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Inaugural lecture upon taking up the post of
Special Professor of Economics of Water and Climate Change
at Wageningen University on 6 October 2011

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Esteemed Rector Magnificus, ladies and gentlemen

The use of water and land are under increasing pressure from population growth and economic development in general and increasing food demand in particular. And I expect that strategies to cope with water scarcity and climate change will have a big impact on food production in terms of what, when and where food will be produced. Especially given the fact that it is currently not feasible to desalinate water for irrigation of staple crops. I will show that due to rising energy prices, globalisation and special characteristics of water, it may become more attractive to make better use of freshwater originating from rainfall where it is available. This is especially important in deltas where half of the world population is currently living and more than half of our food is produced.

In ancient times people established themselves already in deltas, as they depended on water to produce their food, such as the Egyptians along the Nile and Mesopotamians along the Tigris and Euphrates. The difference today is, however, that only food production has to move towards water instead of the entire population, because we now have ample opportunities of transport.

I would like to show that water, food and climate are directly related topics that will deserve a lot of attention in the coming decades. And that well-informed choices have to be made about the use, conservation and allocation of water on the basis of integrated socio-economic analyses, which require insight into the value of water and a careful analysis of what future climatic change may bring.

My lecture consists of three parts. I will start with a historic overview of recognising water as an economic good and trends that affect water availability and water consumption. Then I will discuss what makes water so special and what the implications are for economics. Finally, future research directions of the chair will be presented. But before all of this I will tell a short story about the water rush.

The water rush: securing food by securing water

Last year I read an article in the Observer, the Sunday edition of the British Guardian newspaper, entitled: How food and water are driving a 21st-century African land grab (www.guardian.co.uk/environment/2010/mar/07/food-water-africa-land-grab). Then I realised that we are entering a new era of relocating food production towards water.

Today in more than 22 African countries, among the most hungriest countries in the world, the governments are paradoxically selling or leasing millions of hectares of their most fertile land to rich countries and wealthy investors to produce and export food. The contracts are not only about land, but also about water. These Foreign Direct Investments increase total agricultural production which contributes to food security, but is putting competing claims on land and natural resources.

The land rush has not only been triggered by the worldwide food shortages and rising food prices and by the biofuel policies of the USA and EU, but also by the growing water shortages. The Gulf States, China, Korea, India, Japan and Egypt appear to be among the major investors looking for fertile and water abundant farmland. For instance in 2008 the Saudi government, which was one of the Middle East's largest wheat growers, announced it was to reduce its domestic cereal production by 12% a year to conserve its water. Saudi Arabia faces growing water scarcity as aquifers dry up as a result of decades of irrigated wheat farming (Cotula et al., 2009). It earmarked $5 billion to provide loans at preferential rates to Saudi companies which wanted to invest in countries with strong agricultural potential, such as South Sudan. By turning to Africa to grow its staple crops, Saudi Arabia is not just acquiring Africa's land but is securing itself of scarce water.

This water rush in the 21st century in Africa has a lot in common with the gold rushes that took place in the 19th century in Australia, Brazil, Canada, South Africa and the USA. While gold mining itself was unprofitable for most diggers and mine owners, some people made large fortunes out of it. The water rush also seems to have serious welfare implications for the local rural population.

This story shows that water is a primary concern for many of the countries involved in land leasing and that the focus is shifting from reallocating water to food towards relocating food production to water. Of course there is a lot of geopolitics behind such a shift, but it also shows that water is becoming more leading for where food production takes place and that we should make integrated well-informed choices about its use, conservation and allocation. This is what water economics is about.

1 Historic perspective and trends that affect water availability and consumption

Water as an economic good

For many decades water has mainly been approached from a technical point of view and engineering solutions dominated. The formal recognition that water should be considered as an economic good started almost twenty years ago when the fourth Dublin principle was adopted at the 1992 International Conference on Water and the Environment. According to this principle: Water has an economic value and should be recognised as an economic good taking into account affordability and equity criteria.

However, the interpretation of this principle has caused confusion. According to Savenije and van der Zaag (2002) one can distinguish two schools of thought. The first school maintains that water should be priced at its economic value. The law of supply and demand would then ensure that the water is re-allocated from low value to high value uses. Personally, I am not a proponent of this narrow interpretation, because water allocation is a societal question that should not be left to market forces. The second school interprets 'water as an economic good' as the process of integrated decision making about the allocation of scarce resources, which goes further than financial transactions. I like this interpretation; it is about making informed choices about the use, conservation and allocation of water on the basis of an integrated analysis of all costs and benefits in a broad sense, and not about determining the 'market-clearing' price of water.

