Green growth and water allocation

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Papers presented at a workshop

held on 22–23 November 2012 in Wageningen, the Netherlands

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The Netherlands National Committee
IHP-HWRP

UNESCO

United Nations
Educational, Scientific and
Cultural Organization

Netherlands National Commission for UNESCO

This publication is a contribution of the Netherlands to the International Hydrological Programme (IHP) of UNESCO

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Contents

Foreword

When looking at today's news headlines, one might think that economics is at the centre of our existence. What has been proven over and over again – and is now well known – is that economic development heavily impacts nature. It sometimes causes serious mismanagement of water, and can contribute to pollution, climate change and ecological disasters. This is why one of the authors of this publication pertinently write that 'economists owe ecology an apology'.

UNESCO's International Hydrological Programme (IHP) is the only intergovernmental water programme of the United Nations. Over the past 10 years, the Netherlands – through the effective Secretariat of its National IHP Committee – has been one of the most active countries worldwide contributing to the Programme.

IHP operates in accordance with the needs of its Member States and thrives thanks to their support and contributions. Through its commitment to IHP, the Netherlands has delivered high-quality scientific contributions and has successfully advocated and disseminated the Programme's work worldwide. The Secretariat of the Netherlands' IHP National Committee has also been instrumental in supporting many water professionals from developing countries and countries in transition.

This publication is an example of the invaluable contribution that the Netherlands has made so far to IHP. It is part of a wider series of publications based on several international meetings held in the Netherlands addressing key water issues and challenges. This series reflects the rich expertise of participants from various geographical and disciplinary backgrounds, and thus the true spirit of water cooperation.

It is indeed in this spirit, and in the framework of the UN International Year of Water Cooperation, that economics should underpin effective water management. Water has to be explicitly incorporated into economic development objectives, and sustainable water management challenges need to be addressed. Such activities leave a non-negligible water footprint for consideration.

I sincerely hope that this publication will raise awareness of these sensitive and urgent questions to ensure that ecological principles, including hydrology, are at the heart of economic development and decision-making. In this regard, I would like to thank the organizers of the meeting that led to this work. I also wish to extend my gratitude to the editors of the publication, and particularly to the Netherlands' IHP National Committee and the Netherlands National Commission for UNESCO for this latest publication of such a stimulating series.

BLANCA ELENA JIMÉNEZ CISNEROS

— *Director, Division of Water Sciences*
Secretary, International Hydrological Programme
UNESCO

Preface

For most nations economic development is inextricably linked to the availability and quality of freshwater. Although everyone uses water on a daily basis, we often take this vital commodity for granted – particularly in regions with a natural abundance of water. We forget that, in many regions, the availability of water is a matter of life and death.

The Director-General of UNESCO, Irina Bokova, recently highlighted that water is a common denominator of the leading global challenges of our time: energy, food, health, peace and security. She stated "There can be no development without water, and no sustainable development without sustainable water management".

At the same time, global water demand is projected to increase by 55% between 2000 and 2050 according to the OECD Environmental Outlook to 2050. Increasing competition between ecosystems, agriculture and other economic sectors for access to water resources calls for efficient water allocation policies.

In the Netherlands, the linkage between water and economics goes back a long way. For centuries, Dutch economic activities literally banked on water. As an example, from 1602 to 1796 the Dutch East India Company statistically eclipsed all of its rivals in the Asian trade by sending almost a million Europeans to work on 4,785 ships, netting more than 2.5 million tons of Asian trade goods. In the Netherlands almost all transport – i.e. almost all economic trade activities – was done via water until a few decades ago. Moreover, with over a third of its land below sea level, the Netherlands has a long history of combating high water levels and flood risks. Throughout the centuries, the Netherlands has developed solid technical knowledge (levees, windmills, dikes) and governance (establishment of water boards to manage water systems as early as the 12th century).

I personally believe that the combination of water and economics provides an excellent opportunity to ally the expertise of UNESCO and the OECD. During the World Water Forum in Marseille in March 2012 the OECD was given the mandate of water governance, while UNESCO plays the lead role in the International Year for Water Cooperation in 2013. There is unquestionable scope for strengthening ties between both organizations in this crucial area.

As an active member of the Intergovernmental Council of the International Hydrological Programme (IHP) of UNESCO, the Netherlands National Commission for UNESCO and the Netherlands National Committee IHP-HWRP organized the workshop 'Water allocation and green growth' in cooperation with the Government of the Netherlands. The workshop held in Wageningen in November 2012 served to provide input to the work of the OECD for the coming two years in analysing policy instruments and accompanying measures to facilitate water allocation mechanisms. This publication summarizes the discussions.

Dear reader, it is my pleasure and privilege to wish you an insightful reading.

ROBERT ZELDENRUST

— *Ambassador and Permanent Delegate of the Netherlands to UNESCO*

Water allocation and green growth

Summary of the meeting

Marguerite de Chaisemartin, Karin Thomas, Sophie Primot and Michael van der Valk

The OECD Environmental Outlook to 2050 indicates that competition between water users (including ecosystems) to access water resources will intensify in the coming decades. Green growth policies urge governments to pay more attention to the allocation efficiency of water policies. Climate change increases uncertainty in water availability and calls for flexible allocation mechanisms.

Ms Laan van Staalduinen, General Director of the Social Science Group at Wageningen UR, opened the discussion by outlining the Workshop's aim to formulate guidance on the issue of water allocation within the wider scope of green growth, and the importance of the meeting to Wageningen UR.

The OECD's Environmental Outlook to 2050 predicts a 55% increase in demand for water. As put forward by Mr Anthony Cox, OECD, a closer examination of overallocated systems and allocative efficiency of water policies is needed in several OECD and non-OECD countries. He welcomed the diversity of backgrounds of participants and its benefit to the OECD's future work in water allocation in a green growth context.

Marguerite de Chaisemartin is legal consultant at UNESCO's Division of Water Sciences. **Karin Thomas** is director of Thomas Consulting – Responsible Investments, Tilburg, the Netherlands. **Sophie Primot** is Senior Policy Officer at the Netherlands National Commission for UNESCO. **Michael van der Valk** is Scientific Secretary of the Netherlands National Committee IHP-HWRP, the Dutch governmental advisory body for the intergovernmental water programmes of UNESCO and WMO. This summary greatly benefited from the editorial work by **Penelope Keenan**.

1 What policy-makers need

New perspectives on water allocation: Green Growth beyond Rio +20

As recalled by Mr Niels Vlaanderen, Ministry of Infrastructure and Environment of the Netherlands, the Rio+20 discussions on green growth and on the Sustainable Development Goals leveraged global water challenges and goals to the international level. The OECD's Environmental Outlook to 2050 warns against exogenous developments and drivers affecting water resources and users. In 2013 discussions between the OECD and the Netherlands will seek to evaluate existing national policies and governance systems in view of the future challenges. The move echoes the statement of the new Dutch administration in October 2012 calling for a 'transition towards a sustainable economy and green growth'. Mr Vlaanderen reiterated the need for a forward-looking perspective to inform policy.

Bridging the gap between theory and practice

The overarching goal of the Netherlands' Aid Policy 2012 is green growth. It is focused on four areas, two of which are food security and water. Mr Maarten Gischler, Ministry of Foreign Affairs, outlined three central objectives for water: (i) safe deltas and improved river basin management; (ii) 25 % increase in water productivity in agriculture; and (iii) improved access to safe drinking water supply and adequate sanitation and hygiene (WASH). The Netherlands currently works with 11 countries, many of which are fragile or very poor, and 7 river basin organizations. To bridge the gap between policy and practice in the water allocation reform, Mr Gischler called for rational politicians, coherent policies, national frontiers drawn along water divides, greater control of water flows by water managers, repositioning towards a perfect water market, greater information availability and accessibility, informed and participatory decision-making, and higher levels of productivity of water users. Economists have a key role to play in making the business case for Integrated Water Resource Management

(IWRM). By developing messages that resonate both at the policy and local levels, economists contribute to improving food accessibility, mitigating flood risk and increasing water productivity. Tools for water allocation reform need to be versatile and adapted to each country and development trajectory. Mr Gischler concluded by saying that the economic value that water helps create may be made outside the realm of water allocation.

The concept of green growth from the country where it originated

Mr Tae-sun Shin, Korea Water Resources Corporation (K-Water), focused his intervention on water and green growth in the Republic of Korea. Water has played a pivotal role in Korea's economic growth over the past 40 years. More recently the country started concentrating on sustainable and environment-focused water management policies. An example of this is the Presidential Declaration on green growth in 2008 comprising 3 strategies and 10 policy directions for Korea's green growth. Given water shortages, high rainfall variation, and flood and drought risks, the country needs to invest in and develop effective water resources management policies. A focus of Korea's water policy is the investment in preventative rather than recovery measures.

How water allocation contributes to other issues on the water policy agenda

Ms Josephina Maestu, UN-Water Decade Programme on Advocacy and Communication (UNW-DPAC), recalled that water allocation needs to be seen as part of a more general and broader issue inclusive of water availability. Climate change, floods, droughts and human actions on water resources impact water availability. Many places in the world suffer an overallocation of water resources, which, if not orderly treated, may lead to 'disorderly deallocation'. It is, therefore, necessary to identify the pattern and country-specific factors, such as the level of economic water scarcity, infrastructure and geographic bodies of water. Water allocation also includes assessing the scale of all the water users. Other issues to be considered are prioritization rules and downstream and upstream users' relations. Alluding to the essay 'The end of reliability' by Casey Brown, Ms Maestu underlined that water allocation policies and mechanisms need to be flexible. Prior appropriation was also raised during the discussions, as well as the necessity that all stakeholders – particularly vulnerable groups – take part in open discussions.

2 Setting the scene

Water allocation policies and mechanisms

Different points of departure call for different kind of reforms. In water allocation policies and mechanisms Ms Petra Hellegers, Wageningen UR, addressed four questions: (i) what do we know about water allocation?; (ii) what do we need for water allocation reforms?; (iii) what are the challenges related to such reforms?; and (iv) what is the role of water economics? She stressed that understanding the political processes that drive water demand at various scales is crucial to gaining knowledge of water allocation. What is needed for water allocation reform is practical guidance in the form of tools to support water allocation decisions, substantiated with system knowledge of water availability, responsibilities and regulations. By applying flexible mechanisms water can be reallocated when appropriate. Deriving from the above, different steps of a water allocation reform comprise three dynamic dimensions: (i) knowledge of the water hydrological system; (ii) economic assessment; and (iii) political process. According to Ms Hellegers, the major challenges related to such water allocation reforms stem from a weak knowledge-base, unclear political objectives, varied interests of stakeholders, inadequate implementation and policy incoherence. The main roles of water economics were highlighted, for example, showing the potential water productivity gain of water reallocation among regions, users and generations. Ms Hellegers concluded by stressing that tools can support water reallocation decisions but that reform requires insight into political objectives, good basin governance and policy coherence.

Knowledge-base on water allocation of the UN World Water Development Report 4

As developed in the fourth World Water Development Report (WWDR-4), 'blue water' can be considered through the cycle of water allocation, delivery, use and entitlements. One of the key issues is uncertainty, which according to Mr Pieter van der Zaag, UNESCO-IHE Institute for Water Education, partly lies in the new water allocation paradigm: water markets are often absent or imperfect, water managers and users tend to be risk averse and flexibility is a must. Mr Van der Zaag then proceeded to the lessons learned from case studies from the WWDR-4, including the Pangani River Basin (Tanzania), the Zambezi River Basin (Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia and Zimbabwe), the Imcomati River Basin (Mozambique, South Africa and Swaziland), Andhra Pradesh (India), South Africa and Sri Lanka.

Scenario-based water outlook 2050 and the increasing importance and complexity of water allocation

According to Mr David Wiberg, International Institute for Applied Systems Analysis (IIASA), water management needs to intensify and diversify as water integrates across scales and sectors. Water management is risk-based, but how does risk change? How do we make decisions now that will be effective and robust into the future under increasing risks? Mr Wiberg described the World Water Scenarios approach, a set of options for solutions, organized by categories and scales. The system's objective is to allow stakeholders to navigate through it and select a combination of solutions adapted to their area. This starts with a conceptual model, develops through the identification of drivers' analysis, and considers future narratives or 'stylized scenarios'. Part of the methodology is to analyse the drivers, develop future narratives, examine and quantify changes in drivers, assess the impacts and identify management options. A key element is that all these items are carried out iteratively with the stakeholders.

3 Case studies: current and future challenges for water allocation in various basins

The Rhine/Meuse River Basin

Mr Roy Brouwer, IVM, VU University Amsterdam, explained how the existing macro-economic model 'GTAP' can be employed in researching how water constraints in different economic sectors affect the economy as a whole. He described how he and his colleagues are examining the economic impacts of the increasing frequency of water scarcity due to climate change and the possibility of water reallocation between countries, river basins and sectors. The project focuses on the Rhine and Meuse transboundary basins. Using the GTAP model it simulates the extreme 1976 drought and looks at the effect on the Dutch economy if it were to happen now. The study presented an important reduction in the economic damage cost and greater insight into the economic shadow price of water. Future work will be carried out to incorporate explicit water uses into other sectors of the economy (specifically energy, transport and industry) and to examine possible reallocation of water between agricultural and non-agricultural sectors.

The Murray-Darling River Basin

Overallocation is a problem in itself in Australia, but this links with other concerns such as an overregulation of rivers, water conveyance and governance. According to Mr Brian Davidson, University of Melbourne, the issue in Australia is not so much the amount of water and average rainfall but rather the high variability. Australia doesn't have a water shortage problem; it has an allocation distribution problem. When specifically looking at the Murray-Darling

Basin, transboundary issues and governance emerge as key concerns for water allocation. Indeed, water is the responsibility of the State Government, yet the Federal Government has started intervening with the Murray-Darling Basin Authority. Some positive governance practices are the flexible Cap system (limiting water diversions) established in the 1990s and water trading that created water entitlements and a water market. Mr Davidson outlined that the current Murray-Darling Basin Plan addresses the issue of over-allocation with a realistic timeframe for implementation and foresees a lower quantity of water returned to the environment. According to Mr Davidson, the following issues still need to be addressed in the Basin Plan: increasing water savings, considering marginal changes rather than averages, quantifying environmental water use efficiency, engaging market mechanisms, and improving governance. He referred to the wheel of water allocation reform presented by Ms Hellegers and said that, in the case of the Murray-Darling Basin Plan, most of its steps were followed but not done well.

The Nile Basin

Mr Christian Siderius, Wageningen UR, introduced the WaterWise Nile model, developed to identify the optimal allocation of water and land resources in the Nile Basin in the context of food security. Indeed, 10 countries out of the 11 in the Nile Basin are not food self-sufficient. The model optimizes a yield function, constrained by available land and water resources and a predefined budget. The results of the research indicate that a 76% increase in food production will be needed in the coming years in the Basin. WaterWise simulates various scenarios that investigate how much can be gained from total cooperation within the Nile Basin. It also helps identify the best options to reach this increase in food production. Egypt currently relies heavily on irrigation and is food self-sufficient. According to Mr Siderius, the 76% target increase can be reached through basin cooperation and an increase in food production in South Sudan and the Lake Victoria region. The model shows that a change in water allocation can contribute up to 20% of the needed increase in production, but also that the future of food security in the Nile Basin lies in utilizing the vast forgotten potential of rain-fed agriculture in the upstream interior. Rain-fed agriculture can cover more than 75% of the needed increase in food production by 2025 if it is developed. Stabilizing these regions and strengthening intra-basin cooperation via food trade seem to be better strategies than unilateral expansion of irrigation.

The Senegal River Basin

The Senegal River Basin is located in West Africa and has four riparian countries: Guinea, Mali, Mauritania and Senegal. The Organisation pour la Mise en Valeur du fleuve Sénégal (OMVS) is composed of various permanent and consultative bodies from the Basin to local level. Mr Tamsir Ndiaye, OMVS, reported that reservoirs and hydropower systems are already in place in the Basin, and two new dams are planned to start in 2013: the Félou and Gouina dams, which will further facilitate water allocation in the Basin, yet will have environmental consequences. Mr Ndiaye highlighted that the interest of the OMVS in the Workshop is twofold: (i) the issue of trade-offs between uses; and (ii) available water allocation tools and knowledge to set better informed water prices and to avoid conflict. Water use charges are in place; however, they are not totally satisfactory as processing parameters are political and social rather than scientific. A particularity of the Senegal River Basin is its variability of water uses and the social impact of floods in the region. This variability is a tool for water allocation. The Senegal River Basin is an example where artificial floods have been reinstituted and have a positive function. The first significant trigger for cooperation in the region was droughts. No country on its own could have solved the problem, and donors' funds were not offered to a single country. Responsibilities, benefits and water infrastructures are shared between the riparians.

4 Tools to support water allocation decisions

What do we need to know to allocate water properly? Experience abounds on decision supporting tools, such as water accounting, integrated hydro-economic modelling, trade-off analysis and water valuation. What do we know? What is missing? What mechanisms can facilitate decision-making where information is lacking?

The importance and limits of modelling to support practical policy issues

Mr Willem Ligtvoet, PBL Netherlands Environmental Assessment Agency, presented IMAGE, a model currently under development that aims to explore the effects of water allocation and green growth strategies. This tool and the next global model, IMAGE 3.0, will cover global wide-scale and long-term changes such as: economic and demographic growth; agriculture, irrigation, land use and food production; hydrology (river and coastal systems); pollution and nutrient deposition; and water, sanitation and health impacts. He highlighted the relevancy of the tool for the OECD's work on governance for water resource allocation as an integrated and long-term approach. He identified three areas where IMAGE can be applied: (i) agriculture and water use for irrigation; (ii) nutrient use and pollution of coastal waters; and (iii) flood risks. Mr Ligtvoet underlined that the tool is a framework for gaining insight into regionally-specific conditions, for example, in Africa, by coupling WaterWise improved yield-gap maps with PBL's database. The projection is that regional analysis could be used for national strategies. This is the next step.

Participants suggested that regional analysis could also be useful for transboundary discussions. Mr Van Schaik suggested designing different scenarios and development strategies with options and effects, therefore enabling policy-makers to choose. He referred to the example of the delta in the Netherlands, which denotes a large stakeholder dialogue in the decision-making process. These dialogues will also be necessary when examining some of the solutions offered.

A cohesive approach and an iterative process

Mr Chris Perry, former director of the International Water Management Institute (IWMI), focused his presentation on the components needed to achieve Effective Water Resources Management. He stated that the following five elements are found wherever water is managed effectively: (A) Accounting – understanding how much water is available; (B) Bargaining – prioritizing allocation; (C) Codification – setting rules; (D) Delegation – assigning responsibility; (E) Engineering – developing the facilities; and (F) Feedback. He emphasized the importance of setting priorities rather than achieving the 'right' outcome. The focus should first be on 'effective' (objective) water management and, secondly, on 'good' (subjective) water management. Mr Perry stipulated that by approaching hydrology in the right way the government will automatically take the right decision. According to Mr Perry, the ABCDE framework puts forward the multidisciplinary character of an effective water management system: (A) – (geo)hydrologists and climate specialists; (B) – policy-makers (including technical advisers such as economists, agronomists, environmentalists, business lobbyists); (C) – lawyers; (D) – institutional specialists; and (E) – engineers.

Water trading as a tool to reveal information. Lessons from international experience

In the conventional view, the market is a preference revelation mechanism. According to Ms Maestu, trading allows us to gain information about the marginal value of water among sellers and identify less costly options for achieving self-designated targets. She claimed that the problem in the current water market is that there is a lack of precise information and certainties of who the buyers and sellers are. In most cases in the water market both private and public agents act with imperfect information. Adequate registration of information may not exist and, therefore, the market doesn't work properly. There is uncertainty in water availability, external costs and water productivity.

Mr Diego Rodriguez, World Bank, added that in Latin America, what is in the public domain and what is privatized is a political issue. Ms Maestu concluded that, in relation to trading, mechanisms for reallocation are needed. The market is not going to solve everything. It has political implications.

