on the Ethics of Freshwater Uses and the COMEST (Llamas & Delli Priscoli, 2001; Selborne, 2001; Delli Priscoli *et al*., 2004). In Llamas *et al*. (2008) some cases are described where it is the economic and political circumstances that are the main drivers in groundwater development and not ecological motives. Some may think that this situation is typical of developing countries: this is not the case.

For example, in Spain the Upper Guadiana basin has experienced an intensive groundwater development for irrigation since the 1960s. These groundwater abstractions have generated important socio-economic benefits to the farmers and to the region but has also caused an important ecological degradation to the UNESCO Biosphere Reserve *La Mancha Húmeda*, to the Tablas de Daimiel National Park and to several Ramsar sites located in the aquifer. There has been –and continues– a strong conflict between the conservation lobbies and the agricultural lobbies. Nevertheless, up to now the Central and Regional Governments have not been able to enforce the Spanish Water Code that theoretically has tools to solve this situation. Apparently the power of the farmers is higher than that of the conservationists (Llamas *et al*., 2010).

In the case of groundwater security, there are a number of issues that need further analysis, because of particular characteristics inherent to groundwater as a resource. This relate to (and will be discussed in turn): first, the incentive structure for pumping groundwater; second, the inherent resilience of groundwater to dry spells; third, the individualistic nature and high level of agency inherent in groundwater use as a common pool resource; and fourth, the need in groundwater governance to devise ways to incentivise collective action, seeking win-win scenarios.

Llamas & Martinez-Santos (2005) described the evolution of a series of phases related to groundwater development in most arid and semi-arid countries. This chapter revisits this analysis to add an additional stage. Figure 1 presents an idealised overview of the different water policy stages that

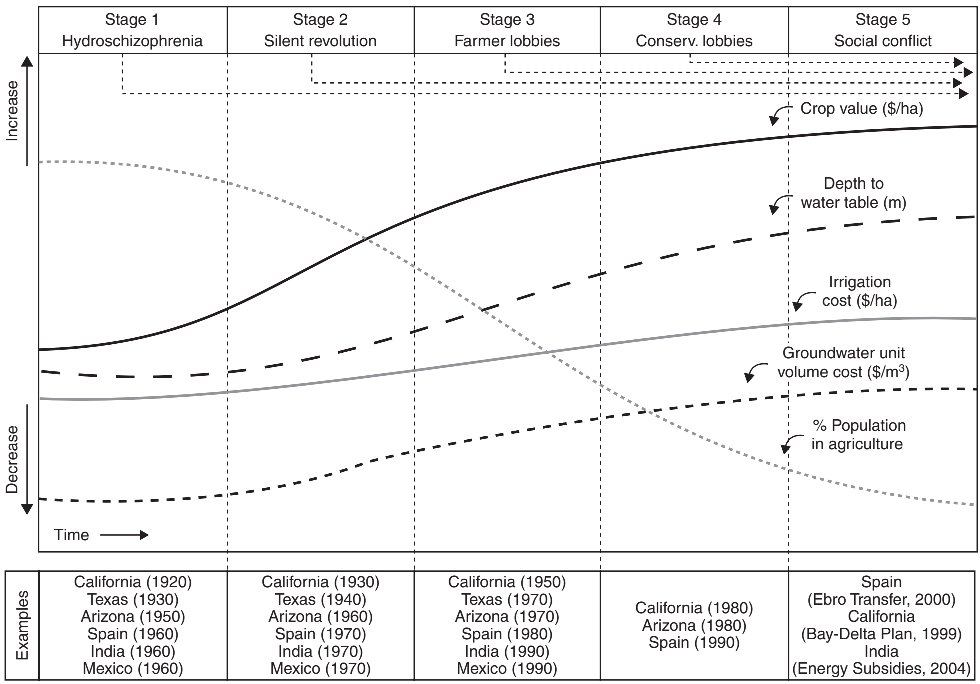

Figure 1. Idealised stages in groundwater-related development in arid and semiarid regions (after Llamas & Martínez-Santos, 2005).

many arid and semiarid countries experience due to intensive groundwater use. Each of the five stages is roughly equivalent to one generation (about 15–25 years).