This is not to say that water pricing is unimportant. I think that water pricing should primarily be targeted to financial sustainability through cost recovery. Further it should give a clear signal to the users not to waste water. And simultaneously it should ensure access to safe water for the poor while taking ecological requirements into account. All this really encourages the high-value use of water.

In practice, the price of irrigation water is often significantly smaller than the value of irrigation water. This means that a considerable increase in price is required to reduce demand. Even if the current price of water triples, it may

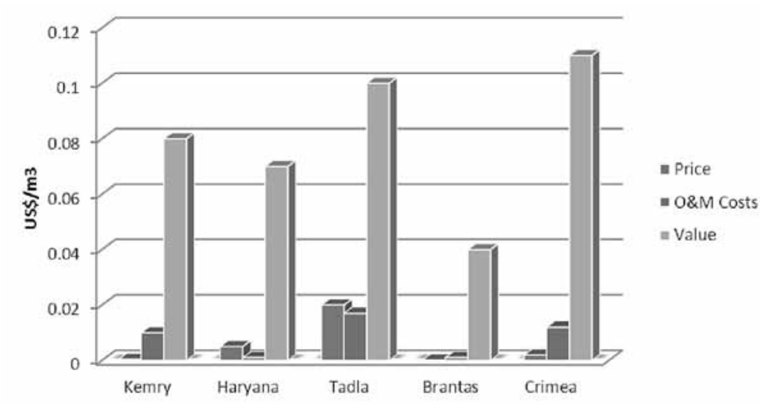

Figure 1. Comparison of the price, costs and value of water.

hardly affect demand. This was shown in a comparison of the price, costs and value of irrigation water in five case study areas (Figure 1), carried out together with professor Chris Perry (Hellegers and Perry, 2006). We also found that the price is often smaller than the operation and maintenance costs, which means there is no full cost recovery. Costs are usually smaller than the value, which means that it is feasible to irrigate.

Which water problems are economic in nature?

There are different kinds of water problems. More than 1 billion people have inadequate access to clean drinking water. There are water pollution problems, flooding problems and there is unsustainable use of groundwater aquifers. But there are also severe water scarcity problems. This growing scarcity of water is regionally hampering the expansion of agricultural production at a time when demand for food is rising. Water scarcity is a typical economic problem, as it is about the reallocation of the scarce resource water among alternative uses. As water scarcity depends on water availability and water consumption, I will first give some facts and figures about water availability and afterwards discuss the various trend that affect water consumption.

Availability of water

There seems to be plenty of water on earth. However, we only make use of a tiny portion of the available water, because the majority is not of the right quality, at the right place, at the right time or not accessible. Only 2.5% of all water on earth is freshwater. The majority of the freshwater, about 70%, is locked away in the form of ice caps and glaciers, mainly in Greenland and Antarctica. Most of the remaining freshwater lies to deep underground to be accessible or exists as soil moisture. Only 1% of the earth fresh water is available for withdrawal.

The importance of considering return flows became clear when I studied together with professor Chris Perry the impact of improved irrigation technology on over-exploitation of Yemen's aquifers (Perry and Hellegers, forthcoming). We found that the extent to which a higher irrigation efficiency at the farm level translates into water savings that can be used by others depends on the hydro-geological situation. This determines whether excess deliveries are recoverable or non-recoverable. In large parts of the Sana'a Basin excess deliveries turned out to be recovered already, which means that there is no water saving at the aggregate level. Besides, improved irrigation technologies increase the profitability of pumping for the farmer, potentially exacerbating problems of over-abstraction.

The costs of making more water available usually increase with the quantity supplied, as first cheap measures such as irrigation scheduling will be adopted and later expensive measures such as desalination. Locally the costs of desalination plus transport can be high, as is for instance the case for Sana'a the capital of Yemen.

As Sana'a city is located on an elevation of 2250 meter at a distance of approximately 100 km from the Red Sea, transport costs of water desalinated at the Red Sea coast will be considerable. They will be even higher than the desalination costs.

If locally the benefits of water usage (i.e. the value of water) do no longer offset the costs of water provision, demand has to be reduced. This is what is currently happening in the Middle East where the production of staple crops is relocated towards areas where water is abundant.