Preparing for an uncertain future through option analysis: the case of the Roode Vaart

Infrastructure projects are subject to policy and exogenous uncertainties such as the impact of climate change. Being able to anticipate and manage uncertainties adds value: investment costs and risks can be reduced and/or benefits and opportunities increased. Ms Gigi van Rhee, Stratelligence, described the Adaptive Delta Management approach (ADM) developed by the Dutch Delta Commissioner, which is meant to manage these uncertainties and avoid over- and under-investment in deltas and water management. One of the characteristics of this approach is the active search for opportunities to link investment agendas and to take advantage of possible synergy benefits. Ms van Rhee illustrated the practical value of this method with the Southwestern Delta case in the Netherlands. In this region, where plans and projects from many domains come together, the ADM approach was first put into practice. Commercial shipping is on the increase and calls for an enhanced capacity of the Volkerak sluices to reduce waiting times. The Krammer sluices and their fresh–salt separation system are up for major repairs. The regional economy, nature and recreation require improved water quality in the Grevelingen and the Volkerak-Zoommeer. And agriculture requires a more robust freshwater supply. Ms van Rhee highlighted that a key element of the methodology is determining measures in uncertainty. In establishing cost-effectiveness in uncertain conditions, she conveyed that measures should have a 'no regrets' basis: (i) contribute to solving existing water quality problems; (ii) have a positive benefit-cost ratio; and (iii) reflect a benefit-cost ratio of positive or neutral in all possible scenarios. She outlined the case of the planned redevelopment of the city centre of Zevenbergen and the two possible alternatives: 'green' and 'blue', which will be decided upon in 2013. The blue alternative has the option to bring water back into the Roode Vaart. Option analysis indicates that pre-investment in the blue alternative is a no-regrets measure. Ms van Rhee added that the impact of ecological issues and biodiversity was not addressed in this option analysis. An important lesson from the Roode Vaart case is that policy-making is carried out without possessing all the information needed. The information simply isn't always available.

5 Transition barriers: political economy and implementation

What are the difficulties in the reform of allocation decisions and mechanisms? What accompanying measures can help overcome the challenges?

The Water Blueprint

The status of water is clear: climate change, economic and demographic developments are likely to make achieving the good status objective of the Water Framework Directive by 2015 more difficult. Without early action, later action will be more complex and costly. Ms Henriette Faergemann, European Commission, put forward the Water Blueprint, a package currently under development by the European Commission to ensure the sustainability of all activities that impact on water, thereby securing the availability of good-quality water for sustainable and equitable water use. The Blueprint is focused on three key objectives: (i) better implementation; (ii) greater integration of water in other policy areas; and (iii) new legal proposals to complete the current framework. The Blueprint impact assessment specifies 12 priority problems and 4 key policy options. Ms Faergemann outlined the European Commission's methodology to realize greater water efficiency though water pricing, Common Implementation Strategy guidance, recommendations on growth, and sharing best practices. To address vulnerability, the European Commission is developing drought and flood risk management plans, and water re-use and retention plans and mechanisms. Ms Faergemann underlined that all consultation and guidance will be carried out with EU Member States.

How infrastructure design and financing can support flexible allocation decisions

Water allocation faces a completely different set of challenges in developing countries when compared to OECD countries. Mr Diego Rodriguez, World Bank, highlighted the central role of (water) infrastructure policies to growth, mainly due to the large timescale. He pointed out that when water infrastructures are not yet in place in developing countries it creates an opportunity to build them in a different way. Particularly in the developing world water challenges (sanitation, urbanization, food production, energy and industry and environment) are growing rapidly and could jeopardize the goal of 'green growth for all'. Mr Rodriguez elaborated on the value of greater flexibility in infrastructure design and planning. Removing rigidity in allocation is more necessary than ever as developing countries are liberalizing economies at a fast pace, thereby putting a premium on flexibility. He pointed out, however, that flexibility brings operational challenges and can be difficult to implement particularly when designing large infrastructures. The World Bank's response is focused on engaging more in discussions on water allocation at political level, accelerating institutional reform, strengthening support for bottom-up regulation, ensuring inclusion of water users, and carrying out traditional cost-benefit analyses to inform economic efficiency, investment decisions and social equity.

In discussions, Mr Rodriguez mentioned there are many options for low-income countries to leverage funds, mainly related to public investment. The World Bank can, for example, advise countries on how to use pension funds. Lending concessions also exist at very low rates for the poorest countries. Mr Van Schaik asked about the World Bank's operational role in implementing policies, and whether there are any methodologies or guidance on setting priorities for allocations. Mr Rodriguez responded that the World Bank doesn't get involved in decisions at policy level. There has been increased demand for analytical tools to inform decisions at political level, however, all decisions are country specific, and it is up to the country to decide when the World Bank assists.

Allocating across new waterscapes? Review of the operational effectiveness of allocation mechanisms

Mr John Matthews, AGWA/Conservation International, opened his presentation with a quote from Vahid Alavian, World Bank Water Advisor: 'We can't wait 30 years for precise science ... I want to see climate adaptation programmes based on non-precise decision-making. Now.' Stationarity has been the problem for a long time, and current decision-making processes tend to result in stationary results. Data are outdated and lack relevance for today's decision-makers. Mr Matthews presented two kinds of resilience associated with climate-driven environmental change: (i) resilience as a buffering change (return to previous status as quickly as possible); and (ii) resilience as a transforming change (how to lower the peak and facilitate the change forward). In the second case, adaptation may also be a contributing factor in managing resilience and moving forward. To make resilient water allocations a consistent outcome, Mr Matthews insisted it is necessary to identify the gaps in knowledge and to break down the silo structure in which expertise is currently captured. Economics alone is not the answer and expertise for resilient allocation lies in many disciplines. Achieving synergies requires reconciling quite different – and often antagonistic – approaches. He added that resilience knowledge is most needed by the technical staff that take small-scale decisions everyday and who need to implement the decisions taken by policy-makers. A new green infrastructure needs to reconcile disciplines that not only lived apart, but hated each other. The participants agreed that there is not a lot of available data, and the existing data is spread over different disciplines and captured in institutions.

Water Outlook 2050: scenario analysis to support decision-making in water allocation

Mr Peter Droogers, Future Water, started by quoting the provocative title 'Little change in global drought over the past 60 years' from a recent Nature issue[1]. This is the case on average, but when looking at maps, some places will suffer from a lot of water while other locations will suffer from drought. This illustrates that many tools exist today to support policy-makers in the decision-making process, each with its limitations and applicability within a certain context and spatial scale. Mr Droogers presented a regional study on the 2050 outlook for water supply and demand of 21 Middle East and North Africa (MENA) countries, focused on adaptation strategies. The results of the study project that water shortages will increase from 42 km^3/yr in 2010 to 199 km^3/yr by 2050 in the region, 14% of which will be due to climate change. Using the marginal cost curves method, the study provides decision-makers with a prioritization of the different adaptation strategies (increased productivity, expanded supply or reduced demand) and calculates adaptation costs of US$ 100 billion per year. Mr Droogers' presentation underlined the importance of the availability of good quantitative tools and public data. He also insisted on the importance of focusing not only on water allocation tools, but also on an all-inclusive analysis (e.g. upstream/downstream, costs/benefits, impact/adaptation).

Water allocation: a participatory approach?

According to Mr Mark Smith, International Union for Conservation of Nature (IUCN), environmental flows are about allocation. Environmental flows and environmental flow management bestow certain uncertainties, competing interests and complexity. Finally the choices to be made are up to the local people in the basins. He presented a case from the Pangani River Basin (Tanzania), which

[1] **Sheffield, J., E.F. Wood and M.L. Roderick (2012)** Little change in global drought over the past 60 years. Nature, vol. 497, pp. 435–438.

illustrates the prioritization of water uses through negotiated flow management. In such a way, negotiation depended on a multi-scale involvement process, where assessments were put into scenarios for stakeholders to understand the key trade-offs and available data. Flow management was used as a process to catalyse change: to equip people to generate information, build capacities, strengthen dialogue between institutions, create negotiation platforms, and ultimately to allocate water. Mr Smith ended his presentation with the open question of the timescale of this change process: is it too long? Can it happen faster? What is missing to speed up the process?

6 Moving forward

Mr Xavier Leflaive, OECD, commented that the Workshop provided an excellent and lively setting to explore some of the policy challenges and responses related to the design and implementation of flexible water allocation mechanisms. He highlighted the need for developing greater practical guidance to facilitate reform of allocation policies and mechanisms. The OECD is considering building a knowledge-base on how OECD member countries allocate water and what allocation instruments exist. Mr Leflaive highlighted water allocation decisions will always be made with a certain degree of uncertainty. Tools and information for taking decisions with more confidence is key, but understanding the political process is crucial.

Preliminary conclusions and agenda for future work

- Recognize that innovative design and processes can bring flexibility. Technical innovation and innovation within institutions are needed;
- Identify compensation mechanisms and measures that facilitate reform of allocation policies and processes;
- Negotiate water allocations, and advocate the establishment of related objectives and regulations at national level;

- Foster flexible allocation mechanisms to adapt to future circumstances. Flexibility in institutions and their strategies is also crucial;
- Develop approaches to achieve a trade-off between flexibility, certainty and efficiency. Overly flexible water rights can lead to less certainty – and thus less investment;
- Establish methods to evaluate and strengthen the knowledge-base on water allocation. For example, the OECD could carry out a preliminary assessment of how water is allocated in OECD countries and the various institutional processes. An interesting tool developed by the UN is the System of Environmental Economic Accounting for Water (SEEAW), a framework for organizing hydrological and economic information in a consistent manner;
- Invest in information, monitoring, capacity-building and lessons learned.

Position paper for the international workshop on Water Allocation and Green Growth

Petra Hellegers

Introduction

Well-managed water resources can be a significant driver of growth and can generate huge benefits for human health and the economy. On the other hand, water insecurity can significantly hinder growth, reduce opportunities for further development, and impose economic costs.

Water allocation is an important topic in a world that experiences changes in population, diet, land use, economic markets and climate. Allocation decisions have normative dimensions. The principles underlying such decisions should be known, and be seen to be legitimate and just. Often various interests need to be considered and weighted according to different criteria, which are difficult to put under one denominator. So it is not easy to reach consensus on priorities.

An increasing number of countries recognize the need to reform their water allocation policies and mechanisms. It is becoming increasingly important to national governments to have reliable and objective information about the state of water resources and how they are used and managed.

The required knowledge base to support sustainable decisions has to be made clear, and evidence that certain allocation mechanisms work – i.e. can deal with an increasingly variable hydrological cycle and rapid socio-economic development effectively and flexibly – has to be made available.

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This paper provides some background to the planned OECD project and an outline of the issues addressed during the preparatory Workshop. The scope of the Workshop went beyond the conventional, often rather narrow, discussions about the role of market-based mechanisms, such as pricing, markets and tradable rights, to encourage the reallocation of water to where it creates most value. It focused on the available tools to address issues regarding over-allocation of water, the political process of water allocation, and decisions made in a wide range of sectors that will affect water. The three points discussed were: (i) the needs for sustainable decisions; (ii) the availability of tools; and (iii) transition barriers. Each of these points was put forward as a starting point for discussions and is described in more detail below.

What is needed for sustainable decisions

According to Perry (2003) sound water resources management requires knowledge about the resource availability (a) in time and space, and about the impact that investments in water resources development can have on further economic development. This knowledge is required to constrain water allocation in time. Availability is, however, dynamic. The allocation process is a political bargaining (b) process. The agreed allocations have to be translated into regulations and procedures, referred to here as codification (c), so that the water services to each user are clear for any hydrological circumstance. Water allocation mechanisms have to be designed – for example rationing, pricing, markets, or tradable rights – that give various incentives, such as encouraging productive usage. Finally responsibilities have to be assigned, i.e. delegated (d) and infrastructure has to be engineered (e) to deliver the specified service to each user. According to Perry (2003), the hierarchy and interdependence among these elements have important implications for the design of interventions. Some argue that finance (f) should be added as well.

This shows that a reform in water allocation policies (b) and mechanisms (c) has to take into account the other elements as well, such as resource availability, the required laws and institutions and existing infrastructure. Below a review is presented of the available tools to analyse: (a) the hydrological system; (b) the political process of water allocation at the macro level; and of (c) mechanisms to guide reallocation of water among users at the micro level. Finally, transition barriers for reform, such as the required elements of d, e and f, will be discussed.

What tools are available?

A distinction can be made between analytical tools to support policy decisions and allocation tools/mechanisms. Analytical tools provide insight into the various implications of water allocation, which makes trade-offs between various development paths visible. Allocation tools are mechanisms that give incentives, such as encouraging productive use, to guide reallocation.

It is also important to mention that the suitability of certain tools depends on the timescale and the geographical scale in which they have to operate. Water entitlements, such as formal agreements, secure for the holder, for instance, the right to water for many years. Temporary water reallocation activities generally adopt a time horizon of one hydrological year and local area, while water distribution and delivery are often based on weeks, days and hours.

Tools for hydrological system analysis at the basin level

Green growth requires that water allocation should be constrained by the amount of water that is available at a specific time. In many places water is, however, currently over-allocated, i.e. more entitlements have been issued for a system than can be sustained (not to be confused with over-used, i.e. more water has been allocated to users within a given period than can be sustained).

An increase in water use is less of a problem if it concerns non-consumptive usage, i.e. if the quantity of water diverted is almost the same as the quantity of water returned to the hydrological system. Many uses of water – domestic use, industrial use, hydropower generation, navigation, fisheries – are predominantly non-consumptive. Water used in agriculture, which transpires in the biomass formation process, evaporates from wet soil and leaves is consumptive usage. It is removed from the local hydrological cycle and availability for downstream users is reduced.

The linkage between upstream consumption and downstream availability justifies the assessment of water availability and use at the basin level. Water accounting and hydrological modelling are suitable analytical tools in this respect. Remote Sensing is a consistent method to provide impartial data on actual evapotranspiration, i.e. water consumption and biomass production. It shows potential benefits from reallocation water from low to high productive usage. (eLEAF, 2012)

Analysing water allocation in the context of green growth requires a long-term view from a system perspective that takes into account the evolution of some of the uncertain hydrological and social processes involved. Scenario analysis is an appropriate tool to deal with uncertainty. The World Water Scenarios Project of IIASA has constructed various scenarios to explore future water availability and its impacts on human well-being and the health of ecosystems that provide life support (IIASA, 2012).

Tools for the water allocation process of decision-makers in a basin or country

Water allocation is the process of sharing the amount of available water between legitimate claimants at a specific time. Because markets for water often fail, allocation of water between competing uses is generally achieved administratively by issuing entitlement, taking into account often conflicting objectives such as economic efficiency, social equity and ecological integrity. Economic, social, political and ecological values of water are often reconciled to prioritize water allocation. It is a debate of a normative kind. It is often not clear what principles, such as food security and food self-sufficiency, guide such decisions and how the principles of equitable access, economic efficiency, sustainability and customary norms and values can be reconciled. If the market plays a role, social and environmental values should be protected.

Tools to assess the implications and risks of various pathways of economic growth are hydro-economic models that can provide insight into the trade-offs of various water allocations, such as Waterwise (Wageningen UR, 2013). Such models can show the comparative advantages of the countries in the basin and the benefits that can be gained, by the users of shared resources, through cooperation. Water reallocation is often a zero-sum game from a hydrological perspective, but not from an economic perspective. The challenge is to unlock and share benefits. The concept of benefit-sharing is helpful in this respect.

Tools for integrated analysis (outside the water box)

According to the 4th World Water Development Report (UNESCO, 2012) water underpins all aspects of development, and a coordinated approach to managing and allocating water is critical. The report underlines that in order to meet multiple goals water needs to be an intrinsic element in decision-making across the whole development spectrum. It highlights the interactions between water and the drivers of change and encourages all water users both in and out of the 'water box' to take responsible action. Effective and sustainable management of water resources and allocation is not only the responsibility of the water sector, but requires cooperation and coordination between sectoral jurisdictions. Explicit trade-offs may need to be made to allocate water to uses which maximize achievable benefits across a number of developmental sectors. Providing decision-makers with tools that show the broader water resource consequences of alternative ways forward will substantially contribute to better overall management of the resource, with the possibility of reducing adverse impacts.

As the world does not revolve around water a better understanding of the economic and political processes that drive water demand at different scales is needed. Water managers should anticipate developments in water demand, such as land grabbing and trade liberalization and rising food and energy prices. Some of the external drivers interact in unexpected ways. The external instead of the internal capacities of water management should therefore be strengthened. Integrated analyses are required, which take international trade into consideration.

The United Nations has proposed a framework that presents physical accounts in a cross-sectoral framework – the System of Environmental Economic Accounting for Water (SEEAW) – and links these accounts to economic sectors. It provides a step towards better national planning and budgeting for water and, if expanded, reflects the substantial role of rainfed landscapes as consumers of rainfall and sources of runoff and recharge.

Mechanisms for water reallocation between end-users

Water rights, permits and entitlements, as well as allocation mechanisms, provide security and predictability in an uncertain world. Their aim is to reduce risk. But there is a trade-off between reliability and the amount of water one can use –the more secure the smaller the flow. How can water allocation systems better deal with uncertain inflows while maximizing beneficial use?

There are various types of water transfer mechanisms. High-value users can compensate low-value water users for the temporary right to use their water traded on the water market. The creation of water banks, by means of a public intermediary between sellers and buyers, is an attempt to improve the reliability of water markets. A dry-year option is a contingent contract between a buyer (who needs a high reliability of supply) and a seller that gives the buyer the right, but not the obligation, to use water owned by the seller. Risk can also be transferred differentially between the interested sectors by paying a premium for transferring the supply risk.

Transition barriers

Many countries are finding the process of reform very challenging as political economy concerns over competitiveness and distribution play a major role in the ability of countries to undertake water policy reform. The implementation of new water allocation policies and mechanisms will have various implications and may face barriers. Water markets are for instance prone to market failure. The main reasons are the public good, nature, externalities of allocation decisions, and monopolies. The required laws and institutions are also often not in place. Certain instruments can for instance only be applied in a certain legal setting (for rationing effective legislation is required). The design of the existing infrastructure may also not be suitable for certain mechanisms, such as volumetric pricing in case water use cannot be measured. Whether transition of existing allocations towards more productive ones will take place depends also on the size of the potential efficiency gains versus the size of the transaction costs.

Final remarks

Every water allocation and green growth challenge is a unique combination of history, climate, social and economic pressures, resource endowment, trading opportunities, and so on. To this extent, the 'best' allocation solution must be uniquely designed, and the result of political processes that allow local preferences and priorities to contribute to the allocation of water.

It is hard in practice to solve issues which are essentially political in nature (income distribution, environment) 'by' economics. Such issues can just be better understood 'through' economics.

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ABCDE

A framework for thinking about water resources management

Chris Perry

Water resources management is a topic of increased attention. The guidance from international forums and academic papers is strong on opinions about what is 'good', but often vague about how to achieve desirable outcomes. Defining what is good, or better, is a legitimate area of debate, but effective management—where the outcome is consistent with expressed policy—is a more concrete objective. The following five elements are found wherever water is managed effectively: (i) physical accounting for water; (ii) political process for priority setting; (iii) formal or informal rules; (iv) defined responsibilities for public, private and other agencies; and (v) appropriate engineering works to accomplish service delivery. These elements are required at all levels (basin, sector, project and user group). As a shorthand, these five elements are referred to as ABCDE: (A) Accounting; (B) Bargaining; (C) Codification; (D) Delegation; and (E) Engineering.

Introduction

Ensuring water services for drinking, sanitation, irrigation and commercial activities is generally recognized as a responsibility of governments—in parallel with ensuring that the environment is protected. The progress of civilization can often be mapped in relation to water, most especially in climates where the reliable production of food and fibre depends on the control of water. Gradually, the cumulative impact of many small interventions meant that

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This paper summarizes a paper on the same topic, published in Water International.

variants applied at one point in a catchment or basin had a measurable impact on availability elsewhere.

When water is scarce, various interests intersect. Should water be released from dams during the summer to meet irrigation needs, or winter to generate power for heating? Are golf courses that generate jobs, tourism and other economic activity, a higher priority than low-value grain crops for food security? Should cities have unrestricted access to water for domestic and sanitation purposes? If some groups in society have historically been disadvantaged in access to water, should preferential entitlements be established? 'The environment' can utilize a great deal of water—but what constitutes protection and sustainability once significant parts of the economy have developed on the basis of restricting environmental allocations? Is 'the environment' more important than feeding people?