The five stages that can be distinguished are: a first stage when groundwater is treated as a *pillar of sand* compared to surface water and therefore is either neglected, ignored or both in water planning by conventional hydrologists or water planners (Stage 1. Hydroschizophrenia). The second stage is mainly due to the inherent *resource blessing* characteristics that groundwater has (namely resilience to drought, low investment costs, agency i.e. control by individuals –e.g. in decision making). This triggers a *silent revolution* in a vacuum of conventional water authorities, often incentivized or encouraged by other authorities (normally agricultural departments). In the third stage the stream of economic benefits, where normally farmers tend to be the main beneficiaries, stimulates the creation and/or strengthening of farmer lobbies to defend groundwater use. In the fourth stage this often comes head to head with conservation lobbies, who campaign to reduce abstractions due to environmental externalities, which become an issue for public policy and a cause for social conflict between competing users and where there is difficulty in changing the *status quo* and inertias in the system. The beginning of these conflicts can generally be traced back to the moment when intensive groundwater development begins. In the later stages (particularly 3–5) there might be some overlapping between stages.

One of the most significant aspects of this *Silent Revolution* is the manner in which farmers, as they grow richer and more educated, move from low value crops to cash crops. This is mainly due to the intrinsic reliability of groundwater, where encouraged by the expectation of enhanced revenues, farmers decide to invest in better irrigation technology and, in turn, shift to higher value crops. As crop value is related to the type of crop, climatic and other natural and social variables particular to each site, and also subject to trade constraints, crop value ranges widely. In Europe for instance crop value ranges between US$ 500–800 per hectare (e.g. cereals) to more than US$ 60,000 per hectare for tomatoes, cucumbers and other greenhouse crops. Frequently in Spain, and probably in other industrialized countries, the ratio between crop value and groundwater irrigation cost is greater than 20; in other words, the cost of water abstraction is usually in the order of 5% (Llamas & Custodio, 2003). This ratio may be radically different in developing countries, where the cost of groundwater abstraction may be in the order of almost 50% of the crop value (Mukherji *et al*., 2009b). Obviously this is a very different scenario, mainly due to the low value of the crop (usually rice and other cereals) and to the use of poor technology in water abstractions.

The *more crops and jobs per drop* motto is considered one of the most effective policy options to secure both water and food. This is because of the large share irrigation has in global blue water use, and the often low efficiency in irrigation. However, few water experts or decision-makers are aware that the goal behind such motto is now often achieved by groundwater irrigation (Hernandez-Mora *et al*., 2001). Groundwater irrigation will play a key role and useful testing ground because of its resilience to climate variability in contrast with rain-fed agriculture and surface water irrigation systems. In the industrialized or rich countries in arid and semiarid regions the new motto should be *more cash and care of nature per drop*, which adds a new 6th stage to groundwater intensive use, since it becomes a win-win for both farmers (and new users like e.g. thermo-solar groundwater use in Spain) and nature. For instance, as previously mentioned, the economic productivity of 1 m^3 used for a thermo-solar plant is about 100 to 200 times higher than if this m^3 was used to produce cereals or cotton. This efficiency gains in both water use and increased productivity can release water for other uses like e.g. water needed by local wetlands.

Examples like this are particularly relevant for *water stressed regions*, since these *water poor* regions can buy staple food from *water rich* regions, normally with abundant (usually green) water and save their scarce blue water for cash crops or other beneficial uses, like wetlands. Green water and surface water irrigation systems cannot guarantee crops due to climate variability, and this is why growers of cash crops generally opt for groundwater irrigation.

The analysis of the *extended* water footprint considers not only water embedded in a product, but also the economic value obtained from every m^3 assigned to each use. For instance in Spain about

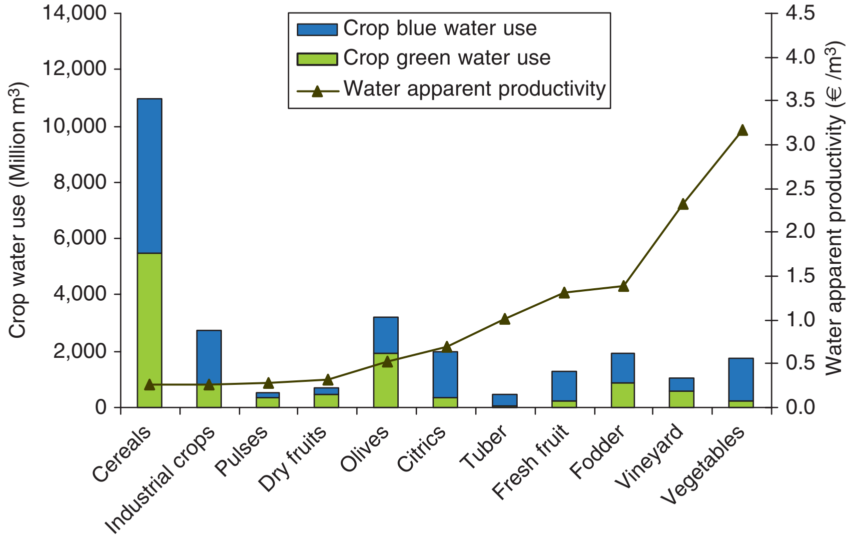

Figure 2. Apparent water productivity and blue and green water footprint for different crops in Spanish agriculture (2002).
Source: Aldaya *et al.* (2009a; 2009b).