I recently contributed to a study of FutureWater for the WorldBank, which aimed to estimate the gap (see Figure 2) between future water demand and water availability in the Middle East and North Africa (Immerzeel et al., 2011). The size of the gap is highly dependent on the climate scenario: wet, average or dry.
I have estimated the costs of bridging that gap (see Figure 3). The unit costs of bridging this gap vary substantially among countries. Relatively cheap measures can bridge the gap in Egypt, Iran, Syria and Tunisia, while relatively expensive measures are required to bridge the gap in Israel, Jordan, Qatar and Saudi Arabia (see Figure 4).

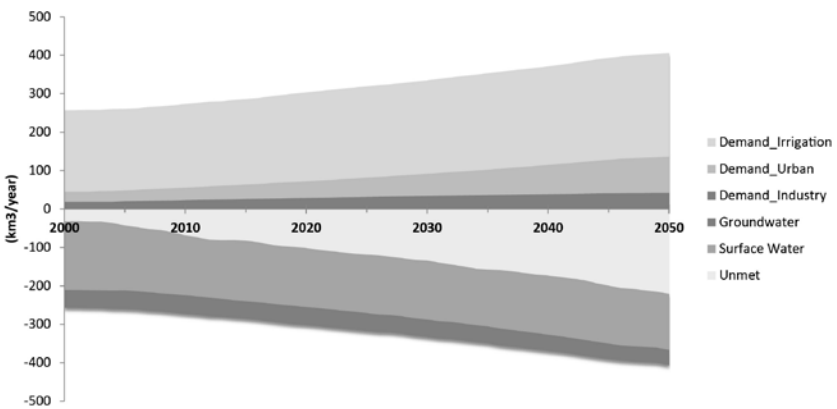

Figure 2. Estimated water supply-demand gap in the MENA region for the average climate projection. Source: Immerzeel et al. (2011)

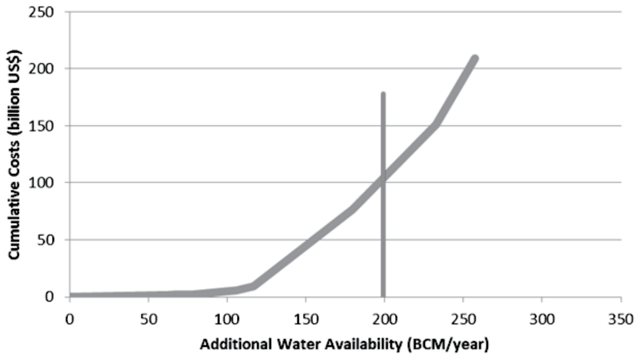

Figure 3. Cumulative cost curve for the average climate projection.
Source: Immerzeel et al. (2011)

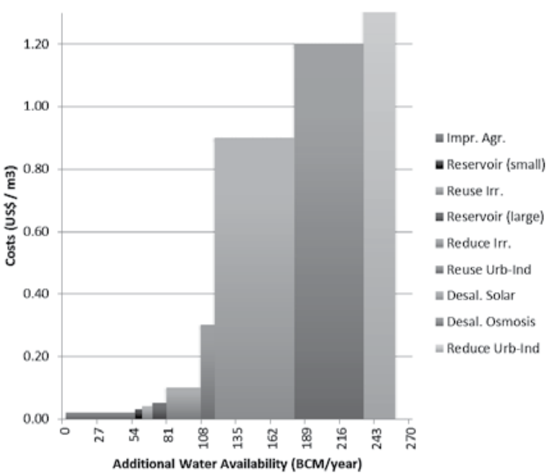

Figure 4. Water marginal cost curve for the average climate projection.
Source: Immerzeel et al. (2011)

Consumption of water

These are the four main trends that put increasing pressure on water consumption: i) Population growth combined with dietary change and urbanisation; ii) climate change; iii) rising energy prices and iv) globalisation. Each of them is discussed in more detail below.

Food consumption is driven by population growth, urbanisation and dietary change

Let me take Egypt as an example. In this country around 38% of the population is currently younger than 15. The population has nearly doubled since 1980 to more than 83 million people. At the current population growth rate of around 2% Egypt's population could double to 160 million by 2050. Most of the Egyptians live in urban areas near the Nile where there is hardly any rainfall. Population growth increases the strain on Egypt's limited resources - especially of water and fertile land. Egypt depends heavily on imported food items and I am convinced that this will increase. A country like Egypt contributes substantially to the fast growing world population, which has doubled over the past 50 years and is projected to grow from nearly 7 billion people today to more than 9 billion in 2050. Population growth rates will slow down. However, coming off a much bigger base, the absolute increase will still be significant. Nearly all of this population growth will occur in today's developing countries.