Recognition of the complex implications of water scarcity and competition for water is widespread, yet advice on the practical steps—and especially the relationship between these steps—is poorly defined and difficult to operationalize. Most advice comprises advocacy rather than analysis of successful systems, of which there are many across the world.

Every 'water' situation is a unique combination of history, climate, social and economic pressures, resource endowments, and so on. To this extent, the solution to every problem must be uniquely designed. But the extreme variety of scenarios has resulted in quite legitimate scepticism about the suitability of proposed general 'solutions': participatory management has been successful in some circumstances and failed in others; tradable water rights are a success in Australia, but inconceivable in most groundwater-irrigated areas; volumetric water allocations work well in Morocco but have limited potential in rice-growing areas.

This paper identifies in generic terms those activities that are intrinsic to effective water resources management, providing examples from a number of countries. The word 'effective' is chosen deliberately. Water resources management is effective if the outcome for users (farmers, municipalities, factories, ferries, fisheries, protected ecosystems, etc.) is consistent with the declarations of policy made at the relevant level of administration. Thus if it is national policy that drinking water supplies have precedence over irrigation, then in case of a drought, effective management would result in cuts to irrigation before restrictions were imposed on household use. If water resources management is effective, the observed outcome for each water user should be consistent with declared policy—nationally, regionally, or locally, depending on the administrative structure.

Effective management is not the same as good management. While effective management can be observed objectively as the consistency of policy with outcome, good management is a far more subjective topic. Most issues in water resources management are subtle and complex: is it appropriate to irreversibly deplete fossil aquifers that (like un-mined minerals) provide no social benefit by simply existing? How much water should be reallocated from wealthier farmers to poorer farmers to achieve 'pro-poor' objectives? What is the appropriate level of restoration for wetlands already damaged by upstream diversions? The approach presented here will not attempt to define or prescribe what constitutes good water resources management—that is for the interested parties to judge—but rather will focus on what is necessary for effective management. However, since the consistency between the outcomes and policy that characterize effective management is an essential precondition to good management, the identification of necessary attributes of effectiveness can contribute to improving water resources management more generally.

Practitioners (policy-makers, planners, politicians, donor agencies, and especially managers) make operational decisions, and want to know the distinction between what must be done (effective management) and what ought to be done (good management). Often, what 'ought' to be done will vary depending on local conditions, and the decision about what ought to be done is often not set by the local manager, but rather by the rules within which they manage.

The structure described in the next section is not prescriptive—a building requires foundations, walls and a roof, but dogma ends there. The materials for each part may vary according to preference and availability, and the critical issue is functionality, fitness for purpose, and internal consistency. With these elements in place, the final structure, be it a mansion or a mud hut, might serve the purpose for which it was designed. But if the walls are not strong enough to support the roof, the structure is bound to fail.

Basic elements of effective water resources management

A number of essential elements are found wherever water management is effective. When they are absent—in whole or in part—water management is ineffective, with typical symptoms being disputes about entitlements, unobserved or unspecified supply schedules, over-exploitation of resources, pollution, and deteriorating infrastructure.

The elements of effective water management can be defined as follows:

- Clear and publicly available knowledge of resource availability in time and space;
- Policies governing water resources development, including assigning priorities among users for the available water;
- Translation of policies into clear allocation rules and procedures for water service to each sector/user, and under any hydrological circumstance;
- Defined roles and responsibilities for provision of all aspects of the specified water service;
- Infrastructure to deliver the specified service to each user.

As a shorthand, the five above-mentioned elements are referred to as:

A Accounting for the available resources;

B Bargaining through the political process to determine priorities and allocations;
C Codification of the agreed priorities and allocations into rules, statutes and laws;
D Delegation of implementation to appropriate institutions and agencies;
E Engineering to create the necessary infrastructure to deliver the agreed services.

A number of points emerge from this list.

First, this process occurs both between and within countries: if the river is transboundary; between regions within a country; between sectors in a region; and within a sector among entities (e.g. municipalities or irrigation projects). Some shared facilities such as dams will have inter-sectoral rules of operation for competing uses. Eventually, at the level of an irrigation project, there may be interfaces between project authorities, federated water user associations and water user associations, before the final service is defined to the farmer.

Second, at each level, the internal ABCDE process is governed by what happened at higher levels of the decision-making framework. The actual allocation of water to an irrigation project (the 'A', at that level) is the result of decisions at higher levels about how water should be allocated between, for instance, irrigation, hydropower and municipal use at a particular dam.

Third, at each level there is a degree of hierarchy and interdependence among the elements. The rules cannot be written (C) until the outcome of the priority setting exercise (B) is complete, and that process must be based on the quantity of available water (A). Roles and responsibilities (D) cannot be defined unless the water service is specified. Infrastructure (E) must be consistent in sizing and control features with the service to be delivered.

Fourth, this hierarchy and interdependence has important implications for the design of interventions to address unsuccessful management.

Fifth, the interface at each level may involve national or local governments, not-for-profit agencies, private companies, user organizations, and individuals.

Sixth, formulating an effective water management system is a multidisciplinary effort involving the ABCDE process as follows:
A Hydrologists and geo-hydrologists, climate specialists;
B Policy-makers (including their technical advisers, such as economists, agronomists, climate specialists, as well as representatives of special interests such as environmentalists, business lobbyists, etc.);
C Lawyers;
D Institutional specialists;
E Engineers.

Each discipline has an essential, specialist contribution to make, and a comprehensive solution is dependent on the input of each discipline and concomitant respect during that process. Indeed most of the unsuccessful initiatives of recent decades can be traced to a failure to appreciate the multidisciplinary complexity of an intervention in water resources management.

Finally, the process needs 'F'[1] – feedback. This process is continuous and, to a degree, circular (a proposed construction of a new dam, for example, may result in a political debate about allocation of the additional water). But the essential hierarchy remains a generally observed and logical sequence.

This neat, coherent sequence is of course never what is faced in the field. Faced with dysfunctional systems, most experts have fallen back to their own discipline to identify 'what needs to be done'. Thus economists have argued that proper pricing will lead to

1 Paul van Hofwegen formalized the need for this dimension during discussions of the approach at the Asian Development Bank in March 2012.

appropriate allocation of scarce resource, engineers argue that improved technology can increase the productivity of water and reduce wastage, management specialists insist that privatized institutions will function more effectively than public agencies, and social scientists will see a role for participatory systems to involve the farmers. Adding gender, the environment, sustainability, virtual water and inter-generational equity does nothing to simplify the problem.

The essential fault with each of these good ideas is that any change to one aspect of the ABCDE sequence has implications (F) for some or all the other components. Participatory management, for example, requires legal definition of water rights to the group, infrastructure suitable to deliver service both to the group and within the group, and clarity about ownership and responsibility for maintenance and rehabilitation of infrastructure.

An additional impact—worthy of special mention as it is the source of so much confusion (see, for example, the European Water Framework Directive) is the impact of improved irrigation technology. Most commonly this is expected to 'save' water because it is more 'efficient'. Unlike domestic use, where 95% or so of water delivered to the household is returned to the system, irrigation is a consumptive user of water: the whole purpose of providing irrigation water is to allow the plant to convert that water into vapour, at which point it is lost to potential reuse downstream. The primary impact of increasing 'efficiency' is to allow a higher proportion of water applied to a field to be consumed, so that return flows are reduced. If these return flows were reusable (as recharge to an underlying aquifer or flows via drains to downstream users) then there are off-site impacts of the 'improved efficiency' that must be properly accounted for by re-visiting 'A'. Evidence from China, Spain and Australia all confirm that improving irrigation efficiency looks quite different 'on farm' from how it looks in a broader hydrological context.

Conclusion

The ABCDE framework provides an initial, comprehensive basis for evaluating the current state of water resources management in a particular area, what is in place, what is working, and what is not working. There will be many details under each heading. It also provides a basis for identifying problems and how interventions will play out in various dimensions. Most importantly it provides a place 'at the table' for each concerned discipline, and reduces the possibility that a single point agenda obscures the legitimate technical, legal and organizational aspects of a scenario or a proposed intervention.

Reallocating water for the environment in the Murray-Darling Basin of Australia

Current concerns, practices and remaining questions

Brian Davidson and Hector Malano

In the past 20 years Australian policy-makers have become aware of the need to reform and reduce the water allocated to irrigators in the Murray-Darling Basin. This is especially the case as the environment is also recognized as a legitimate user of the water and the amount extracted for irrigation from the Basin's rivers is considered to be too large to maintain the health of those rivers. In response to these concerns, a set of policies has been put into place to return the water from irrigators and back to the river. This process has not been an easy one and has resulted in an additional set of unexpected concerns and consequences. The aim in this paper is to document and comment on this process of reform, concentrating on most of the current issues and concerns, especially that of buying back water entitlements and attempts to improve the efficiency of water use and delivery in Australia's Murray-Darling Basin. It is concluded that in many ways the problems of taking water away from the irrigation sector will never be adequately resolved. However, if a solution exists, then what is required is a better idea of the technical and allocative efficiency aspects of not only the irrigation sector, but also of the environment. Until these aspects are known, understood and applied, it is impossible for policy-makers to allocate water in a way that society desires. Furthermore, the approach taken by the Government to reallocate water to the environment is not the most ideal as it is at times driven by political considerations, rather than by some concern for the welfare of the users. Its approach is not a complete one either, as it does not account for the fact that irrigators usually farm relatively small holdings of land, whose viability depends on water availability, rather than on the factors that give Australian agriculture its comparative advantage. Moreover, the approach that has been under-

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taken has been an expensive one, one that has not necessarily been very economically efficient. However, as this is an ongoing project, there are policies the Government can take to improve things, making the whole process more efficient.

Introduction

Australia has a long history of being at the forefront of concerns about irrigation and the regulation of water. Cathcart (2009) traces these beliefs from the days of early European settlement through to the current concerns regarding the environmental crisis facing Australia's rivers. It is a somewhat sad and sorry 120-year history of developers dreaming and planning the regulation of rivers on a large scale, taking water from the environment to 'make the desert bloom'. After the schemes were started, governments were then required to bail them out and take over the developments, which were, in turn, financially mismanaged. State governments failed to recover the costs of construction and maintenance of these schemes and they tended to overallocate the available water supplies to consumptive use. This has led to the recognition that the environment had suffered and that the health of the rivers had deteriorated significantly.

While the State and Federal Governments recognized these problems and put in place a number of measures to remedy them in the 1990s, the millennium drought (2002–2009) spurred policy-makers to take a more radical approach. In the Murray-Darling Basin (hereafter the Basin) governing power was centralized away from parochial State governments to the Federal Government and its agency, the Murray-Darling Basin Authority (hereafter the Authority). The Authority's main task has been to develop the Murray-Darling Basin Plan, and thereby remedy the problems that exist in the Basin. In addition, the Authority had responsibility for presenting this plan to the stakeholders in the Basin and to assist in implementing it. Their overriding aim was to return some water from the irrigation sector and use it for environmental purposes. While the attempts to achieve this aim are by no means complete, or have received universal support, they illustrate the problems

Figure 1: The Murray-Darling Basin.

governments around the world will face if they attempt recover water from irrigators and return it to the environment.

The aim in this paper is to briefly outline some of the causes and problems that have arisen in Australian irrigation in the past two decades, as the nation attempts to address its environmental problems associated with regulating rivers. The central issue addressed in this paper relates to remedying what could be called the 'overallocation' problem; a situation in which water is being returned to the environment. However, overallocation is not the only concern that policy-makers need to address, as difficulties in the irrigation sector tend to be very complex 'wicked' problems. It should be noted that this account is by no means complete as the size of the problem is large and the area precludes a more comprehensive review. The region assessed is the Murray-Darling Basin, Australia's largest and most complex irrigation region and where these concerns would seem to be most constraining (Figure 1). The process by which water is recovered is outlined, prior to an assessment of what might be required to further resolve these concerns.

Current concerns

The problem of over regulation of rivers

The degree to which rivers are regulated in the Basin seems excessive. The annual average runoff at the mouth of the Basin is approximately 15,000 Mm^3/yr (million cubic metres per year). The total diversions are on average 11,000 Mm^3/yr, of which irrigation accounts on average for 9,000 Mm^3/yr. However, the regulation capacity in the Basin, the amount that can be stored and handled, is over 35,000 Mm^3 (MDBA, 2010). It is known that the system has to handle an extreme level of climate variability, but this level of regulation would be extreme if it wasn't for the explicit purpose of improving the security of supply to irrigation. As averages are not a good basis to work from, a more appropriate way of evaluating the situation is through an analysis of the flows on a yearly basis, where the extremes of wet and dry years can be accounted for. Nevertheless, such an approach would complicate the debate and using averages simplifies it.

Another way of looking at this issue is to assess the amount of water required per head of population in the Basin in comparison to the amount available. It could be argued that by acquiring this security of storage a form of buffer supply is obtained. What needs to be asked is how much water is regulated or controlled and available for use at all times. As the intended use is by people, availability needs to be evaluated per head of population.

The Basin is home to two million people, which on the basis of 15,000 Mm^3/yr of available runoff translates into an availability of 20,500 l/day/head. Of the amount controlled (11,000 Mm^3)

the amount available for use is approximately 15,000 l/day/head. For comparative purposes Lomborg (2001) provides data on the availability of water for use in a range of countries. Nationally, in Australia the figure is 50,913 l/day/head available for use, while in China the figure is 6,108 l/day/head and in the UK it is only 3,337 l/day/head. It is quite apparent from this data that Australia has vast amounts of water under its control and available for use, much of it in the Basin, way beyond its requirements and that of all but two other countries. These figures must be ignored by those who believe greater water security is needed. To put this in the clearest possible terms, if water availability is measured as the amount of the resource humanity can get its hands on (the only measure that should be used), then Australia is not the driest continent in the world and the Basin does not necessarily suffer from a water availability problem.

The data presented above would suggest that an excessive investment in water regulation has been made. Even with extreme levels of variability, one has to wonder why any policy-maker would invest more in water control infrastructure in a region that is already vastly greater than that of other more populated regions and countries. The only justification could well be that the benefits from this investment outweigh its costs. While this is known not to be true (Davidson, 1969), fears of lack of water security would also seem to be similarly ill-founded.

Overallocation issues

Both the irrigated area and diversion rates in Australia increased substantially after the 1960s (Figure 2). This trend continued well into the 1990s, and most of this later development occurred in the Basin, which holds about 75% of the country's irrigated area (ANCID, 2007) and Davidson (2010). Looking at the Basin in more detail, it is evident that total use has expanded greatly since 1960. Most of this development occurred in New South Wales followed by Victoria (Figure 3). The decade of the 1970s was considered to be a wet one and, as a consequence, water tended to be overallocated in the expectation that inflows into dams would be maintained. However, the problems with this policy soon became apparent in the dryer 1980s and especially during the millennium drought after 2003. Water was clearly overallocated, particularly in New South Wales. By 1994 the various State governments agreed to place a cap on further allocations.

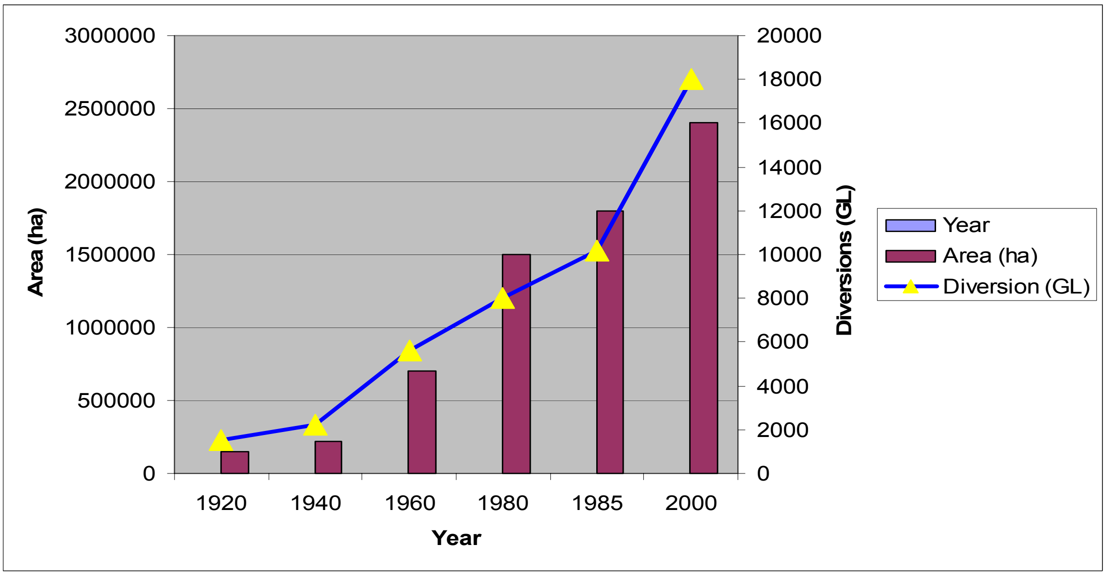

Figure 2: Total water allocations and diversions in Australia.

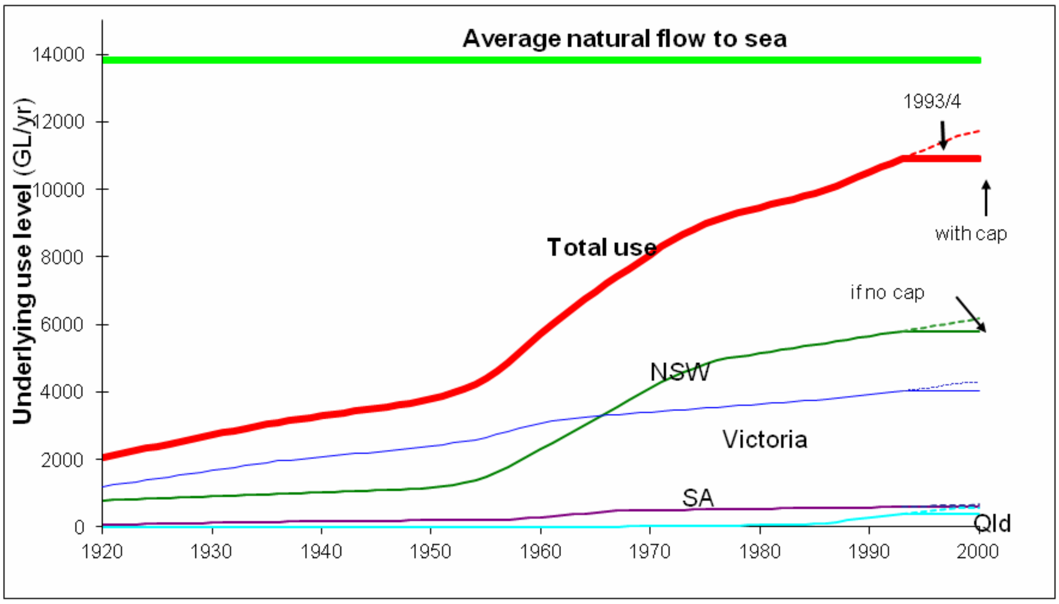

Figure 3: Evolution of water entitlements in the Murray-Darling Basin States.

Overallocation is a complex concept to understand in the Australian context. Farmers have a water entitlement, which is really nothing more than the right to divert a certain quantity of water, subject to a small probability of supply deficit. So, if the fixed stock of water in a reservoir is low (because of a drought) then a farmer's allocation of the water is determined as a percentage of their entitlement. Before a season starts, a river manager announces the allocation a farmer will receive and it may be below the amount to which a farmer is entitled. This announced allocation acts as a guaranteed minimum for the season and becomes the basis upon which farmers make their production and financial decisions regarding water. This amount allocated could rise if more water becomes available during the season.

In an aggregate sense water can be overallocated if the environment continually receives less than what is required to sustain its environmental function. This is the situation that currently exists in the Basin. In addition, if the amount allocated to irrigators increases the level of water supply reliability will fall. This situation can arise, and has done so in the Basin, because excessive entitlements for irrigation have been issued which have the effect of reducing the reliability of supply.