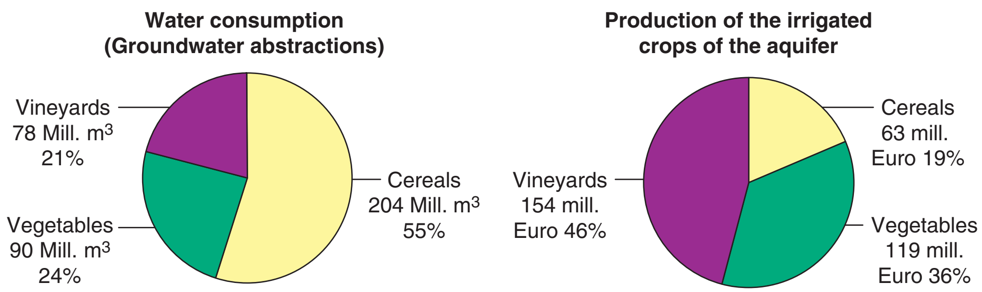

Figure 3. Water consumption and irrigated crops in the Western Mancha aquifer (Upper Guadiana Basin, Spain).
Source: López-Gunn & Zorrilla (2010).

90% of green and blue water is used for agricultural production; yet in Spain the driest country in the European Union, 10% from this 80–90% of water used for agriculture produces almost 90% of all the economic agricultural value (Aldaya *et al*. 2009a; 2009b) (see Figure 2). This means that almost 70% of water used in Spain is applied to produce *low value crops*. It might be better to buy these low value agricultural goods in countries with abundant (green) water and use the theoretical scarce water for cash crops, tourism, industry or meeting the new regulatory requirements for ecological flows under the EU Water Framework Directive.

For example, in the Upper Guadiana basin, in 2006 cereals represented 55% of the water volume abstracted; yet, in terms of economic productivity, cereals only accounted for 19% of the economic added value generated (see Figure 3). Meanwhile, vineyards, which accounted for only 21% of the water abstracted, generated 46% of the economic added value. This situation is even clearer in the Mediterranean regions of Spain where it is possible to grow crops with much higher economic returns than in the Upper Guadiana basin which has a continental climate.

At the moment the dominant incentive structures drive the use of groundwater intensively in a highly atomised manner, where there are few perceived benefits from managing groundwater resources collectively[9].

As previously mentioned, the economic productivity of groundwater irrigation is usually higher than the economic productivity of surface water irrigation. This can be explained because of inherent characteristics in groundwater resources which make it a *resource blessing*, in terms of buffering from rainfall variability, low investment costs, control in time and space. The buffering capacity may become also a crucial point for the adaptation to the potential greater variability and scarcity of precipitation generally predicted by some models of the Intergovernmental Panel on Climate Change (IPCC) for the Mediterranean region, identified as a potential hotspot.

There are some pressing questions in relation to groundwater governance and how to generate the right incentives and institutions to favour collective action, avoid the potential boom and bust model of groundwater use, and prevent associated environmental negative externalities. Some of the issues that have to be further understood are *whether* and *if*, groundwater governance is inherently different to surface water governance because of the nature of the resource and the individualised and entrepreneurial aspects of groundwater use. This also set in the context of almost 5,000 years of surface water development as compared to a short 50 year span of groundwater use.

In previous sections we have mentioned the new motto *more cash and care of nature per drop* as one goal to achieve in the near future in global water policy, beginning in the industrialized and emergent economies. At a later stage this might be applicable to developing countries. The first part of the motto *more cash per drop* seems clearly feasible, mainly if more just and equitable international trade regulations are achieved. However, we cannot ignore that the second part of the motto: *more care of nature per drop* may be fraught with difficulties. Agricultural diffuse pollution is possibly one of the main problems in global water policy. It is a common issue to both rain-fed and irrigated agriculture. Probably this problem is today more serious in humid countries than in arid and semiarid ones. On the other hand, it seems that the use of agrochemicals for cash crops (like tomatoes, cucumbers, and so on) is higher than for low-value crops (like cereals, rice and so on). Albiac (pers. comm.) estimates that in Spain the use of agrochemicals in greenhouse crops may be one order of magnitude higher than in open air crops for staple foods. However, the economic value might be two orders of magnitude higher in greenhouse crops. Obviously, this is an issue that deserves a thorough assessment although it is out of the scope of the present chapter.