Urbanisation

By 2050 more than 70% of the world's population is expected to be urban. Urbanisation triggers changes in lifestyles and consumption patterns. In combination with income growth it may accelerate the ongoing diversification of diets in developing countries.

Dietary change

While the shares of grains and other staple crops will decline, those of vegetables, fruits, meat, dairy and fish will increase. Such changes in diets affect the consumption of water considerably. About 1,000 litres of freshwater are needed to produce 1 kg of wheat, while it requires about 15,000 litres of freshwater to produce 1 kg of beef.

It takes on average about 3,000 litres of freshwater per person to produce our daily food, which is substantially higher than our daily drinking water requirement of about 3 litres of freshwater per person.

To feed this larger, more urban and richer population in 2050, food production (net of food used for biofuels) must increase; according to the FAO (2009) by 70%. Personally I expect that it will be less than 70%, if we are able to reduce losses that occur in the food production and marketing chain. World agriculture has been able to meet the rapidly growing global demand for food, feed and fibre over the past 50 years at real agricultural prices that were falling for much of the time, at least until the mid-80s. This was only possible due to sizeable agricultural productivity growth. However, in recent years, yield growth rates have slowed down notably in many countries and for major commodities. In particular, the growth rates of cereal yields have been falling since the Green Revolution (FAO, 2009).

As the value of water is sensitive to commodity prices, it is important to mention that global market prices of cereals can escalate rapidly. That is because the international cereal market is thin, which means that relatively small shifts in supply or demand will lead to sharp fluctuations in global market prices. Currently only 18% of world wheat production and 6% of world rice production is exported; the rest is consumed domestically (FAO, 2009). At the height of the recent price shock some major wheat and rice-exporting countries banned exports for fear of not being able to feed their people. These bans contributed to the rapid escalation of global market prices (Meijerink et al., 2011).

As the demand for food continues to grow, further increases in water use for agriculture are inevitable. Irrigated agriculture is already the largest consumptive user of water, accounting for about 70% of all freshwater withdrawals, and for more than 90% of consumptive water use (i.e. the water volume that is not available for reuse downstream). By far, most of the water used by crops is, however, derived from soil moisture.

Irrigation provides only about 10% of agricultural water, but has a strategic role. It supplements rainfall where it is not sufficient to reliably satisfy crop water requirement, in areas vulnerable to climatic variability or where multiple cropping requires the provision of water outside the rainy season. Irrigation ensures crop production and allows farmers to invest in more productive agriculture. About 40% of the world's food is produced on irrigated land, which is only about 17% of the world's cropland. Proponents of irrigation conclude from this that irrigated agriculture is about three times more productive (in terms of yield/ha) than non-irrigated agriculture. In making this claim, they seem to forget that irrigation water is obtained by harvesting the rain (or snow) that has fallen elsewhere. I therefore would like to emphasize the importance of taking a macro perspective, in which we should also consider the benefits that might have been obtained by using the rainfall locally.

This corresponds with the first recommendation of the Comprehensive Assessment of Water Management in Agriculture (2007): Change the way we think about water and agriculture; instead of a narrow focus on rivers and groundwater, view rain as the ultimate source of water that can be managed. I therefore would like to argue that is it important to make better use of rainfall when and where it is available. For example by means of improving the adaptive capacity of farmers to deal with changes in rainfall patterns.

Climate change will affect water availability, water demand and flood risk

Higher temperatures and increased variability of precipitation as a result of climate change will, in general, lead to an increased demand for water for irrigation. Increased atmospheric CO_2 levels will have the potential to improve water productivity (defined as crop output per unit of consumptive water use, often referred to as crop per drop) of most plants, as it improves the photosynthesis in C3 plants. In hot regions, water productivity may, however, decline as yields decrease due to heat stress.