Rivers as irrigation carriers

Taking a step back from the allocation problem in Australia, a potentially greater environmental concern arises from the way water is transported from the storages to users. Two issues stand out as being important with using rivers as irrigation carriers: (i) timing differences in irrigation and environmental flows, and (ii) spatial impacts related to how water is excluded from and returned to the river landscapes.

Reservoirs are often located hundreds of kilometres upstream from where the water is used and the water must be conveyed between the two along existing rivers. The environment becomes affected because normally the rivers would naturally peak in July-October when precipitation is at its greatest, yet with irrigation the rivers peak in February when the irrigation water is required (ANCID, 2007).

In addition, there is a policy in place where farmer's allocations only count once they have been diverted from the system into the farm. System operators, while requiring farmers to provide some notification of when their allocations will be used, need to anticipate several days in advance when the system needs to supply water. If it rains in the meantime, water will flow through the system and may flood downstream areas. The problem can be summed up simply by stating that the rivers have high flows when they should have low flows and have low flows when they should have high flows. This is a timing problem, first and foremost, before it is a quantity problem. If water is to be allocated to the environment, then a significant quantity needs to be taken to provide water at the right time of the year and to reduce it from farmers who require it at a different time.

How environmental water is used is important. Two not altogether independent approaches would seem to exist; one which can be called an 'icon site approach', the other an 'ecological flood plain approach'. With the icon site approach, water is directed to a select number of environmentally sensitive sites, whereas what is important in the ecological flood plain approach is the linking of ecological communities along the river valley. The holistic thinking of the ecological flood plain approach requires a massive degree of watering over wide spatial areas if it is to be achieved, whereas an icon site approach requires a lot less water. While the choice of approach will have a profound impact on the amount of water required to fulfil the environmental requirements, it will also have a big impact on the timing of environmental flows.

Governance

The governance of water in Australia, especially with respect to the Basin, was seen to be a major obstacle to reform. The concern can be traced back to before Australia was formed as a political entity comprising six separate State governments. The Murray River was at that time a major transport route. In the Constitution, water and rivers were defined to be a State responsibility. To overcome these problems, in 2007 the Basin States agreed that the Federal Government would take more control of policy in the Basin.

Even today, interstate rivalries tend to dominate political discussion of the rivers. For instance, South Australia, at the bottom end of the Basin, has always been dependent on flows from the upland States. Recently, the South Australian government threatened to raise the issue with the High Court of Australia. Regardless of the merits of any case the South Australians may make, it is symptomatic of a general malaise that New South Wales and Victoria have developed their parts of the Basin to the point where water is overallocated. It should be noted, however, that the South Australians have not held back from developing their reaches of the Murray River and now use the water to service Adelaide and many of its population centres further to the west and north.

At another level, according to the Constitution, the Federal Government is responsible for international agreements. The Federal Government has signed up to the RAMSAR agreement, especially with respect to the maintenance of the Coorong and the other lakes at the mouth of the Murray River. Their responsibilities under the same agreements also extend to other sites spread throughout the Basin. It is through this hook that the Federal Government has brought into the debate the concerns in the Basin and, ultimately, the solutions that are required. Perhaps this was inevitable as the Federal Government is the only entity with the taxation base required to fund the changes needed in the Basin.

The wicked social element

Wicked problems are those that have multiple interacting systems – physical, economic and social – and are subject to a number of social and institutional uncertainties and knowledge Imperfections. These problems cannot be solved by relying on biophysical science alone because the problems involve multi-layered physical and social systems. Furthermore, isolating the property rights and the equity considerations that ensue cannot be done to a degree that would satisfy all interested parties. These problems are continually evolving. As a consequence no single or definitive optimal policy solutions to wicked problems exist. Instead, solutions can only be transitory, and an adaptive approach is required to address the continued evolution of the problems.

Malano (2010) and Davidson and Malano (2011) argued that water resource management in Australia should be thought of as a wicked problem. With water management there is often no clear cause and effect paths to investigate, no optimal solutions to suggest, no history to follow and no way of resolving the social, political, economic and biophysical complexity. In addition, irreversible climate change, poorly defined property rights and the inability to manage transboundary water resources all add to the complexity of the problems.

The changing nature of wicked problems and large uncertainties surrounding physical predictions and future policy changes, require an adaptive approach to the problem. Those who call for certainty and a one-off solution have misread the nature of the problem and have ignored its underlying variability. Usually they incorrectly couch the problem in terms of the need to invest, and/or that the river's health is in such a dire state that it will expire, and/or that the science is settled. The problem is that wicked problems defy a simple and single solution.

A little understood social issue associated with irrigation in the Basin could be termed the 'small farm problem'. In establishing irrigation, the Government also implemented a policy of establishing irrigation schemes where farmers had, by Australian standards, very small plots of land. This long-standing policy known as a pattern of 'closer settlement' does not work towards the nation's comparative advantages of combining a lot of readily available and inexpensive land with mechanisation as a substitute for labour (Davidson, 1981).

Irrigation farming in Australia used little land and a lot of labour to produce higher yielding water dependent crops (Davidson, 1969). The social problem that arises from this policy of closer settlement is that if farmer's water allocations are removed or reduced, they are left with a plot of land that is too small to sustain a viable enterprise based on more conventional extensive agricultural practices. As a consequence, any policy to reduce the overallocation problem needs to also solve the social small farm problem as well.

As Davidson and Malano (2011) suggest, in attempting to solve the problems in the Basin the first requirement is to think of and conceptualize the problem correctly. Then there is a need to recognize that these types of problems defy an optimal once-off solution, and that any partial solution requires some degree of compromise and should be subject to continual review and adaptation over time. To achieve that solution and to negotiate the compromises involved requires more knowledge about ecosystem responses to additional environmental water. It also implies considering complementary measures such as structural adjustment needed to deal with the 'small holder' problem. Thus, the adoption of an adaptive approach, one that is flexible enough to account for the vagaries of the Basin's climate and Government policies, is required. It would appear the Authority is now applying this adaptive approach to the problems in the Basin.

Recovering water for the environment – recent practices

Much of the reform focus in the Basin in recent years has centred on recovering water from the irrigation sector. This act itself is thought to simultaneously solve the overallocation and conveyance concerns. The Federal Government has taken a greater role in these solutions in an attempt to solve the governance issues. The environmental lobby argued that 4,200 Mm^3/yr was required as a minimum if irreparable environmental damage was to be avoided (Wentworth Group of Concerned Scientists, 2010). After much negotiation and a failed initial Basin plan, the Government finally settled on recovering 2,750 Mm^3/yr for the environment. This argument has been a vicious one because of the two entrenched positions held by the irrigators who are unwilling to part with their entitlements, and the environmental lobby who insists on a large quantity of water to undertake an improvement in ecology of the river.

Before discussing current measures, it should not be forgotten that a number of measures were implemented in the 1990s that, it could be argued, went further to resolving these concerns. The first of these measures was the cap on diversions of 11,000 Mm^3 that was put in place in the Basin in 1994. This cap was a flexible measure that the irrigators could exceed in any one year, but couldn't exceed on average over a long period of time. The second measure was to allow irrigators to trade water. To do this, it was necessary to separate the title to water from the title to land. The policy to allow water trading occurred at a time in Australia's history when a policy of improving competitiveness was in vogue. The currency was floated, protection levels in the manufacturing sector were lowered, assistance to agricultural marketing was abolished and the economy was opened up to international trade to a degree that had never been considered in the past (Kelly, 1992). In such economic and political environments water trading was introduced to improve the efficiency of water use. The benefits and flexibility that trading water could bring, however, was somewhat blighted by the restrictions that were placed on it by the Basin States. These restrictions were by and large promoted by the water supply authorities who were worried about maintaining their systems left with stranded assets in light of water being traded to other districts (Australian Government, 2011).

While the Federal Government has always been involved in the concerns surrounding the Basin, in 2007 it significantly increased this involvement by reconstituting its main governing entity, the Murray-Darling Basin Commission, to the new Murray-Darling Basin Authority. The original entity was set up under the Council of Australian Governments to coordinate the activities of the relevant governments in the Basin. Yet in the 2007 reforms, it was agreed that the Federal Government would take significant control of major initiatives in the Basin, especially those related to recovering water for environmental purposes. Its main activities related to making assessments of what each sector required, and with purchasing entitlements for the environment from irrigators. In addition, the Federal Government has recently become a large player in facilitating the renovation of existing schemes in order to save water through making efficiency improvements. This includes a contribution of nearly half the AU$ 1.953 billion needed for the Northern Victorian Irrigation Renewal Project (NVIRP) to 'save'

214 Mm^3 for the environment (DSE, 2012) and a AU$ 1.7 billion plan to 'save' 450 Mm^3 in South Australia. In the following section the recent reform measures are discussed in terms of the original Murray-Darling Basin Plan (hereafter the Plan 2010) and the modified Basin Plan (hereafter the Plan 2012), along with the more ambitious plans to 'save' water.

First Basin Plan (2010)

In its first incarnation, the Plan released in October 2010 appeared to satisfy all the demands of the environmental lobby. The Plan contained assessments of the water needs of all users of the Basin. The Authority argued strenuously that it had undertaken all the science required to maintain the river system by establishing a set of sustainable diversion limits (SDLs) for each sub-catchment and specifying the amounts that would need to be recovered in each. A problem with these reductions was that, in percentage terms, they all looked the same for all nearby rivers. For example, in the northern parts of the Basin the reductions in most rivers were in the order of 25% and in the south they were all approximately 37% of existing irrigator's entitlements (Malano and Davidson, 2010).

There are two related questions that needed to be internally consistent if the proposed reductions in entitlements requested in the Plan 2010 were to be considered a valid request. First, was the extent of overallocation the same in each sub-catchment of the Basin? Clearly the answer to this question is no, because they were allocated by different State governments. Second, was the environmental function in each sub-catchment the same? Clearly again the answer to this question is also no, because the northern part of the Basin is sub-tropical/tropical with summer rainfall and the southern part is temperate with winter rainfall. Also, the degree of rainfall variability across the Basin is not the same. So, if the degree of overallocation and the environmental functions are not the same in each sub-catchment, why were the amounts of reductions in each sub-catchment very similar? The only instance where these two questions are actually consistent in the Basin is when considering questions about the mouth of the Murray River. This problem with the Plan 2010 was most stark when comparing the Ovens and Goulburn sub-catchments in Victoria, both of which were scheduled to reduce the allocations to irrigators by 37%. In the Ovens sub-catchment there were only three irrigators and a regulation of the flows at roughly 3% of its natural flow, while in the Goulburn sub-catchment flows were fully regulated and the river accounted for 10% of all the Basin flow. These reductions, as it turns out would result in a certain acceptable flow through the mouth of the River. The logic that the environmental needs of the rivers might differ along the course of the River, or that different sub-catchments contribute vastly different amounts the flow at the mouth of the River was not considered in the formulation of the Plan 2010 (MDBA, 2010).

However, it was not the issues of the validity of the SDLs that destroyed the Plan 2010 within days of its release. Rather, it was the reaction of irrigators to the loss of their entitlements that went some way towards ending it. While the farmers were volatile over the issue, it was the banks who suggested that the only asset farmers really held was their entitlement to water, and it was based on this asset that they were granted loans. By cutting farmers' entitlements the Authority was reducing their asset base and the banks would need to foreclose on some of the loans they had made to irrigators, even though farmers were promised more than adequate compensation. To be clear on this point, what the buyback policy was doing in effect was reducing the asset base of irrigators, thus reducing the collateral upon which they could borrow. While they were adequately compensated for the sale of this asset, selling it had a flow on effect into the investment sector. Faced with this problem, the Federal Government reacted quickly and withdrew the Plan 2010 on the grounds that the socio-economic implications were not well understood. Ultimately the Authority Chairman and its CEO resigned on the grounds that all they were doing with the Plan 2010 was enacting a flawed piece of legislation that required them to find the water needed to improve the health of the rivers.

Second Basin Plan (2012)

In 2012 the Authority reissued the Plan with vastly reduced allocations to the environment of only 2,750 Mm^3. In addition, the amounts taken from each sub-catchment differed. For instance, in the southern parts of the Basin three main tributaries (the Murray, Goulburn and Murrumbidgee) contribute to most of the water flows. It is these sub-catchments that were now required to make the greatest contribution to the water for the environment.

To meet these environmental requirements, the Federal Government has begun to purchase water licences from irrigators who are willing to sell. It has so far refused to compulsorily acquire water, something it has the power to do. As at September 2012 1,094 Mm^3 of water was acquired to meet the environmental targets at a cost of AU$ 2.27 billion (Australian Government, 2013).

What this water should be used for, and how it might be managed in the long term, is still subject to some debate. An Environmental Water Holder Office has been created whose task it is to do this. In 2012–13 the buyback of environmental water by the Federal Government is estimated at 943 Mm^3. It will be applied to environmental sites within the Basin, with nearly one third of this amount expended on the sensitive lakes at the mouth of the Murray (Australian Government, 2012).

Arguably the most important thing the Authority has done with the Plan 2012 is to take an adaptive approach to the problems in the Basin by allowing an extended implementation period until 2019. It has also taken further action to adjust the volume of water allocated to the environment in the future if needed. This adaptive approach is in part recognition of the wicked nature of the problems faced in the Basin. The environment, like the irrigators, has always had to deal with a variable flow despite the degree of regulation involved. After all, the natural variability of the Australian climate caused the River to run dry for long periods of time before storages were introduced.

Programmes to 'save' water through improving efficiency

Rather controversially, the Federal Government has also revealed that it is willing to pay to improve the efficiency of the irrigation systems. In northern Victoria, in October 2011, it agreed to fund the AU$ 953 million required to complete the second stage of the Northern Victoria Irrigation Renewal Project (NVIRP). It also agreed to purchase the 102 Mm^3 of efficiency derived water 'savings' from the scheme for an additional AU$ 219 million from the irrigators and to pay an additional AU$ 43.7 million for on-farm improvements that would save another 10 Mm^3. All this (AU$ 1.216 billion in total) is in addition to the AU$ 1 billion spent on Stage 1 of the NVIRP (supposedly to 'save' 225 Mm^3), which was paid for by urban water authorities and the State government of Victoria (Department of Sustainability and Environment, 2012). In addition, in October 2012 the Federal Government pledged AU$ 1.7 billion towards 'saving' an additional 450 Mm^3 in the South Australian reaches of the Murray River. This programme in South Australia is in addition to its savings of 2,750 Mm^3 already required under the Plan 2012.

Under the NVIRP much of the infrastructure scheduled for improvement still has an average life of more than 40 years (ANCID, 2007). In addition, a significant proportion of the back channels and pipelines are to be retired. However, ANCID (2007) found that the water delivery distribution scheme in the region was working to a fairly high degree of efficiency. In 2005–2006 they estimated that in all years somewhere between 70% and 96% of water ordered was delivered. In the ANCID (2007) study, the major concerns expressed by the management authority (Goulburn Murray Water) related to environmental issues, the use of natural waterways as the prime conveyance system, salinity and water contamination. Only in one component of scheme (Torrumbarry) was water saving measures thought to be of concern, and it was a secondary concern.

Ombudsman Victoria (2011) found that the State government committed to the NVIRP without making the required business case for it. The Ombudsman was also critical of the cost-benefit analysis undertaken prior to approval and cast doubt on the amounts of water that were estimated to be 'saved'. The Ombudsman also documented a range of serious problems associated with the management of the project. These problems were not only confined to the NVIRP, but also involved public servants and those employed by the local water authority to implement it. The Victorian Auditor General Office (2010) concluded that the, Victorian Government decisions to invest around AU$ 2 billion in irrigation efficiency and related projects between 2004 and 2007 were poorly informed. Whether these projects represent the best solution to achieve the government's policy objectives of saving water and securing Victoria's water, remains unclear.

This was particularly evident for the Foodbowl Modernisation Project (the first stage of NVIRP), where the decision to commit AU$ 1 billion was based on advice of water savings and cost assumptions that had not been verified, technology that had not yet proven itself and the feasibility of the project, which was unknown. As a consequence, assumed water losses have been significantly revised down, making the achievement of intended water savings less certain.

Quite simply AU$ 2 billion to save 225 Mm^3 is not a good deal. This represents a cost of approximately AU$ 8,9/m^3, when the price of buying back permanent water allocations was approximately AU$ 1,2/m^3. In addition, the size of the water saving, at 225 Mm^3, is quite small in a system in which 2,400 Mm^3 is regulated. In South Australia the proposal is that each cubic metre of water costs approximately AU$ 3,8 to acquire.

Rather interestingly, it was the concerns over the environment that had a lot to do with establishing the NVIRP and other schemes like it. The perceived idea is that in some way engineering water efficiency can create water, like repairing a leak in the system, rather than just direct it from one use to another. If a leak is to be stopped (by lining canals, improving infrastructure to increase conveyance rates, etc.) more water is used locally and less seeps into the groundwater aquifers. As a consequence, less is available downstream as return flows are reduced. As there is only a fixed quantity of water, arguments about fixing leaks are really about having more control over the environment, as a leak (or loss) is nothing more than an entry into the environment at a place where it is not desired. Fixing leaks means that the quantity of water controlled increases and that increase can be placed elsewhere else in the environment. Sharing the efficiency improvements with irrigation really means that the environment, somewhere, must lose because return flows are reduced.

These schemes are nothing more than a gift to the irrigators, although sometimes they are asked to make a small contribution to them. In the case of the NVIRP, the local authority was asked to contribute AU$ 106 million towards the project. This would have meant that water prices would rise by somewhere between 25 and 45%. However, in the funding for the second phase of the NVIRP, the irrigators have agreed to sacrifice 102 Mm^3 of 'savings' in water they were to receive in return for not meeting this debt (Department of Sustainability and Environment, 2012). To be clear, the inference that cannot be ignored with NVIRP is that it was made on political – rather than sound economic, environmental or engineering – grounds.

Remaining questions – what is required for a better solution

It is quite evident that the process of resolving the concerns people have with the Basin will continue for a long time. One should not be surprised by this as 'wicked problems' tend to defy a definitive solution. The volatile nature of this debate is to be expected and does not really need to be resolved. After all it is in the nature of democracies to be unstable platforms for decision-making. This instability is a good thing as it provides a role for science to play in providing criticism of existing measures, thus stopping governments from making big and expensive mistakes, although there has not been much evidence in the Basin to support the case that science has succeeded in doing this yet.

A role science should play in resolving any problem, after establishing that the problem actually exists, is to provide a range of options to solve the problem. As Pielke (2007) suggests, in many environmental debates the scientific community has become an advocate for a particular solution, rather than 'honest brokers' of a range of solutions. Advocating a particular 'silver bullet' solution to a wicked problem needs to stop, not only because it clouds the debate, but principally because it is illogical. There are no single solutions to a wicked problem.

There is a lot of information missing in the debate on Australian rivers. Despite claims to the contrary, there is little - if any - information available on the environmental response function of rivers. It is not known how many extra environmental outputs are derived for every extra unit of water applied. Without this information there is no possibility of understanding the technical efficiency of environmental water use. In turn, without this, any idea of what the allocative efficiency of environmental water is cannot even be ascertained. In addition, making a rational choice between the irrigation and environmental sectors is not possible.

While the overallocation problem would seem to be addressed, what is not as clear is how the problems associated with conveying irrigation water in the rivers will be tackled. Spatially, it would seem that the Federal Government's Environmental Water Holder has targeted a number of icon sites to provide water to (Australian Government, 2013). However, the temporal problems of sending water down river at inappropriate times have not yet been addressed.

The governance issues within the Basin also need to be further resolved. It could be argued that the Federal Government has already gone a long way towards doing this by taking control and establishing the Murray-Darling Basin Authority. It has also enunciated its objectives in the Plan and is fulfilling them with the water buyback schemes. However, a governance issue that has so far attracted no attention is what can be termed the 'small farm problem'. In establishing the irrigation sector, the governments involved have violated the Tinbergen Rule (Knudson, 2009). They attempted to achieve two goals from the one policy; that by regulating river flows, farmers could get higher agricultural output and achieve it on a smaller land base to get closer settlement. Despite the Government's desire for it, a closer settlement development plan works against the competitive advantages the country holds in having a lot of land and scarce labour to farm it. Buying backwater licences from irrigators with small holdings leaves them with a land base that is far too small to make a living from in the conventional manner by undertaking extensive agricultural practices.