Yet despite the exponential growth in groundwater use and its increasing strategic value, e.g. for public water supply, in coastal areas and for some of the most heavily populated countries in the world (e.g. China, India, and Brazil), groundwater governance is in its infancy. The approach has to be very different to surface water irrigation governance. In order to cope with the current groundwater development anarchy, it is increasingly important to analyse institutional aspects of water use and allocation for groundwater, since much groundwater use in many countries operates under *informal* rules. Yet the key issue is the same in surface and subsurface water: institutions for cooperation among stakeholders to achieve collective action.

Groundwater offers unique opportunities for testing out the first part of the motto *more cash and care for nature per drop* because groundwater development is resilient to climate variability, which

[9] This is also known as the Gisser-Sánchez effect, i.e. an economic model that demonstrates theoretically what many people observe empirically, that farmers experience great incentives to use groundwater intensively and have little economic benefit from controlling use (see Koundouri, 2004, for a detailed explanation), i.e. the *no-management* (competitive) dynamic solution of groundwater exploitation is almost identical (in terms of derived social welfare) to the *efficient management* (optimal control) solution (Koundouri, 2004: 706). This is a management paradox because the serious depletion of aquifers is a major risk to many freshwater ecosystems yet the social benefits from managing collectively groundwater abstractions are numerically insignificant. This also has significant implication for water managers because it is a severe constraint to the effectiveness of policy options since implementing reduced extractions is not socially, economically or politically costless.

is the Achilles heel of green water (rain-fed) agriculture as to most surface water irrigation[10]. If the pessimistic predictions of the IPCC concerning the decrease and greater irregularity of precipitation in some regions materialize, the role of groundwater to achieve an adaptation to these changes will increase as a natural insurance and buffering system to climate variability (Hetzel *et al*., 2008; López-Gunn, 2009). Groundwater has higher hydrologic and economic productivity in comparison with surface water irrigation. This advantageous economic aspect of groundwater irrigation may compensate the requirement of *more care of nature* (using less agrochemicals) and the result means a win-win for the farmer lobby to then facilitate farmers acceptance of *more care for nature*.

7 CONCLUSION: 10 SUGGESTIONS TO HELP RE-FRAME GLOBAL WATER POLICY

1) Freshwater and food are not a scarce in this blue planet. The existing security problems are local and affect to a small proportion of humanity (less than 15%).
2) The increasing need for food because of the improvement in quality of life and population growth can be met without a significant increase in either the use of blue water or area of arable land. However, this requires a greater effort from industrialized countries to transfer agricultural technology and know-how to developing countries.
3) The scarcity of green and blue water in arid and semiarid regions can be partly compensated through virtual water trade. In reality, virtual water trade is already functioning and solving the problems in some countries in the MENA region, like Jordan, Libya and Israel.
4) Virtual water trade is not yet a panacea to solve water and food security problems. The main obstacle is the lack of international regulations that guarantee the security of poor countries against political pressures, embargos, and oligopolies by international food corporations. The efforts currently underway under the World Trade Organization should be improved and strengthened.
5) Most virtual water traded is green water from humid countries, like Canada or Argentina. One potential problem is the great variability of precipitation and its impact on corresponding crops. Up to now there has never been a global drought. Nevertheless, it seems that the global staple food storage should be assessed in order to mitigate this potential contingency.
6) While irrigated agriculture is more resilient to precipitation variability, surface water irrigation systems can also fail in long dry spells. Meanwhile groundwater irrigation is strongly resilient to dry spells. Groundwater farmers obtain greater profit during droughts, when irrigation with surface water systems are vulnerable to failure.
7) The groundwater *silent revolution* is a fact in most arid and semiarid regions. It has increased ten fold in the last half century. It has produced stupendous social and economic benefits but also colossal groundwater management anarchy.
8) It seems relevant and urgent that governments in arid and semiarid regions obtain better information on the situation of groundwater irrigation as a preliminary stage to correct this current general global anarchy.
9) Probably the most serious concern in water resources policy is how to cope with diffuse pollution due to rain-fed and irrigated agriculture.
10) The new motto in industrialized and emergent countries should be *more cash and care of nature per drop*. Developing countries probably should still operate in the paradigm of *more crops and jobs per drop*.

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[10] Pressures and increased competition on water resources, and in particular groundwater which is particularly attractive because of its high productivity, means that the *low hanging fruit* (i.e. quickest and easiest gains) lies in increasing productivity, for which groundwater is particularly well adapted to, and where generating *more cash and care of nature per drop* is a win-win for farmers and the environment.

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