Climate change will not only affect water demand (through increased demand for irrigation water), but also the availability of water due to widespread melting of snow and ice and changes in the timing of release of melting water. It is expected that there will also be more frequent periods of droughts and floods, the latter due to more extreme river discharges and sea level rise. There is, however, still substantial uncertainty regarding the physical effects of climate change on water. The question is how to deal with this uncertainty, for instance by means of resilient agriculture and adaptive management

Implications of rising energy prices on water

Rising energy prices triggers demand for alternative energy sources, such as hydropower and biofuels, which increases the demand for water. It also makes extraction, purification and conveyance of water more costly. Hence, in my view many water problems could be solved, if only energy would not be so costly. This has been described in a special issue of Water Policy about the water-energy-food-environment interface, edited together with professor David Zilberman of UC Berkeley, Pasquale Steduto of FAO and Peter McCornick of IWMI. (www.iwaponline.com/wp/010S1/wp010S10001.htm).

Globalisation and liberalisation go hand in hand

Due to globalisation and trade liberalisation, an increasing number of countries will be dependent on imported food. The water challenge is therefore closely tied to food provision and trade. I think that agricultural and trade policy may even have a bigger impact on water demand than water policy. I therefore would like to stress the importance of integrated policy, which is one of the focus points of my chair.

Are virtual water and water footprints useful concepts?

Virtual water trade and the water footprint seem interesting concepts in the context of increasing international trade. The virtual water content of a product is the water embedded in a good. Professor Tony Allan launched this concept. The volume required depends on climatic conditions and agricultural practice. The water footprint of an individual, community or business is defined as the total volume of freshwater that is used to produce the goods and services consumed by the individual or community or produced by the business. Professor Arjan Hoekstra defined this concept. It provides information for evaluating the dependency of a national economy on external water resources. But how useful are both concepts?

Neither virtual water nor water footprints are developed to determine best allocation of water or trading strategies, as water is only one of several inputs (whereas regions might have competitive advantages in other production factors, such as land, energy and labour.) Besides, water footprint accounting does not distinguish whether the source of the water is sustainably used or causes externalities on the environment and therefore fails as an indicator of sustainability and environmental harm. This requires the next step: the water footprint sustainability assessment, which puts volumes in their local context. Finally, I think that consumers and producers need much more information than just the volume of water required. They need to know more about the local context and the implications on livelihoods and the environment.

2 What makes water so special and what are the implications for economics?

Why is water not an ordinary economic good?

Water has special characteristics:

- Usage can be consumptive as well as non-consumptive.
- Water is part of a system. Many water resources are transboundary and there are macro-economic interdependencies amongst users.
- There may be high costs involved in water re-allocation, due to all kinds of capital intensive hardware required as water is bulky and heavy.
- The structure of property rights to water is often unclear.
- Water can be considered a public good in many situations. In such situations markets fail and it is the responsibility of governments to make sure that there is safe access to water, which is essential for life. Distributional concerns are paramount.
- Finally, freshwater can hardly be substituted for an alternative liquid, except by desalinisation. This is indeed an increasingly viable source of water for coastal cities, but far too expensive for low-value crops at current desalination costs of 0.5 $/m^3$.

If we realise that to produce 1 kg of wheat about 1 m^3 of water is required, wheat would have to cost at least 0.5 $/kg just to recover the water input costs. This means that it is currently not feasible to desalinate water for irrigation of staple crops. Whether desalination will be feasible in the future depends on the development over time of commodity prices, desalination costs and transport costs of desalinated water. These costs depend in return on future energy prices and technological breakthroughs.

Allocation is a societal question

Because water is special, its allocation is a societal question that cannot be left to market forces alone. There is a growing competition for water among the various users: agriculture to grow food, feed, fibre and fuel; the environment; industry; domestic usage; and in situ usage, such as hydropower. The essential requirements for domestic and industrial users will generally get priority over irrigators, as a

result of political priority setting. This does not require a market. As long as fair compensation is paid to those who are forced to give up water, such a political allocation system is relatively efficient. According to professor Chris Perry, the irrigation water price would have to rise substantially to bring supply and demand for water into equilibrium. In most countries this would mean revolution. That is why a mix of instruments including regulation, property rights and pricing offers the best hope (The Economist, 2010). I am therefore not a proponent of market-clearing water pricing as 'the solution' to balance supply and demand for water.
It is important to realize that economists analyse problems. Politicians eventually decide. Nevertheless, credible advice is important even if politicians make decisions that are not fully based on science. This will strengthen the basis for arguments to transfer water between categories of users.

The value society attaches to all kinds of social concerns, such as equity, sustainability and food self-sufficiency, poverty alleviation, economic growth, wealth and risk, is, however, subject to change. Hence, if a government wants to reallocate water, it is important to know the trade-offs, i.e. what the implications are of that decision in terms of foregone benefits. This is what water valuation is about.