A major initiative that would result in a significant improvement for all in the Basin is to free up the restrictions that currently impede water trading. At a broad national level, the trade in water between states is also restricted. For instance, Victoria does not allow more than 4% of the water it allocates to be traded outside the state in any single year. Even within a State, at present little water is traded between irrigators, let alone between the urban and rural sectors (Australian Government, 2011). In the same vein, water trading between the agriculture and urban sectors is also impeded.

A question that could be asked is why the Federal Government did not buy its environmental requirements in the same market that farmers trade in? The answer to this question is simply because not enough is traded on this market for them to meet their requirements. A further criticism that the Federal Government pays too much for its infrastructure improvements can also be dismissed on the grounds of a thinly traded market, as the price revealed in the market may not actually reflect the true marginal value of water. Despite this, there is little doubt that while the price that is paid in the market might not be an equilibrium price, the Government has paid too much for efficiency 'savings' of water simply because there is no way of guaranteeing the amount of water actually 'saved'. However, nothing that has been said previously precludes the Government from removing the restrictions to water trading and then joining the market by applying its allocations to environmental water and actively trading it, selling when it does not require as much, and buying when more is required.

The problem with freeing up the trade in water is that it could lead to the 'stranding' of assets. Most irrigation costs in Australia involve maintaining an extensive distribution network. Currently, the stranded assets issue has received less attention than it should. It could be argued that concerns over stranded assets have limited one of the best reforms to ever occur in regulating water flows in Australia: water trading. It is not only about farmers getting a higher price and trading to their advantage, but about how water supply companies price and make their returns. Taking water for the environment also means taking water from water supply companies. Although they charge by volume, they also have a fixed fee in place. In the current reforms little is mentioned about the impacts on these organizations. This issue causes great concern as they have to operate and maintain their often depopulated canal network with important implications on their fixed cost structure.

It is imperative to know the marginal conditions on both the environmental functions of a river and its socio-economic aspects if the current reforms are to succeed in the longer term. In other words, what is not known with any degree of certainty is the impact of diverting water from irrigators to the environment. What is needed is some knowledge on the effect each unit of water diverted from the irrigators has on the environment and on the economy (so how much environment is derived from each unit of water diverted and how much economic activity is lost). The work that has been conducted to date, including the Wentworth Group of Concerned Scientists (2010), the CSIRO in Overton et al. (2009) and in the Appendices to the Murray-Darling Basin Authority Plan (2012), is somewhat inconclusive. Most of this work was conducted for the Plan 2010 and as such has been dismissed with the acceptance of the new Plan 2012. The only way to make good policy is to have a solid scientific base backing it up. That condition is not currently met and what has transpired is an urgency argument of environmental irreversibility to justify the new policy.

Lindblom (2001) makes a valid point when he suggests that markets are ideal entities for making voluntary transactions between individuals and entities that want to trade. For those involuntary transactions (associated with market failures, fraud and corruption, equity and the like) government involvement and planning is not only required, but also necessary. The real challenge in governance is achieving the amount of planning required in a market system, and then not exceeding that level so that it intrudes on the amount of voluntary transactions that could be undertaken. A government has no reason to interfere in a voluntary transaction between two individuals or entities, which will result in an efficient, costless and mutually beneficial outcome to all involved. However, in planning for all those involuntary transactions that are also required, the government needs to put in place a set of incentives that will result in it achieving its desired outcomes.

Conclusions

Australia has an enviable (and probably undeserved) reputation for the way it operates its irrigation schemes, especially in the Basin. This reputation exists because a reasonable amount is known about the supply of water, users are charged volumetrically, water trading exists to a limited extent, and future water allocations have been capped. In addition, the Government acknowledges the nature of the problem of allocating water to the environment and has put in place an approach to solving it.

While not ideal, the Plan 2012 does at least move in the right direction towards redressing the imbalance in supplying the environment with water. The Federal Government is in the process of purchasing 2,750 Mm^3 of water from irrigators and returning it to the environment, something that will continue until 2019. It is also funding efficiency improvements to the system in order to achieve additional water 'savings'. However, all these attempts might well be in vain, as the problem is a 'wicked' one; one that defies an easy solution that all can be reasonably happy with. It would appear that the Federal Government eventually appreciated the difficulties involved in this problem and with the Plan 2012 is taking a more adaptive approach.

To move towards a more ideal solution some knowledge of the technical and allocative efficiency aspects of not only the irrigation sector, but also of the environment, are required. Until these aspects are known, understood and applied, policy-makers will not be able to allocate water in a way that society desires. As a consequence, the inefficient approach currently undertaken by the Government to engineer water savings will continue. Further, the Government's current approach is not a complete one, as it does not account for the fact that irrigators usually farm relatively small holdings of land, whose viability depends on water availability, rather than on the factors that give Australian agriculture its comparative advantage. To resolve this problem more effort has to be put into the agricultural adjustment questions that will arise amongst irrigators. In addition, it would appear that with respect to the Basin, the Federal Government still does not have the right incentives in place to achieve its desired outcomes. While stating its objective, to improve the health of rivers, the Government is still unsure of what outcome will result from its endeavours. It pursues a policy of buying back entitlements that are expensive and subsidises additional purchases in an even more expensive manner, without knowing the full impact environmental purchases will have. Finally, it will not allow water to be traded freely. Removing the restrictions on water trade, like all the other measures suggested above, will improve the technical and allocative efficiency of water use in the Basin.

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Implications of international water law for water allocations and transboundary agreements

Annukka Lipponen

Geographically, transboundary basins cover more than 40% of the pan-European region. Worldwide, 263 transboundary lake and river basins cover almost a half of the Earth's land surface and account for an estimated 60% of freshwater flow globally. In these transboundary basins, water allocation decisions need to take into account agreed cross-border flows (where applicable) as well as the general principles of international water law that determine a State's entitlement to the benefits of using a transboundary watercourse.

The United Nations Economic Commission for Europe (UNECE) Convention on the Protection and Use of Transboundary Watercourses and International Lakes[1] (Water Convention) provides guidance on sustainable management of shared waters, including both surface waters and groundwaters. Among its general obligations is not to cause transboundary impact – i.e. any significant adverse effect on the environment. Significant withdrawal, diversion or impoundment of flow could result in such effects and therefore respect for the obligation not to cause transboundary impact limits the allocation of resources to the riparian States. Another key obligation of the Convention is keeping the use of transboundary waters 'reasonable and equitable', which is particularly relevant in cases where there is a 'conflict of uses' between the riparian States.

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1 The UNECE Water Convention was signed in Helsinki in 1992 and has been in force since 1996.

An accurate assessment of water resources available for allocation requires information from the whole basin. In the case of transboundary basins, this requires exchange of data and information between the co-riparian countries. It also requires comparable data across a transboundary basin, which means that the methods of water resources' assessment have to be harmonized among riparians. To ensure reliable prediction of flows to determine allocation and for early warning purposes in case of hydrological extremes, observations from upstream must also be available.

Many river basin agreements established in the pan-European region from the 1990s onwards are based on the Water Convention, but may include specific provisions for addressing, e.g. variability in water resource availability that poses particular challenges to water allocation in a transboundary setting. Many agreements on transboundary waters lack specific provisions or mechanisms for addressing changes in resource availability. Nevertheless, when there is an established institutional structure and official communication channels for a transboundary dialogue, in such basins the authorities are also better positioned to address variability.

Under exceptional circumstances, such as droughts, it may be difficult for the upstream riparian country to respect the entitlement agreed upon. Specifying water allocations to be delivered from upstream to downstream countries in percentage shares of the overall flow rather than in absolute volumes may permit a more flexible reaction to flow variability in the long term, in particular in view of climate change. Dealing with high flow/flooding situations is facilitated by provisions on warning and alarm systems as well as mutual assistance.

It is crucial that developments on the transboundary watercourse, notably for major withdrawals, storage and flow regulation, are subject to prior consultation of the co-riparian countries. Different uses have their particular requirements for water availability, regarding not only volumes but also timing of the flows (agriculture). Navigation, on the other hand, requires a certain minimum level of flow (or storage) for ensuring adequate water level in the body of water. Among the tools employed in the management of transboundary waters that allow water availability for the downstream riparian State during fixed periods are reservoir operating rules.

Transboundary agreements concerning shared waters, in which the minimum cross-border flow to be ensured is specified, help to ensure the availability of a certain amount of water resources for the downstream riparian country for planning and realizing its internal water allocation.

A certain minimum environmental flow in the watercourse is necessary for ensuring the sustainability of the resource and its ecological quality. Some agreements on transboundary waters make an explicit reference to environmental flow which consequently reduces the volume of water that can be allocated for use by the riparian countries. Determining the ecosystem needs is admittedly difficult, however, and the approaches to defining minimum environmental flow vary.

Where transboundary water allocation has been formally fixed in agreements, the efforts and time required to renegotiate such an agreement may make changing it difficult. It is not uncommon in transition economy countries that the monitoring infrastructure and capacity have deteriorated to such a degree that it is not possible to verify whether the riparians respect the agreed allocation. Such a situation is not likely to strain relations between riparians when water resources are abundant, but in situations of scarcity, it may be easier to liberate more water for allocation in the form of water savings from improving water use efficiency; water-saving investments have been negotiated also in the transboundary context.

There are only a few cases where the issue of groundwater allocation – or maximum abstraction from the aquifer by an aquifer State – is mentioned in a transboundary agreement. The main tool for groundwater allocation is licensing abstraction. Understandably, the quantification of the groundwater resource is more complicated than that of surface water and has a more significant uncertainty involved, underlining the importance of jointly monitoring the status of the resource.

Appropriate institutional mechanisms help to manage variability in the availability of the transboundary water resource in a cooperative way and to adjust to changing situations regarding water use. The UNECE Water Convention obliges the Riparian Parties to cooperate through agreements and joint bodies such as bilateral or multilateral commissions or other institutional arrangements, which serve both as forums and tools for dialogue and decision-making. According to the Convention, the tasks of joint bodies include collection and exchange of information and data and monitoring in order to obtain an adequate knowledge base for water allocation. Several guidelines for monitoring and assessment of transboundary water resources have been developed and published under the Water Convention, and some of this experience is summarized in the publication, 'Strategies for monitoring and assessment of transboundary rivers, lakes and groundwaters' (UNECE, 2006). The Convention obliges Parties to undertake a number of measures to prevent, control and reduce transboundary impacts; among them, in addition to information exchange, Parties are required also to consult.

Among the challenges facing water allocation is ensuring water availability for priority uses but still accommodating other water uses. Commonly, the main water use in each co-riparian country differs, which means that in a transboundary basin, intersectoral water allocation is actually a transboundary issue (and the other way around). The capacity of the joint bodies to effectively address issues related to different water uses may be influenced by their variable mandates and the diversity of representation of the different sectors concerned. The 'Second Assessment of Transboundary Rivers, Lakes and Groundwaters' (UNECE, 2011) provides an overview of the water resources and management situation in transboundary basins of the pan-European region, including main water uses and the legal and institutional bases for cooperation.

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Allocating scarce water

Why traditional approaches need to evolve

Daniel Zimmer

We want to advocate that when water is becoming scarce, focusing solutions on allocating blue water resources is not sufficient. Decision-makers and water managers need to develop new approaches that consider blue, green and grey water, and virtual water trade in making relevant decisions. Several analyses developed in past years have paved the way to a new way of thinking that needs to be transformed into new tools and methods. One example is provided here from the Tunisian case.

In Tunisia, blue water resources amount to 4.6 km^3, that is 430 m^3/cap/yr. Tunisia is one of the poorest countries in terms of water resources per capita. As producing food requires 1200–1500 m^3/cap/yr and irrigation is required in arid countries, the blue water resources are obviously very scarce. Therefore, food production consumes more than 90% of the blue resources. But this is not enough to produce the food that is increasingly imported. Similar situations are observed in many countries including those in the South Mediterranean area.

If we take a step back and look at the Tunisian water footprint of food consumption (20.5 km^3), we notice that only 8% of the water required for food production comes from blue and grey water in Tunisian irrigated areas, that 60% of the water is green water used by local rainfed agriculture, and that 32% is imported as virtual water from abroad. Looking more carefully at the latter shows that in fact 0.3 km^3 are exported as high value crops and 4.3 km^3 are imported mainly as cereals or staple food. The dependency of the country on external water is thus 25%, which is considered

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manageable at the moment, although a food and energy crisis such as that in 2008 obviously generates tensions.

Looking toward the future, the Tunisian experts have developed various scenarios that detail the evolution of the demand and look at the supply side. These scenarios show that the dependency of Tunisia on external water will increase (probably to about 50% by 2030) which will become seriously hazardous for the country. The only way to reduce this dependency is to devote significant efforts to improving the green water efficiency in rainfed agriculture, which, although possible, poses serious challenges.

What are the solutions for the Tunisian authorities? The problem is not primarily how to allocate their blue water resources in a better way. This allocation is already changing given the pressures of urban development and a growing industry that provides higher economic returns to the economy with the water they use than agriculture. The issue is to choose whether to allocate financial resources to irrigation or to rainfed agriculture, i.e. to blue or green water resources. Linked to this are difficult choices on the types of food to produce, to export and to import, and identifying the measures that would ensure the country's stability in case of a new international food crisis. Such measures should also be discussed in a national cooperation on water where all stakeholders could express their needs.

In acknowledging that similar conditions will also prevail in neighbouring countries, the problems probably cannot be addressed in an isolated way. It would require a concerted approach from the South Mediterranean countries and possibly negotiations with the European Union.

What tools should be developed to help?

First there is an urgent need to strengthen water management in rainfed agriculture. This is of course not a water allocation issue but rather questions the traditional allocation of financial resources to irrigated agriculture vs rainfed agriculture. The yields in rainfed agriculture remain very low, resulting in very low water productivity.

To make decisions on the appropriate combination of blue, grey and green water, a second set of tools is needed. Decision-makers need estimates of the social, economic and environmental values and productivities of water. Water productivity has so far been looked at with a very narrow perspective, largely only considering the water losses (more crop per drop) and economic productivity (more income per drop). Social (more jobs) and environmental (considering both terrestrial ecosystems and aquatic ecosystems) aspects are needed to complete the picture. So far these approaches have been limited to blue water. Consideration of the various types of water (blue, green, imported and exported virtual) is needed in order to improve decision-making.

Finally, it is important to be conscious that while water problems (e.g. drought) occur at seasonal scale the big challenges will result from slow evolutions that are not only triggered by water. Tools that help develop scenarios for the future need to be developed. And addressing these scenarios should probably go beyond national level and be discussed at regional scale. For instance, it would be very helpful to have such scenarios for the South Mediterranean countries collectively in order to anticipate the regional difficulties and address them in a comprehensive way.

The above issues and potential solutions are in line with the 2012 MED Report 'Towards Green Growth in the Mediterranean Countries' by the CMI[1], which demonstrates that enhancing economic growth in the Region requires seriously addressing issues related to environmental degradation.

[1] Center for Mediterranean Integration (2012) Toward Green Growth in Mediterranean Countries: Implementing Policies to Enhance the Productivity of Natural Assets, CMI, Marseille.

IMAGE

A tool for exploring the effects of water-allocation and green growth strategies

Willem Ligtvoet, Hester Biemans, Elke Stehfest, Tom Kram, Lex Bouwman, Arno Bouwman, Johan Brons

Introduction

Over the past few years the PBL Netherlands Environmental Assessment Agency has published a series of reports on global environmental problems and sustainable development. In these reports, the world food system and its interrelations with land and water resources have a prominent place. In these studies, the integrated assessment tool IMAGE is used (figure 1) to explore the challenges and effects of various socio-economic and climate change scenarios and the effects of potential policy options.

The PBL studies using IMAGE thus seek to support policy-making by: (i) characterizing current trends in global development; (ii) identifying potential socio-economic and environmental threats, with a time horizon up to 2030–2050 (sometimes 2100); and (iii) assessing 'options' to mitigate threats and foster sustainable development by balancing competing claims on natural resources.

Within the context of water allocation and green growth, this paper focusses on the challenge of food production and water use. On-going research at PBL is presented in the following structure. First, the key issues are presented from a global perspective, it shows how global issues possibly have regional and local impacts and therefore require coordinated analysis and action. Second, an example for water and agriculture is elaborated; the focus is on the relevance of global assessments to support policy-making at the national and local levels.

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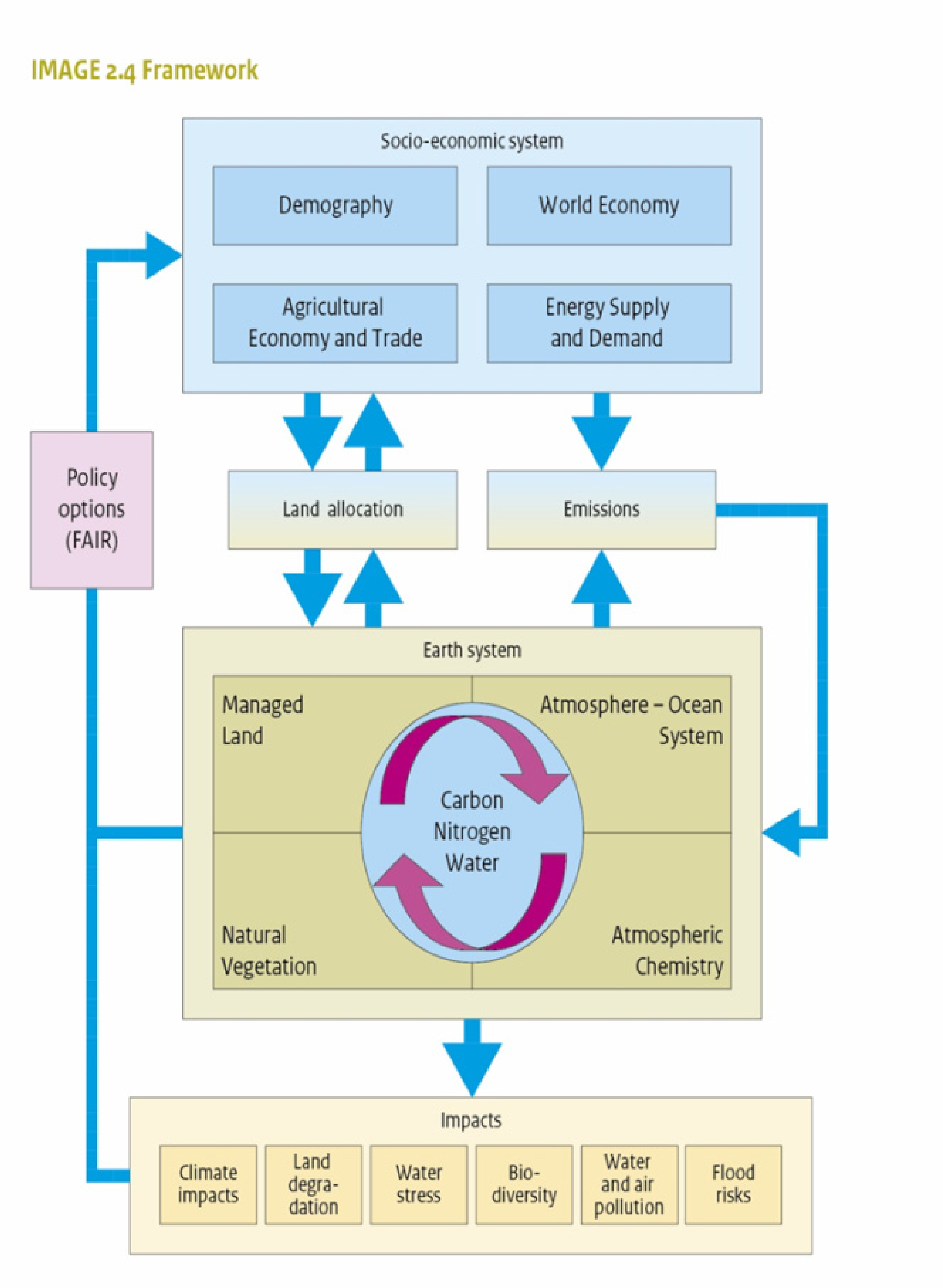

Figure 1: Conceptual framework of the integrated assessment tool IMAGE 2.4 encompassing the interaction between the socio-economic system and the physical earth-system, the feeding mechanism of policy options and a selection of output indicators.

Water allocation and green growth: the challenges

The achievement of global sustainability goals concerning environment and poverty alleviation is feasible provided that regional issues such as soil degradation, water excess or shortage, and water pollution are resolved (Van Vuuren and Kok, 2012). A single focus on agricultural productivity, thus improving food security, is insufficient because new problems, such as excessive nutrient deposition and water shortage emerge, or because regional solutions, such as increasing rice production in Africa, may be suboptimal from a global economic perspective. Through a global assessment of possible development paths, this study quantifies the combined impacts on food, water and soil.

On water allocation, key findings of the OECD Environmental Outlook 2050 include worrying prospects for 2050 on water stress, water scarcity, groundwater depletion, excessive nutrient deposition, and more frequent occurrence of floods and droughts (OECD, 2012). Some observations are the following. Of the world's population 40% are likely to be living in river basins with sever water stress. Water demand is projected to increase by 55%, mainly due to increased demand for manufacturing, electricity and domestic use. Consequently there is expected to be limited scope to expand the area for irrigated agriculture. Groundwater depletion rates are increasingly exceeding replenishments rates. Nutrient flows from agriculture and poor wastewater treatment are expected to lead to eutrophication, biodiversity loss and disease, especially in non-OECD countries. Water-related disasters (floods and droughts) are expected to occur more frequently.

The recommendations of the OECD Environmental Outlook include: to create incentives for water use efficiency; to improve water quality; and to invest in green infrastructure, for example innovative water storage capacities, and restoring of ecosystem functions of floodplains and wetlands. For this it is necessary to assure policy coherence between water, energy, agriculture and urban planning and to fill in information gaps.

Water and food production (food security) are focus areas of Dutch development cooperation. These issues are strongly related to climate change. Climate change is expected to have a large impact on developing countries (World Bank, 2012): crop productivity is expected to decrease in seasonally dry and tropical regions; flood risks will increase, especially in highly vulnerable cities in, for example, Mozambique, Vietnam, the Philippines, India, Bangladesh and Indonesia. The study by the World Bank additionally concludes that much more uncertainty associated to climate change is due to societal effects rather than due to the physical changes in water system. A more variable rainfall pattern, more frequent floods, and water salinization will reduce the food production capacity and thus increase the policy challenge to achieve sustainable development and food security. Developing countries have a deficit in capacity and in funds to adapt to these climate changes

There are intentions to establish international funds to support developing countries to adapt to climate change and to overcome a so-called climate adaptation deficit. In the study 'The Economics of Adaptation to Climate Change', the World Bank estimates a required annual investment in climate adaptation of about US$ 100 million. This equals the total annual worldwide Official Development Assistance (ODA) funds.

In order for national and international policies to anticipate changes in climate and in water systems it is necessary to quantify these large-scale changes and effects. Expected changes concern the agricultural production potential (climate, soil and water quality) and economic conditions (markets, technology, demography and urbanization, and infrastructure). Possible strategic choices that will emerge concern investments in rain-fed or in irrigated agriculture, and in large-scale production of bulk crops or in high value crops such as vegetables. Water management upstream (retention and reservoir) and downstream (investments in protection against floods) will require consideration in these agendas. Optimal use of ground water reserves and control of quality of groundwater will also be necessary.

The increasing water demand requires responsible water-allocation mechanisms at river basin level as well as at national level that address a sustainable use of the available water resources within the context of sustainable economic development, or 'Green Growth'. For OS countries water-allocation for industrial use, households, energy supply or food production, but also nature, will be challenging, and will require balancing economic growth (industries, energy), health, food production and security, and biodiversity conservation. In addition the risks of disruption due to flood disasters need to be challenged as well.

Water for agriculture

In order to feed more than 9 billion people in 2050, food production needs to increase. Such an increase in production can only be achieved by a combination of expansion of agricultural area and increase in productivity. To sustain the increased food production, agricultural areas will have to be irrigated and, therefore, inevitably the water demand for agriculture will go up, albeit at a lower rate than projected for other water using sectors (figure 2).

In the Baseline scenario of OECD (2012) the world population will increase to over 9 billion in 2050. Alongside this Baseline scenario is the projection that global water demand will double largely due to the expected increase of water use in households, manufacturing, and electricity production (figure 2). As a consequence, competition between different water users is expected to grow, and the number of people living under water stress will increase. At the same time, the world population living in areas at risk of flooding will increase by 40%.

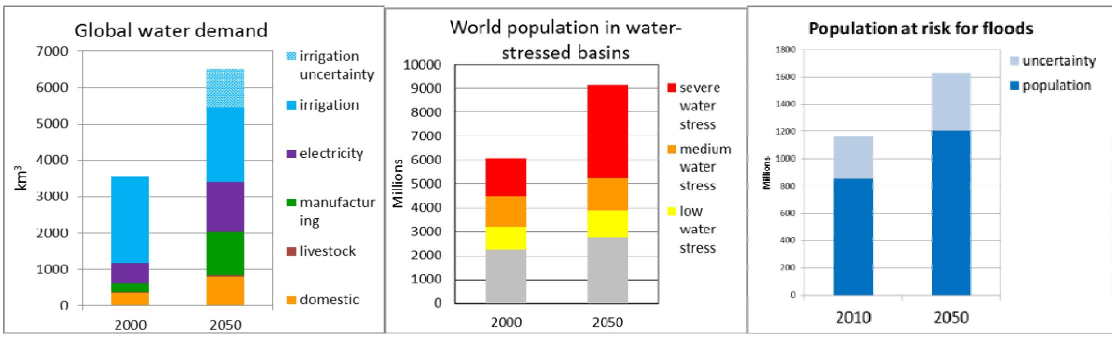

Figure 2: Global water demand (left) and people living in water-stressed basins, and people at risk of flood disasters (right) according to the OECD Baseline scenario (OECD 2012). The estimated uncertainty range in irrigation water demand also includes results from Biemans (2012).

During the twentieth century, the water used for agriculture has increased strongly, due to a huge expansion of irrigated area worldwide. For a large part, this increase relied on the construction of many large dams and reservoirs and the use of groundwater (figure 3). However, it is unlikely that a similar trend can be continued in the next half century. There is a limit to the amount of freshwater accessible and extractable for human use.

Climate change may put additional pressure on available water resources in some already water scarce regions.

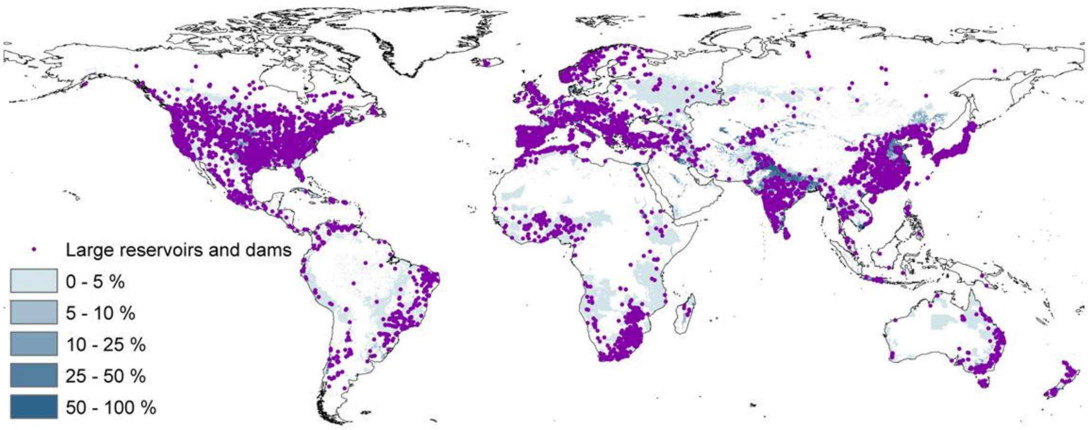

Figure 3: Controlling the global water cycle. Locations of large dams and reservoirs (purple) and the percentage of area equipped for irrigation by the end of the twentieth century.

The key questions that emerge from this preliminary scope are:

1 What is the combined effect of climate change and socio-economic changes on water demand, water availability and the associated agricultural production?

2 What is the potential of adaptation measures aimed at reducing water stress and water-related crop production losses?

3 How can water demand be reduced while providing similar levels of service to the demand sectors?

To answer these questions integrated models of IMAGE and WaterWise are used. IMAGE can be used to study the combined effect of climate change and socio-economic changes on water demand and water availability. In close collaboration the PBL Netherlands Environmental Assessment Agency, Wageningen

University and Research Centre (WUR) and the Potsdam Institute for Climate Impact Research (PIK) have extended the global integrated assessment model IMAGE with an explicit representation of water (by including the LPJmL model). Both water availability and water demand are calculated at high spatial (0.5 degree grid cells) and temporal (daily) resolution. Water demand is calculated for different sectors, and areas where conflicts between different sectors are expected can be identified. There is an explicit distinction between water availability in different sources (figure 2). If water availability is not sufficient to meet potential agricultural water demand, the model calculates the associated reduction in crop production.

Waterwise is a bio-economic optimization model developed by WUR that can be used to explore the most optimal allocation of water and land resources in a river basin, under given boundary conditions or policy options (Van Walsum et al., 2008).

The results so far focus on the issue of water availability and use efficiency in irrigated agriculture. Approximately 18% of the irrigation water is supplied by large reservoirs, but with major differences between regions (figure 4). Expansion of irrigated areas as projected in recent food system scenarios implies a 30% increase in global irrigation water demand (Biemans, 2012). A quarter of the total irrigation water demand by the end of the twenty-first century (~1200 km^3/yr^{-1}) might not be available, leading to a reduction of irrigated crop production.

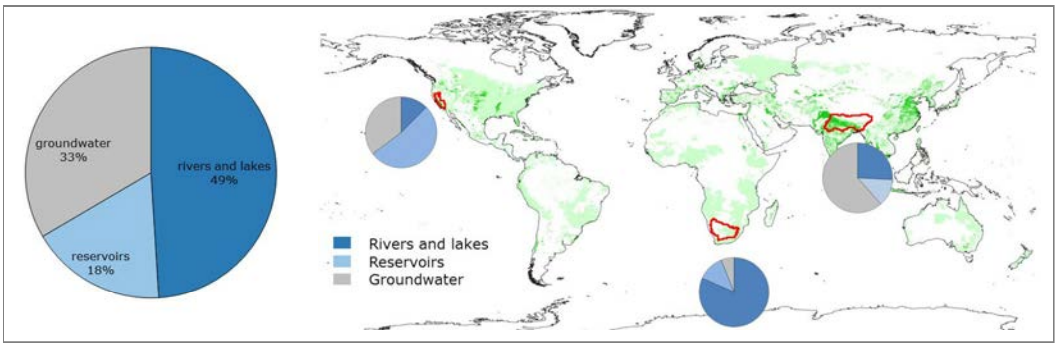

Figure 4: Contributions of different water sources to irrigation supply. Left: global average. Right: assessment per river basin. Green shades represent irrigated areas. Basins in the western United States rely to a large extent on water stored in reservoirs whereas in South Asia groundwater is the major source for irrigation (adopted from Biemans et al., 2012).

Irrigation expansion as projected in recent agricultural outlooks may not be possible due to water shortages, unless major improvements are made in irrigation efficiency or unless better allocation of available land and water is established (Biemans, 2012). Some regions might face a reduction in total crop production by more than 20% due to water shortages (figure 5). Vulnerable basins are to a large extent depending on irrigation for crop production, but an increase in irrigation water demand cannot be fulfilled by available water, leading to reduction in crop production. Additionally, basins that depend on groundwater are highlighted, because supply might not be guaranteed.

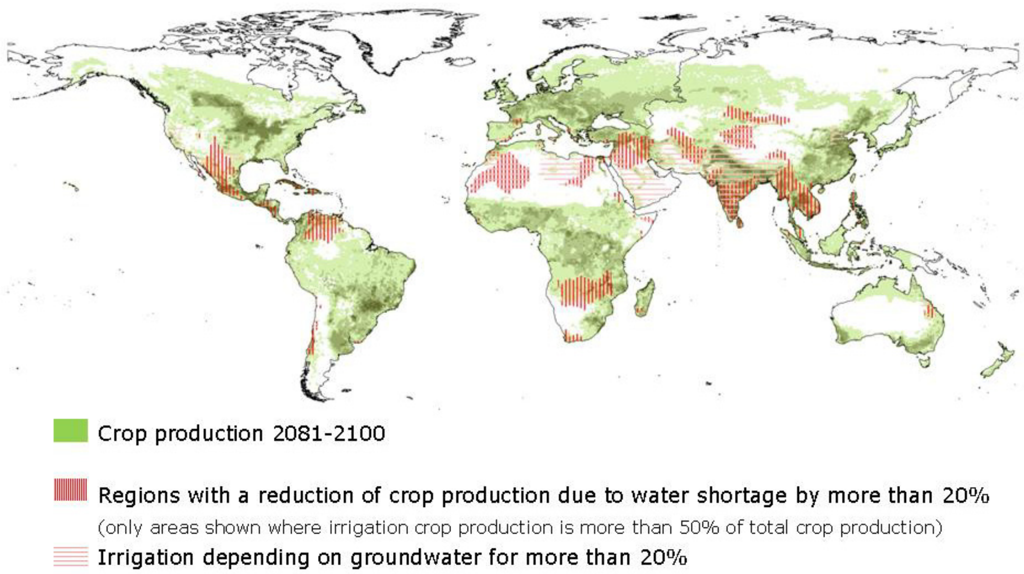

Figure 5: Regions vulnerable to crop production loss due to water shortage (IMAGE-LPJmL analysis, Biemans et al., 2012).

Further research will focus on combining global and regional scales of analysis. We have shown that recent land use scenarios may not meet the required increase in food production due to water shortages. With the extended IMAGE we can assess how future food security can be reached in a more sustainable manner, given limited water availability. The research questions that are proposed at global scale (assessment with IMAGE) include: (i) where are potential areas for sustainable expansion of irrigated areas?; (ii) under what conditions are groundwater use, water use efficiency and possible degradation expansion of irrigation possible?; (iii) where will conflicts between different water users arise?; and (iv) what are potential effects of large-scale adaptation (water storage, increased efficiency)? At regional scale (e.g. large catchment, assessment with WaterWise) the question to be addressed concerns the most optimal (spatial) allocation of water and crop production at given boundary conditions (e.g. required outflow to downstream country, food production target, cost of adaptation).

Conclusion

Because of current anthropogenic pressures on the earth system there is a need to have an integrated knowledge base on the global environmental system. The water cycle – with run-off, water storage, droughts and floods – is influenced by economic development, spatial planning and production techniques, especially in terms of agriculture and climate change. The IMAGE model provides a framework for such a knowledge base. This policy brief illustrates the relevance of global assessments for developing international and national policies to address sustainability issues related to water.

Global and regional integrated models generate a long-term perspective that facilitates the analysis of investment and climate adaptation options, and of trade-offs between different regions. Such global assessment identifies the vulnerable regions in the world, for example regions where groundwater reservoirs are exhausted or irrigated agriculture encounters the limits imposed by water shortage. Policies at national level will benefit from these insights by a greater coherence of internationally available development funds, for example for development cooperation and climate adaptation. The findings of the global development scenarios can be used as proxies for national and regional development perspectives.

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Water and green growth in Republic of Korea

Tae-Sun, Shin

Water as a pivotal role in Republic of Korea's economic growth

From being one of the poorest countries in the world to the world's 11th largest economic power, Republic of Korea has come a long way. The figure below (Figure 1) well illustrates the economic development of Korea in terms of Gross National Income (GNI) per capita. One of the main drivers behind the exceptionally rapid growth has been the Government's well-planned indicative development plans, namely the 'Five-year Economic Development Plan' and the 'Ten-year National Territorial Development Plan'. Particularly during the period from the 1960s to the 1980s, a combination of these two plans played a significant role in achieving national economic growth.

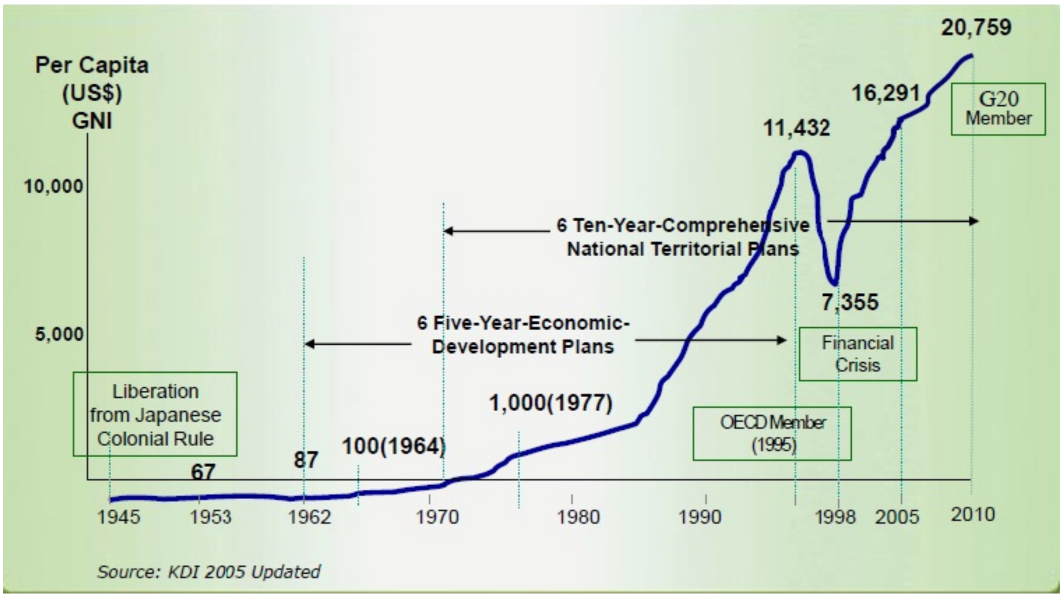

Figure 1: Economic growth through indicative plans in Korea.

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It is often said that Korean history, culture and economic development have benefited from water resources management planning. From the mid-1960s to the 1980s, which was a time of industrialization in Korea, water policies centred on building basic infrastructures, such as multipurpose dams. The objective was to sustain water supply by securing enough quantity of water, and to obtain hydropower. Taking preventive measures for frequent and unexpected flooding and drought was another goal during those times. As the economy of Korea grew, water environmental pollution arose as a social issue. The fatal chemical substance Phenol was found in the Nakdong River in 1991, and public awareness on water quality matters escalated significantly. Hence it was a turning point for the Government to consider water quality as a primary goal of water management policies. Since the early 2000s, the Government started to focus on eco-friendly development and sustainable management of water resources.

The new kind of environmental threats caused by climate change has triggered and will continue to trigger more imbalanced water shortages such as changes in the patterns of evaporation and precipitation. As Republic of Korea is no exception to the impacts, the current policy measures prioritize climate change adaptation and mitigation.

Green initiative in the Republic of Korea

To rise to the challenge of climate change, which is one of the most evident and serious challenges that humanity faces, and to sustain economic growth without destructing environmental assets, green growth was initiated in Korea. In order to confront climatic and energy challenges, the Government had to find a new growth engines.

Green growth was first declared by President Lee Myung-bak on 15 August 2008, at the 60th anniversary of the National Foundation Day. Following the declaration, in 2009 a Framework Act on Low Carbon Green Growth, the first law of its kind in the world, was enacted and the National Strategy for Green Growth and Five-

Year Plan for Green Growth were released. In particular, the Framework Act represents a milestone in the national development strategy and the legal foundation of the nation's green growth policies; approaching green growth in a comprehensive and systematic manner.

The Global Green Growth Institute (GGGI) started as an international organization in 2012. In terms of developing green technology, the Green Technology Center (GTC) was launched in the same year. Hosting the Green Climate Fund (GCF), which is equivalent to the World Bank in terms of dealing with issues related to climatic change, finalized the Government's efforts in building a Green Triangle of strategies, technology and finance. The Government is now more ambitious than ever to continue its commitment to developing the green growth path. It aims to pioneer its own green route through demonstrating its green leadership and building green partnerships. Based on its experiences and knowledge of unique pattern of economic growth, Republic of Korea is particularly keen on playing a bridging role between the developing and the developed countries in achieving green growth.