Water Valuation is complex and there is no general method

Water valuation is an analytical tool, which has a number of important roles to play: Firstly, in supporting decisions regarding water reallocation among sectors, regions and generations. Secondly, in selecting the locations where food can be produced viably and sustainably. Thirdly, in supporting decisions regarding investments in adaptations to climate change.

The value of irrigation water for staple crops is estimated to vary between 0.05 – 0.15 $/m^3$ (Hellegers and Perry, 2006), but is highly sensitive to the commodity price. When water is used for high-value crops, the value of water can be much higher, sometimes comparable to the value of water in domestic and industrial uses. A nice example is the value of irrigation water for Qat production in Yemen, which is around 1.0 $/m^3$. If the value of irrigation water is that high, it is even feasible to irrigate by means of water supplied by tankers.

Why is water valuing agricultural water use so complex?

- Values are not stable and change all the time. They vary due to seasonal and spatial variation and depend on rainfall, usage, commodity prices, quality, accessibility and reliability. In addition, water has cultural, religious and social dimensions to it.
- As irrigation water is an input into a production process, its demand is a derived demand.
- Values can generally not be derived from observed water markets. The price of tradable water rights does not yet provide a reliable indicator of value because markets are too 'thin' (too few traders). So we must estimate the value of water.
- Water values are highly site-specific and therefore not suitable for benefit transfer.
- Besides there is no single value for agricultural water use because farmers do not have perfect knowledge, do not all possess the same resource base, plant different crops for a variety of reasons (some for a financial return on land instead of water and others for sustenance), apply different crop rotation practices and are possibly risk adverse and they all value water differently. Results of work together with Brian Davidson (Hellegers and Davidson, 2010) indeed revealed that values need to be interpreted with care as the crop with the lowest return to water is probably not the one to be sacrificed if water is restricted.
- Finally, there is no general method to estimate the value of water.

Table 1 shows the main methods used to determine the value of water. The residual value (value of marginal product) is the easiest and most commonly used valuation technique. It is also the one I use. It relies on the belief that the value to a producer from producing a single good (its price by its quantity) is equal to the summation of the quantity of each input required to produce it multiplied by its value. The production function approach measures the marginal change in output from a unit increase in water input. Programming models measure the change in sectoral output from reallocation of water across the entire economy. Such a model is suitable for valuing multiple uses of water and for evaluating water reallocation, rather than values in current allocation. Hedonic pricing is the price differential paid for land with water resources. Opportunity cost is the value of the best alternative user. However, the water market is not homogeneous. Irrigation needs a lot of water, but has a low ability to pay and may accept water of lower quality and lower reliability, whereas for urban and industrial use is it generally the opposite. The true opportunity cost of water may therefore only be a fraction of the highest value use.

Agriculture	residual value (and variations), production function, programming models
Industry	production function, programming models
Hydropower	programming models, opportunity costs
Consumer goods	Contingent Valuation Method, programming models

Table 1. Most commonly used water valuation techniques.

The following examples give an idea of the usefulness of water valuation

To assess the implications of policy decisions on economic water productivity, an innovative method was developed together with professor Wim Bastiaanssen of TU Delft and eLEAF (Hellegers et al., 2009). It combines remote sensing and socio-economic analysis. In the technical part, the variability in crop water productivity (CWP in kg/m^3) is analysed on the basis of actual water consumption and associated biomass production using the Surface Energy Balance Algorithm for Land (SEBAL). This generates input for the socio-economic analysis, which aims to quantify the foregone economic water productivity (EWP in \$/m^3) of policy decisions to allocate water in a socially desirable way. The usefulness of such an approach is shown in the Inkomati Basin. We used this methodology to assess the productivity implications of the current land reform in the Inkomati Basin in South-Africa. Our approach is useful for determining the spatial differences in water consumption and productivity, for identifying farmers that consume more water than allowed, for refining allocation policies and for assessing the cost-effectiveness of ways to reduce agricultural water consumption.

This method was the basis for the interactive web-based rapid assessment WIBIS tool that generates transparent, impartial and verifiable key water-related indicators to support decision making in land use planning, which was built together with Herco Jansen of Alterra (Hellegers et al., 2011a). The usefulness of the tool is demonstrated in the Inkomati Basin, where the tool is used to assess the impact of converting land use on water productivity, water consumption, water availability and employment.