Water and Green Growth in the Republic of Korea

The idea for green growth was initiated in response to the high environmental cost of rapid economic development and urbanization. Water and green growth is a recently promoted concept that examines the role that water resources play as a catalyst to sustainable economic and social growth. Water and green growth targets economic and social growth in the manner of greening, and intends to provide concrete and practical ways for green growth through and with water. The Four Major Rivers Restoration Project, which was introduced in my presentation, is a good example of a water and green growth initiative in Republic of Korea.

Roughly 60% of the country's territory is covered by mountains, thus it presents vulnerable conditions for water resources management. The characteristic seasonal weather conditions cause great variation in annual rainfall. Thick layers of accumulated sediment on the riverbeds cause frequent flooding. In addition to these environmental conditions, intensive use of rivers by the public, worsened as the economy grew and led to significant problems of river pollution and degradation of the ecosystems as a whole.

The 4 Major Rivers Restoration Project is a multi-purpose green project aimed at resolving the above-mentioned water management issues. The main objectives and approaches of the project can be summarized as follows:

1 Achieve a paradigm shift in river management in terms of reaching sustainable river management, enriching cultural values and intensifying quality of local economie;
2 Prioritize protection and conservation of river and freshwater resources at national level. Even though the development of Republic of Korea has benefited greatly from the rivers, the value of these resources was not given adequate recognition. By acknowledging the rivers as important environmental infrastructures, the project intended to invest more financial resources in preventative measures rather than recovery;
3 Secure more water resources and provide abundant water resources for the well-being and survival of the next generations.

The project offers an important driver for the realization of green growth in Republic of Korea. In addition to resolving water-related issues, the project provides the projection of low carbon green growth to various regions and the ecological basis for new cultures and civilizations.

Preparing for an uncertain future through option analysis

The case of the Roode Vaart

C.G. van Rhee

Infrastructure projects are subject to policy and exogenous uncertainties such as the impact of climate change. Being able to anticipate and manage uncertainties adds value: investment costs and risks can be reduced and/or benefits and opportunities increased. In order to manage these uncertainties and avoid over- and under-investment in deltas and water management, the Dutch Delta Commissioner has developed the Adaptive Delta Management approach (ADM). One of the characteristics of this approach is the active search for opportunities to link investment agendas and to take advantage of possible synergy benefits.

A case from the Southwestern Delta in the Netherlands illustrates the practical value of this method. In this area of the Netherlands, the ADM approach was first put into practice in the regional implementation strategy for the Grevelingen, Volkerak-Zoommeer, and freshwater supply. To secure allocation of sufficient freshwater for agriculture and water level management purposes now and in the future, there is a temporary opportunity to (pre)-invest in a water passage through the city of Zevenbergen. This has immediate value during cyanobacteria outbreaks in the Volkerak-Zoommeer when the water from the Volkerak-Zoommeer is not usable. But it also has a potential future value in case the Volkerak-Zoommeer becomes salty or if the demand for freshwater surges due to climate change and changes in land use.

This paper presents the case of the Roode Vaart – or the water passage through the city of Zevenbergen – and compares the alternatives and the values of these alternatives, concluding that pre-investment is a rational financial decision in spite of the policy and climate uncertainties. Due to the fact that this freshwater measure is still under adminis-

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trative debate, the statistics employed in this paper are indicative, and actual figures are omited to avoid interference with the policy process. The use of another set of alternatives and assumptions in the evaluation may lead to different conclusions.

Uncertainty and the financial implications of climate change require adaptive delta management

The anticipated climate change requires increased protection and additional measures to secure adequate freshwater supply for deltas in the Netherlands. This task is large because of a delta's natural properties, which amount to a number of both advantages and disadvantages. There is an increased vulnerability to sea-level rise and greater river water discharge in winter, and reduction in summer rainfall and land subsidence by groundwater withdrawal. At the same time, there is usually a high population density and greater prosperity in deltas, with excellent transport links to and from the hinterland and other parts of the world, and more fertile soil. As a consequence, much has been invested in deltas, and this makes their protection essential. Hence, there is a need for delta management.

To ensure the long-term goals in the areas of water safety and freshwater supply, the Dutch Delta Programme was set up. The infrastructure in the Netherlands has to be adapted, but how can this be done effectively? What decision or series of decisions are necessary? There is a need for a sober and flexible approach.

The uncertainties are huge: both the socio-economic developments and the pace of climate change are difficult to predict. We cannot make statements about the distant future with certainty. The further we look forward and the more uncertain our estimates of the costs and benefits are, the more problematic this becomes. We cannot afford to assume the worst possible climate scenarios. That would lead to draconian measures and extreme cost, which might well prove unjustified in the end. On the other hand, we cannot wait until things go wrong. In addition, (regional) executives have to deal with the often uncertain outcomes of decision-making processes at national level or across regions and disciplines, all of which can have a large impact.

Therefore, we have to look ahead and to develop our environment in connection with changing spatial conditions, because adequate measures often have both a long lead-time as well as an interaction with socio-economic activities. This is not only about reducing drawbacks but just as much about seizing economic opportunities and synergy benefits. To meet these ambitions, flexibility is crucial. Hence, we add the term adaptive to our method: Adaptive Delta Management.

This approach adds the aspect of time as a variable to cost-benefit analysis. It no longer assumes investments being made at a fixed moment in time, but seeks to optimize the timing of investments or decisions based on coupling opportunities and actual developments as they unfold. Adaptive Delta Management aims to include uncertainties about future developments in decision-making in a transparent way. It focuses on the following points:

- Connection of short-term decisions with long-term challenges. Why? Because short-term savings can be realized or unnecessary future cost increases can be prevented with the relatively limited effort of coordinating initiatives. Example: making land reservations for future expansion.
- Working with decision sequences and adaptive pathways instead of end states. Why? Because it is not always cost-effective and necessary to implement short-term measures in favour of a long-term target situation. Example: the phased strategy to ensure water safety and freshwater supply in the cases of the IJsselmeer and Afsluitdijk. Postponing measures has the advantage of a better understanding of the actual developments before a decision is made, but the risk of being too late to move.
- Identifying and valuing flexibility in strategies and measures. Why? The ability to accelerate, delay or alter strategies or measures provides more opportunities for their implementation in line with actual developments, and prevents possible over- or under-investment. Example: regular sand nourishment instead of single dike reinforcement.
- Seeking opportunities to connect various investment agendas. Why? By linking agendas, synergies can be realized in terms of

social benefit and cost savings. Example: the water passage of the Roode Vaart, where an investment in future freshwater supply is brought forward and combined with the redesign of the city centre of Zevenbergen.

In Adaptive Delta Management we look for solutions that are both robust and flexible. A robust strategy is one that is useful across various plausible scenarios. A flexible solution simplifies switching to other strategies later on, should actual developments demand so, and makes it easy to speed up or slow down the pace of implementation.

Adaptive Delta Management leads to a compound adaptive strategy or a set of alternatives with intermediate adjustment options. By this we mean that the method results in a roadmap or series of possible decisions, of which perhaps only the first stands. Final choices on timing and execution can be adapted to the actual developments identified in water management and spatial planning, and to new insights and operationalization of innovative technologies.

The approach consists of several qualitative and quantitative analyses (table 1). In practice, comparing the valuation of the alternatives is considered the most difficult. This is because of the combination of multiple options and uncertainties. However, with option valuation it is possible. We will illustrate the approach with the case of the Roode Vaart.

Table 1: Combination of investment agendas is an important element of Adaptive Delta Management to reduce costs.

Linking of short-term decisions to long-term challenges	Pathways instead of end states	Identification and valuation of flexibility	Linking of investment agendas
• No regrets • Urgent opportunities • Anticipatory measures • Scenarios	• Tipping points • Time windows • Lock-ins and lock-outs	• Optimal order decision-making • Risks and indicators • Option valuation (real options analysis)	• Linking opportunities • Windows of opportunity • Synergy

One of the characteristics of the Adaptive Delta Management approach is the active search for opportunities to link new investments to proposed and possible plans, investments and initiatives by public and private parties. Linking the investment decisions for the water challenges to the investment agendas of others is a way to seize benefits for society and make better use of investments. Combination of measures realizes synergy or prevents cost duplication.

Examples include the combination of activities in a single period, which reduces both inconvencience and construction costs, and the merging of actions that join multiple features and solutions, such as an open connection between the basins of the Grevelingen and Volkerak-Zoommeer. This facilitates both a salty Volkerak-Zoommeer, improving water quality, and also provides a passage for temporary excess water storage in the Grevelingen, improving water safety.

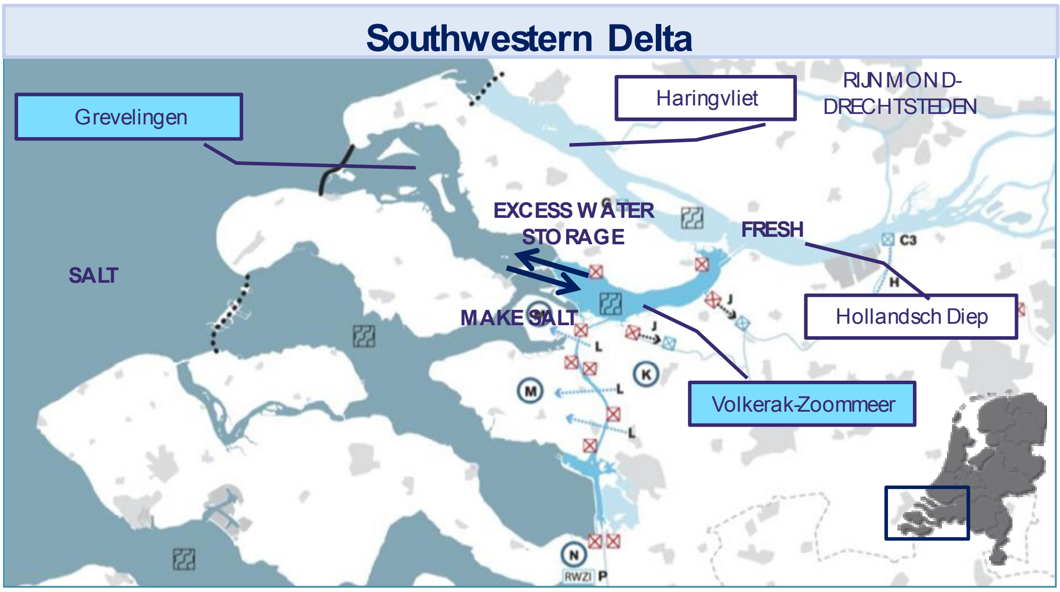

Figure 1: Overview of the Southwestern Delta (adapted from the implementation strategy for the Southwestern Delta, 2012).

It is necessary to weigh the cost of deviating from the original optimal timing, which was based on an autonomous choice, against the benefits of combining measures by advancing or delaying them. A new optimization can be derived from the required sequencing of actions, interdependencies, separate lead-times, and the costs and benefits of advance or delay. An illustrative example is the chosen solution for the Prins Hendrik Dike on Texel. Its traditional reinforcement would lead to adverse effects for housing and agriculture. With an alternative, sandy solution, these disadvantages are avoided and measures meet regional objectives in the field of nature. This alternative effectuates a more natural Wadden system and makes contributions from the Wadden Fund possible. Similar examples can be found in the Southwestern Delta. We will elaborate on one of these opportunities: the Roode Vaart.

The Dutch Southwestern Delta: background and problem description

In the Southwestern Delta (figure 1), plans and projects from many domains come together. Commercial shipping is on the increase and requires an enhanced capacity of the Volkerak-sluices to reducing waiting times. The Krammer-sluices and their fresh-salt separation system are up for major repairs. The regional economy, nature and recreation require improvement of water quality in the Grevelingen and the Volkerak-Zoommeer. It is desirable for agriculture that freshwater supply in this area becomes more robust. The question is being examined as to whether excess water storage in the Grevelingen can postpone or downsize measures along the Haringvliet, Hollandsch Diep and in Rijnmond-Drechtsteden needed for long-term water safety.

The costs and benefits of all of these projects and their execution options are interdependent. Some choices exclude certain solutions and some choices affect costs and benefits. In order to find an overall solution for the whole area that is as efficient as possible, a comprehensive implementation strategy considering all options and scenarios is required. In this particular case: three main issues need to be decided upon:

1 For/against the reintroduction of tidal movement in the Grevelingen to improve water quality in this salty lake;
2 For/against temporary excess water storage in the Grevelingen to improve water safety in the area north of the Grevelingen;
3 For/against whether the Volkerak-Zoommeer should become salty to solve water quality issues. After the flood in 1953 and the construction of the Delta Works, the Volkerak-Zoommeer developed into a freshwater lake. However, the water quality of

this lake needs improvement, as it suffers from annual cyano-bacteria outbreaks. This results in little water recreation and economic activity, especially in comparison with the Greve-lingen. A salty lake could solve this problem.

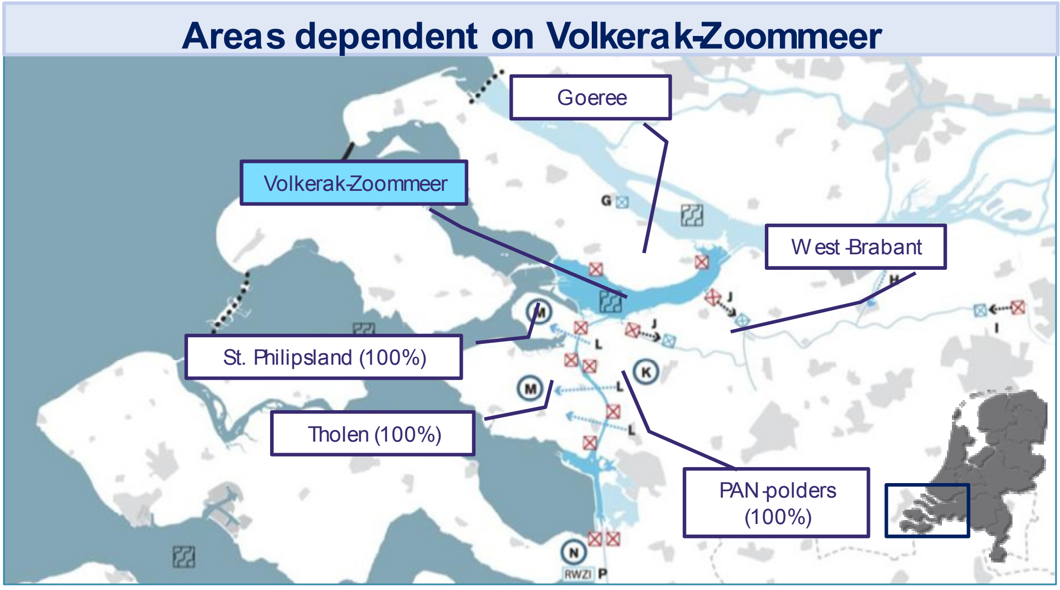

Figure 2: Overview of areas dependent on Volkerak-Zoommeer for freshwater supply.

Issue 3 is relevant for our case of the Roode Vaart. A future salty Volkerak-Zoommeer would require additional supply of fresh-water, since its water is currently being used for irrigation (sprin-kling), water level management and flushing. Adjacent areas even depend fully on the lakewater, as can be seen in figure 2. Hence, in the future an alternative supply of freshwater is a prerequisite should the Volkerak-Zoommeer become salty. But this is not a matter of certainty. This decision requires expensive measures to make the lake salty, for combating salt intrusion and for an alterna-tive freshwater supply, and the consequences of climate change and changes in land use are not clear. The balance between demand and supply of freshwater may change.

But even now, the freshwater situation is problematic. During summer, its intake is sometimes prohibited due to the develop-ment of cyanobacteria in the Volkerak-Zoommeer. These bacteria produce a smelly slush and secrete toxins that make people and animals sick. The areas around the lake that are 100% dependent on the supply from the Volkerak-Zoommeer experience diminished crop growth and production yields, due to the lack of freshwater. There is also damage due to inadequate water level management at such times. In these conditions, a second freshwater 'tap' would be beneficial.

Even at present there is an advantage to the autonomous start of freshwater measures such as the passage of the Roode Vaart through the city of Zevenbergen (figure 3) if benefits outweigh costs. *So how can be determined whether measures are cost-effective under these uncertain conditions?*

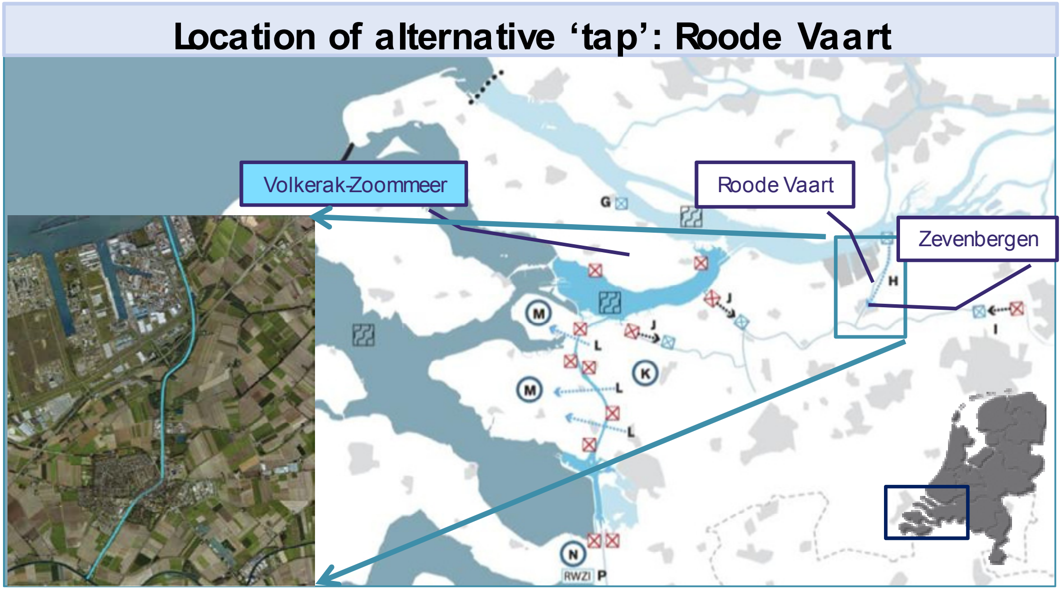

Figure 3: Alternative freshwater tap: the Roode Vaart.

Valuation of the opportunity

Because of policy, climate and social-economic uncertainties it is not easy to determine whether investment in a passage through Zevenbergen is a no regrets option or a sound opportunity that should be pursued. Before expanding on this evaluation, first we explain the opportunity at hand.

Redevelopment Master Plan for the city centre of Zevenbergen

The city centre of Zevenbergen will soon be redeveloped. Two alternatives for the redevelopment are being put to the vote: a 'green' one and a 'blue' one. The green one consists of the development of a park-like promenade. The blue alternative includes the restoration of the Roode Vaart and the old quay walls. This waterway was filled up in the seventies. This alternative has the option to carry freshwater from the Hollandsch Diep to the Mark-Vliet-Dintel river system, possibly in two or more capacity steps: first 3.5 m^3, later 10 m^3 or 12.5 m^3. Through this river system, freshwater can be distributed further into the western parts of the province of Brabant and via some additional measures to Tholen and St. Philipsland in the province of Zeeland. In this way, an alternative supply can be achieved for the areas that are now fully dependent on the Volkerak-Zoommeer for freshwater.

Basic construction costs of the green or the blue alternative are the same. In order to avoid double counting, construction costs of the water passage itself is excluded from the comparison. They are accounted for within the cost-benefit analysis of the option to make an initial investment in freshwater supply in combination with the redevelopment.

Both the blue and the green alternatives deliver comparable benefits. The attractiveness of the area will be enhanced, resulting in a value increase of the surrounding homes and buildings and an expected growth in retail sales. There are no indications that these effects will differ between the alternatives. The blue variant may cause an increase of leisure spending if moorings for recreational boating are built. Since it is uncertain whether they will actually be constructed and at what cost, this benefit is not taken into account. On the other hand, the passage of recreational vessels could deliver additional benefits. But this opportunity comes at high cost and its implementation is currently considered unlikely.