Water valuation has also proven to be useful, to estimate the own-price elasticity of demand for irrigation water. deployed over a wide range of crops, seasons and regions, and orders them from the highest average value to the lowest. Then, the amount of irrigation water used for each product, in each season and in each region is cumulatively summed over the range of uses according to the order of values. This data (Figure 5), once ordered, is then used to econometrically estimate the demand schedule from which the own-price elasticity of demand for irrigation water can be derived. Together with Brian Davison of the University of Melbourne this method was illustrated in the Musi catchment in India (Davidson

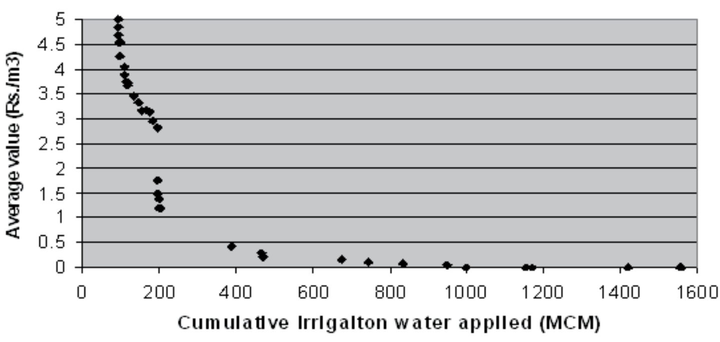

Figure 5. Ordering of the Crops from Highest Average Value (Rs/m3) to the Lowest and the Associated Cumulative Water Use (MCM). Source: Davidson and Hellegers (2011)

and Hellegers, 2011). For the crops where water is valued most highly, a relatively elastic demand was estimated. For the crops, where water is less valued, a relatively inelastic demand was estimated.

My work together with David Zilberman, of the University of California in Berkeley, is more theoretical oriented. We developed a framework to analyse how the specifications of new technologies and the heterogeneity of micro-units of production affect the input use, the adoption pattern and the average productivity of the fixed asset (Hellegers et al., 2011b). It shows that asset-productivity enhancing technologies that increases the productivity per unit of asset, such as drought resistant plant species, tend to be adopted by micro-units with high-quality assets. Variable-input, efficiency-enhancing technologies that increases the utilisation rate of variable input, such as modern irrigation technologies, tend to be adopted by micro-units with low-quality assets. In both cases variable input productivity increases, but the average productivity of the fixed asset may decline in the case of the latter technology. The distribution of asset-quality and the new technology specifications will therefore determine the change in average productivity of the fixed asset.

3 Future research directions of the new chair

I would like to distinguish three key research areas of my chair:

Firstly, the chair will focus on further developing methods to assess the economic implications of water reallocation. Including more elaborated water valuation methods

Secondly, the chair will focus on further developing innovative approaches to support decisions about adaptations in water management to climate change under uncertainty

Thirdly, the chair will focus on studying opportunities for integrated policy. For instance to support decisions regarding where food production has to take place.

The last two are discussed in more detail below.

Decision-making under uncertainty

To address climate change, there are two approaches: one deals with the cause and the other with the effects of climate change. Mitigation focuses on the reduction of greenhouse gas emission and adaptation tries to reduce potential damage resulting from global warming. Setting international mitigation targets has been done by signing the Kyoto Protocol in 1997. The European Union aimed at limiting the global average temperature increase to less than 2 ^{0}C compared with pre-industrial levels. Through the adoption of adaptation measures, the adaptive capacity may increase and the sensitivity of the system may reduce, thereby reducing the vulnerability of society. Adaptation will be inevitable, due to the 2 ^{0}C increase in temperature and due to the long time-lag in response to emissions reductions.

To know whether to adapt, what to adapt (see table 2), how much to adapt (optimal width and height) and when (optimal timing) to adapt by whom, insight is needed into the costs and benefits of various adaptation measures. This requires stakeholders involvement. Water valuation is a useful analytical tool to support investment decisions regarding adaptations to climate change under uncertainty.

There is not only uncertainty regarding the physical effects of climate change on water (such as the flooding probability), but also regarding the avoided expected damage (which increases by economic growth), and regarding technological innovations such as drought resistant plant species and a low-cost desalination breakthrough. Innovative advanced methods for decision making under uncertainty are therefore required.

To bridge the supply-demand gap	**To improve safety**
Rainwater harvesting	Dams and dykes
Artificial recharge	Retention areas
Desalination	Evacuation plans
Modern irrigation technology	Multifunctional solutions
Farm management practices	Accommodating uncertainty strategy
Irrigation scheduling	
Flexible land use	
Drought tolerant crops	

Table 2. Various kinds of adaptation measures in water management

Many of the benchmark studies (Stern, 2006; IPCC, 2007; The World Bank, 2010) are, however, so aggregated that they provide little guidance for economic analysis at the local level, where adaptations must occur. According to the IPCC (2007), efforts to quantify costs and benefits of adaptations are hampered by sensitivity to different estimation methods and assumptions regarding the allocation of changes in water availability. The World Bank (2010) estimates the cost of developing countries to adapt to climate change between 2010-2050 at US$ 70 -100 billion a year

Most adaptation decisions share a number of characteristics: investment costs are partially irreversible (sunk costs), there exists flexibility in the timing of investment (ability to postpone), uncertainty over future payoffs (reduced damage) and more information about payoffs becomes available over time. When this is the case, the decision problem is linked to the theory of investment under uncertainty of Dixit and Pindyck (1994). As there will be gradual resolution of climate change uncertainty over time; the question is: whether to postpone investments or to invest now?

Regular Cost-Benefit Analysis (CBA) does not take account of the possibility to partially delay the decision until more information becomes available. However real option theory does take the value of being flexible into account. When this is incorporated in an extended CBA, investments may become viable.

Cost-Benefit Analysis (CBA) in the context of climate change is also complicated by climate change uncertainties and by the choice of the discount rate (Weitzman, 2001). A low discount rate, such as used by Stern, makes current investments that generate benefits in the future look more attractive. Further research is needed into the ability of these tools to deal with uncertainty and irreversibility, and how they incorporate flexibility.

Opportunities for integrated policy

According to professor Arjan Hoekstra (2005), about 80% of the problems, we refer to as water problems – problems of water scarcity, flooding and water pollution – cannot be solved by water managers, because they are closely related to land use, energy use, spatial planning, demographic developments, international trade and economic growth. It is therefore not about what instruments water managers can use to solve water problems. It is about the broader question, in what ways can society as a whole better manage water. I am convinced that there is a lot of scope for improvement by means of good governance and integrated policy, which can result in substantial cost savings. I see many challenges for the Dutch water sector to export such knowledge. This corresponds with the advice of the topsector water (2011).

So many adaptations go beyond water management. As Wageningen has a long tradition in addressing water problems through land use adaptations, we have a clear role to play in this respect. For instance in studying the feasibility of multifunctional land use, wider dikes and the flexibility in land use to accommodate uncertainty.

Education

Currently I am the co-supervisor of two PhD students: Karianne de Bruin and Christian Siderius. The PhD thesis of Karianne (de Bruin, 2011) has provided us with useful new insights into the costs and benefits of adaptation options at different spatial scales under climate change uncertainty. The PhD thesis of Christian focuses on spatial adaptations (i.e. flexible land use) to temporal variations in water scarce areas. I am currently preparing two other PhD proposals. One about the future feasibility of desalination for irrigation of staple crops. The other one is about the relationship between water reliability and returns from water. A more reliable irrigation water supply seems for instance to increase the ex-ante investment decisions of famers and may therefore increase the water productivity. However, as farmers start to produce crops with higher returns (such as perennial crops), they will be exposed to more risk and hence the income variability may increase.

This kind of research requires multidisciplinary collaboration with national as well as international organisations, universities and private companies.

In recent years I have given guest lectures in different parts of Wageningen University and at IHE Delft. Currently I am involved in regular courses of the Environmental Economics and Natural Resources Group headed by professor Ekko van Ierland. It is always a great pleasure to exchange ideas with him, as well as with the staff members, PhD candidates and students of that group. Ideas about the world's most valuable asset water, which is well worth valuing. I feel privileged to hold this position.

Esteemed Rector Magnificus, ladies and gentlemen: Ik heb gezegd.

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Water resources are under increasing pressure from population growth and economic development. Scarcity of water and climate change induce a relocation of food production. The availability of freshwater originating from rainfall is a decisive factor in choosing the production location, given that it is currently not feasible to desalinate water for irrigation of staple crops. The allocation of water is a societal question that cannot be left to market forces alone. Economic research can provide knowledge for better informed decisions.

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