An initiative called Waterpoort aims to connect cities by water in the region around the Volkerak-Zoommeer. Five municipalities around the lake, the three responsible provinces and several other institutions and stakeholders have signed a Cooperation Agreement. The blue variant for the centre of Zevenbergen fits well within this framework.

Cost and benefits of the option

As discussed before, the passage of the Roode Vaart is required should the Volkerak-Zoommeer become salty. If it remains a freshwater lake, there are benefits whenever cyanobacteria prevent the use of water for agriculture. However, is an initial investment cost-effective? It is not yet certain whether pre-investment is worthwhile: a salty Volkerak-Zoommeer requires a higher freshwater capacity than the initial investment can provide, and phased construction is usually more expensive than a single investment. A fresh Volkerak-Zoommeer does not require additional water supply immediately. The current financial means do not allow for ‘nice to haves’. Only if combining the investment agendas of the national and regional government pays off for all parties involved under all scenarios, the option is likely to be exercised. The option should be a real no-regrets option. To qualify as a no-regrets option, a measure should:

- contribute to solving existing water quality problems;
- have a positive benefit to cost ratio, which is likely to be positive or neutral in all possible scenario, i.e. for both a fresh and a salt Volkerak-Zoommeer and under changing demand and supply conditions.

To evaluate whether this option is cost-effective, we first explore the required measures and corresponding costs and benefits for all plausible scenarios. These scenarios differ in: (a) whether the Volkerak-Zoommeer becomes salty or stays fresh; (b) the demand and supply for water, depending on climate change and social-economic developments; and (c) the development of new alternatives to the Roode Vaart for freshwater supply. Since this case is used to illustrate option analysis, we will focus on the impact of a freshwater or salty Volkerak-Zoommeer.

During the first years the Volkerak-Zoommeer will stay fresh, because making it salty would require costly and time-consuming changes to the infrastructure and several measures to mitigate any adverse effects. In this period the pre-investment (for 3.5 m^3/s) can be made, consisting of a pumping station that sends the water from the Hollandsch Diep through the Roode Vaart, the reconstructed canal through the centre of Zevenbergen and some pumping stations, culverts and water inlets to lead the water to the PAN-polders (1a and 3 in figure 4). This water supply can already be used during cyanobacteria outbreaks to prevent crop damage in Brabant.

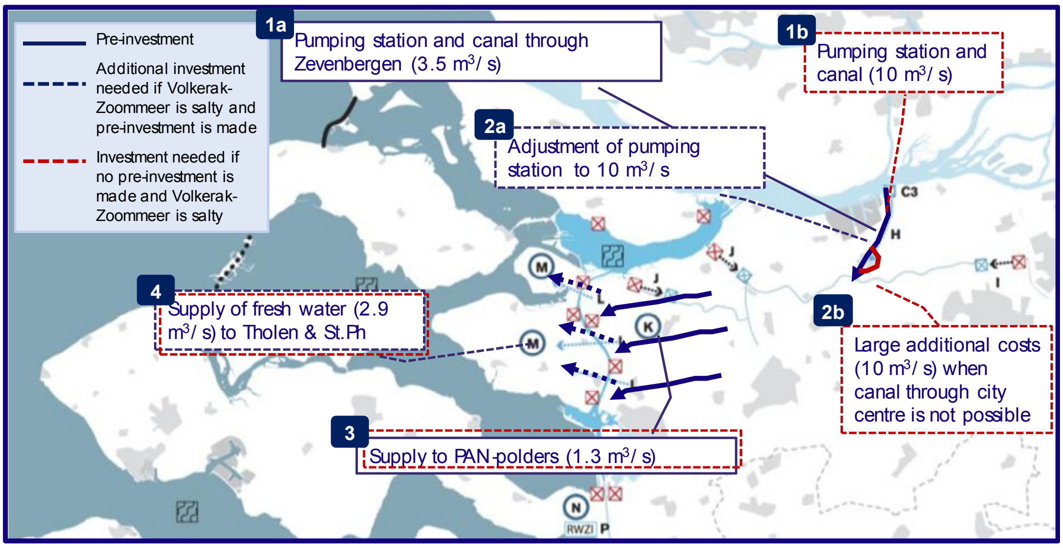

Figure 4: Overview of measures included in the Roode Vaart option.

Should the Volkerak-Zoommeer become salty, the canal's capacity can be increased (2a in figure 4) and the water supply can be extended into Zeeland (4 in figure 4). This phased construction of the pumping station near the Hollandsch Diep is slightly more expensive than immediate construction for maximum capacity.

In the case that this option is not used and the Volkerak-Zoommeer becomes salty, a passage through Zevenbergen would no longer be possible. It is not probable that the city centre will be reconstructed a second time. A detour must be made in the green alternative as well as in the blue one without the initial investment. Such a canal around Zevenbergen is more expensive (2b in figure 4) because it is longer and greenhouses and other industrial activity need to be expropriated. As for the required pumping station, this can be constructed all at once, saving cost. Extension of the water supply to the PAN polders and to Tholen and St. Philipsland requires the same costs as when an initial investment is made.

Comparing the different costs, we may conclude that, in the case of a fresh Volkerak-Zoommeer, making an initial investment causes higher expenses, but in the case of a salty Volkerak-Zoommeer exercising this option is cost-effective. A detour would be much more expensive than the difference in costs between a phased or single construction of the pumping station. In this example, the annual agricultural benefits of the supply to West-Brabant and to the PAN-polders are considered to compensate for the initial investment cost (1+3). So even if the Volkerak-Zoommeer remains fresh, exercising the option has a positive return.

Decision roadmap

Basically, there are three issues:

1 The blue or green alternatives which are to be decided upon at municipal level;
2 A pre-investment in the Roode Vaart to be decided upon by the province and regional water boards. This decision is needed within the next five years, but is only possible if the blue alternative is selected. For the green alternative this option does not exist;
3 Whether the Volkerak-Zoommeer becomes salty or stays fresh. This decision is related to two other primary decisions in the Southwestern Delta that have a national impact through the Delta Programme. A decision is not expected before 2015 and needed by 2027 at the latest.

The third issue is outside the scope of the regional decision-makers in Brabant, and will not be decided upon shortly, as it is connected to other Delta decisions. But the first decision is urgent. We can decide upon the first two, even without knowing what will be the result of decision three. How is this analysis done?
The three alternatives (see figure 5) are:

A The green alternative (without a pre-investment option);
B The blue alternative with the option exercised;

C The blue alternative without exercising the pre-investment option.

First we examine the mid-term future with a freshwater Volkerak-Zoommeer. In this case there are no differences between the alternatives resulting from the decision to keep the Volkerak-Zoommeer fresh. In case of alternative A (no option) or alternative C (not exercising the option) there are no costs and benefits in the short term either, because there is no pre-investment. The costs and benefits of the blue and green redevelopment alternatives are roughly the same, possibly with a slight advantage for reconstructing the canal because this would align with the Waterpoort ambitions. Hence, it is required to assess whether the benefits of the pre-investment outweigh its costs. As a matter of fact the net present value of the investment is positive. Within a few years, the avoided damages to crop productivity and water level management are higher than the investment costs. Consequently selecting the blue alternative with the option of the water passage has the highest return.

However, what will happen when the Volkerak-Zoommeer turns salty? In the case of no pre-investment (alternatives A and C) the costs and benefits are identical in the short and medium/long term. The most urgent decision about the redevelopment of the city centre slightly favours one of the blue alternatives, or C in the case that only A and C are compared.

Then alternative C is compared with alternative B. The pre-investment option has a higher return because of the expensive expropriation and detour that it prevents.

Even if a salty Volkerak-Zoommeer is a matter of certainty, pre-investment is cost-effective. Weighed against the one-off construction, the additional costs of a phased decision are small given the annual costs it prevents. Hence, this investment will break even before a salty Volkerak-Zoommeer can be implemented.

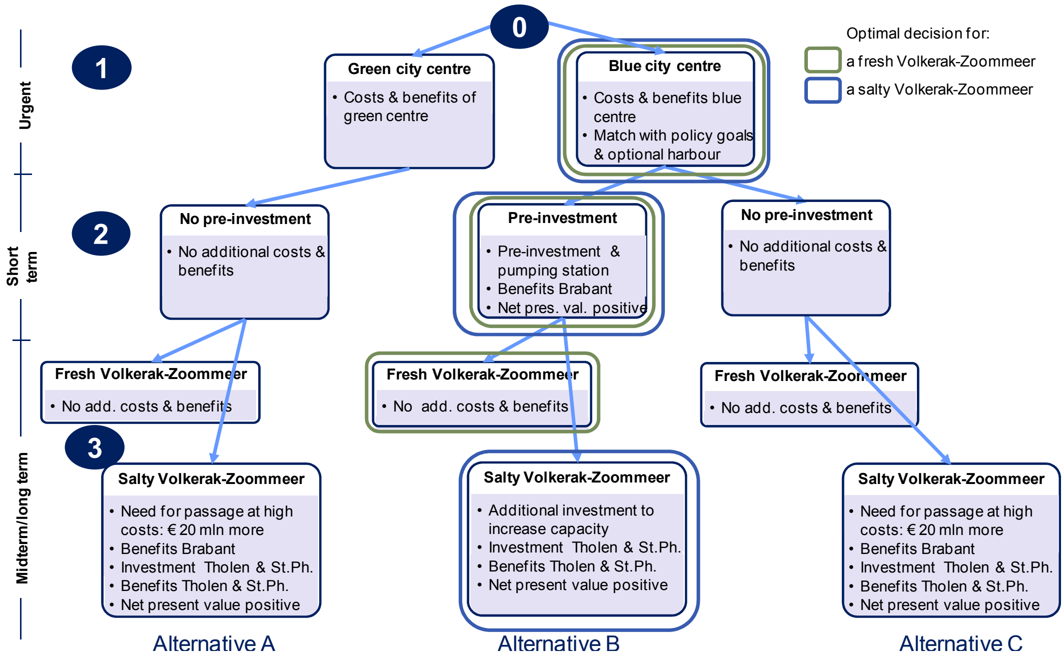

Figure 5: Overview of decisions, scenarios and alternatives.

Conclusion: pre-investment is a no-regret measure

For a lasting, fresh Volkerak-Zoommeer

For a lasting, fresh Volkerak-Zoommeer there are no clear differences between the three alternatives in the medium and long term if we ignore changes in supply and demand for water. However, there is a difference between alternatives B and A/C in the short term. This depends on the benefits of the pre-investment. Do the benefits of the investment outweigh the costs during the period of temporary water shortages? In this case they do. Recuperation of the investment is done within a few years.

For the city of Zevenbergen, there is no clear distinction between the returns of the blue and green versions of the Master Plan. Since construction costs for these alternatives are equal, the choice is financially neutral but the choice for the blue variant is in line with the Co-operation Agreement Waterpoort.

For a salty Volkerak-Zoommeer

The measures constructed in alternative B are for the most part equally useful for a salty Volkerak-Zoommeer. Additional costs for the capacity extension are relatively limited. Since the Volkerak-Zoommeer will not become salty within a few years, the annual agricultural benefits are sufficient to recover this investment before then. Starting with a throughput of 3.5 m^3/s is a wise choice as well for a Volkerak-Zoommeer becoming salty.

The construction of the Roode Vaart through the centre of Zevenbergen (blue version) prevents the need for a future canal around Zevenbergen. The total costs for a route around Zevenbergen are much higher than the additional cost of increasing pumping capacity, in particular if the greenhouse area should develop further. Another advantage of the blue variant is that the capacity adjustment of the Roode Vaart needed for a salty Volkerak-Zoommeer will have a shorter duration than the construction of a new route including land acquisition.

If the Volkerak-Zoommeer becomes salty, there is a need for an alternative freshwater supply to Tholen-St. Philipsland. The costs of creating a freshwater supply from West Brabant are lower than the increase in agricultural income. This applies equally to a flow capacity at the level of current demand, and to an upgraded one. Moreover, there would be additional advantage of ensuring continuous availability of freshwater.

Combination of scenarios

Based on the information used, it can be stated that the blue variant of the Master Plan can be considered as a set of no-regret measures. This also applies to the initial investment in the water passage.

The choice of this alternative is positive in both scenarios, fresh and salty. Taking into account long-term changes in demand or supply also support this conclusion. The investment has a positive return within a few years. Should freshwater demand reduce, this would only impact the need for a future capacity extension. If demand decreases, capacity will not be increased. If there is a growing need, the initial investment becomes part of the end state and has a positive return, both for a salty and fresh Volkerak-Zoommeer. For a freshwater lake, pre-investment will actually bring greater benefits. Crop damage during cyanobacteria outbreaks will be better avoided, giving initial investment a higher return.

Therefore, in spite of the many policy and climate uncertainties it has been possible to determine a rational financial decision. Systematic option analysis as promulgated in the Adaptive Delta Management method prepares for an uncertain future and limits the chances of over- or under-investment. It gives us a roadmap with a decision sequence that provides benefits and allows us to seize the opportunities offered by linking ambitions and investment agendas.

Water allocation in 2050

Tools and examples

Peter Droogers, Walter W. Immerzeel, Wilco Terink,
Johannes E. Hunink and Godert W.J. van Lynden

Water allocation tools are required to support policy-makers in their decision-making processes. These tools are able to explore and quantify the spatial and sectoral impact of measures considered by policy-makers, on the water available for allocation, and under future changes in water demand and supply. Nowadays, many tools are available for this purpose, each with its limitations and applicability within a certain context and spatial scale. The increasing amount of data available in the public domain, principally from remote sensing, provides an ever-increasing range of possibilities to be used for water allocation and planning. This paper summarizes two case studies in which allocation tools were used to assess the impact of management and structural measures, as well as the impact of external changes, as climate and population change. The case study from the Middle East and North Africa (MENA) region assessed options of various water allocations as a response to the impact of changes in climate, population, economic development and irrigation. It showed that water shortages will increase from 42 km^3/yr in 2010 to 199 km^3/yr by 2050 in the region. Results show that the projected water shortage is mainly due to socio-economic developments and that climate change only contributes 18%. Measures to overcome all water shortages will cost an estimated US$ 147 billion annually by 2050, of which the climate component in this figure is US$ 48 billion annually. The case study from the Green Water Credits (GWC) program in Kenya demonstrates that the use of the two-tier modelling approach is very effective to estimate cost-benefits of alternative land and water management. Moreover, these tools have proven effective in unravelling the complex upstream-downstream interactions of water and ero-

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sion/sedimentation. It was concluded that over the coming decade decision-makers will increasingly use these water allocation tools to develop robust and well-accepted water policies.

Water allocation tools

Policy-makers and planners at all levels require practical guidance on how to allocate water and design effective allocation mechanisms. To design allocation mechanisms (prioritization, regulation), it is necessary to fully understand to what extent possible decisions affect the water availability, and to obtain insight into the broad range of related impacts. This understanding is the start of the political process that leads to the prioritization of water allocation, taking into account the sectoral priorities and socio-economic factors.

To generate the knowledge or information base for this decision-making process, allocation tools should be used for the quantitative analysis of future measures and strategies, based on data from the past, predictions of future developments and the definition of opportunities (figure 1).

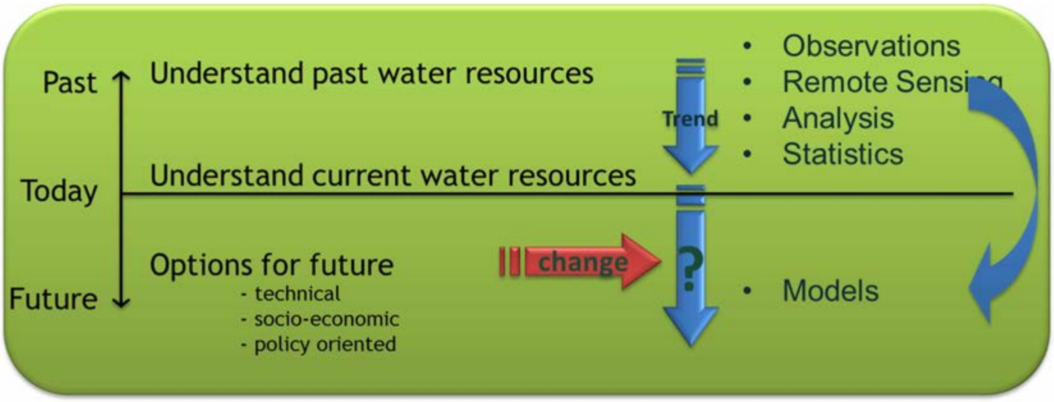

Figure 1: Graphical overview of water allocation approaches, focusing on options for the future.

Water allocation tools offer an efficient way of analysing spatial and temporal data to predict the interaction and impacts, over space and time, of various future management and policy options. These tools can be used to assist in the identification and evaluation of different prioritization schemes and rulemaking processes. In summary, water allocation tools provide the opportunity to: (i) estimate water resources at locations where data is lacking (in time and/or space); (ii) analyse trends; and (iii) undertake scenario analysis (what-if).

The usefulness of each allocation model is related to the temporal and spatial scale of study. Therefore, the selection of the appropriate tool is essential and not straightforward given the substantial amount of tools available. Most important is to choose a modelling scheme that accounts correctly for the differences between the scale on which the allocation decisions are taken, and the scale on which the relevant processes take place, are monitored and are measured. A compromise has to be found between the physical detail or process knowledge and the spatial scale of output. In fact, there is a certain continuum between physical detail and spatial scale of water allocation models. In general it can be stated that the larger the spatial scale the less physical detail can be included (figure 2). A field scale model that aims at simulation crop growth water transport through the unsaturated zone, percolation to the

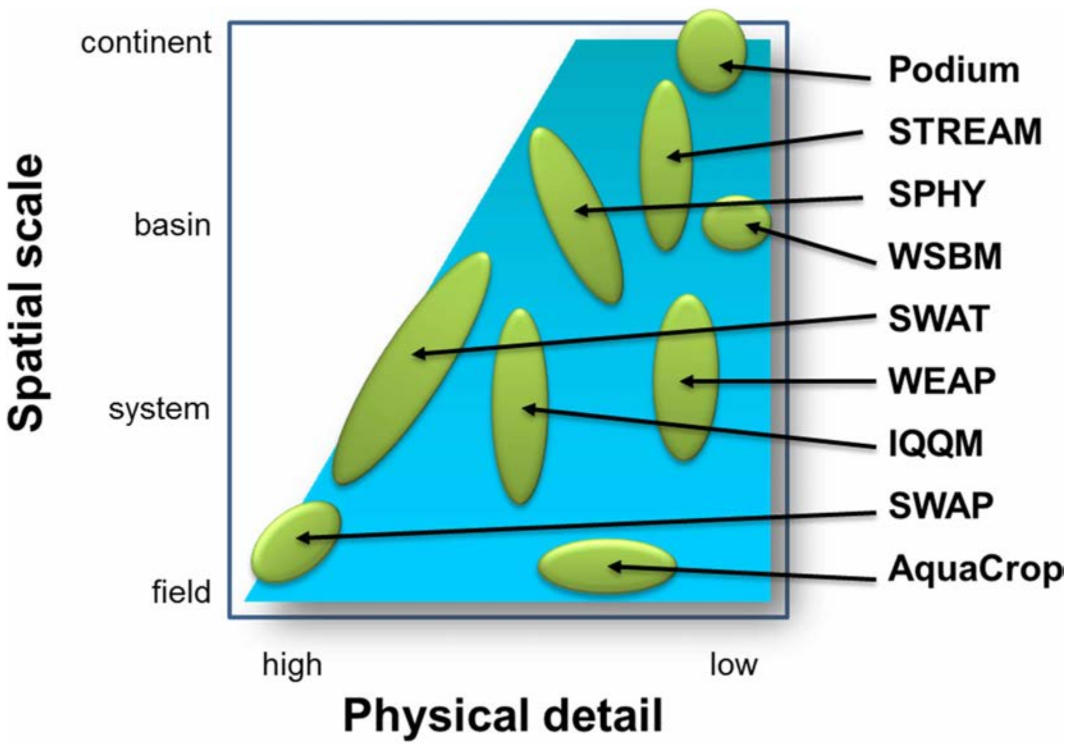

Figure 2: Relation between spatial scale and physical detail in water allocation tools. The green ellipses show the key strength of some well-known models.

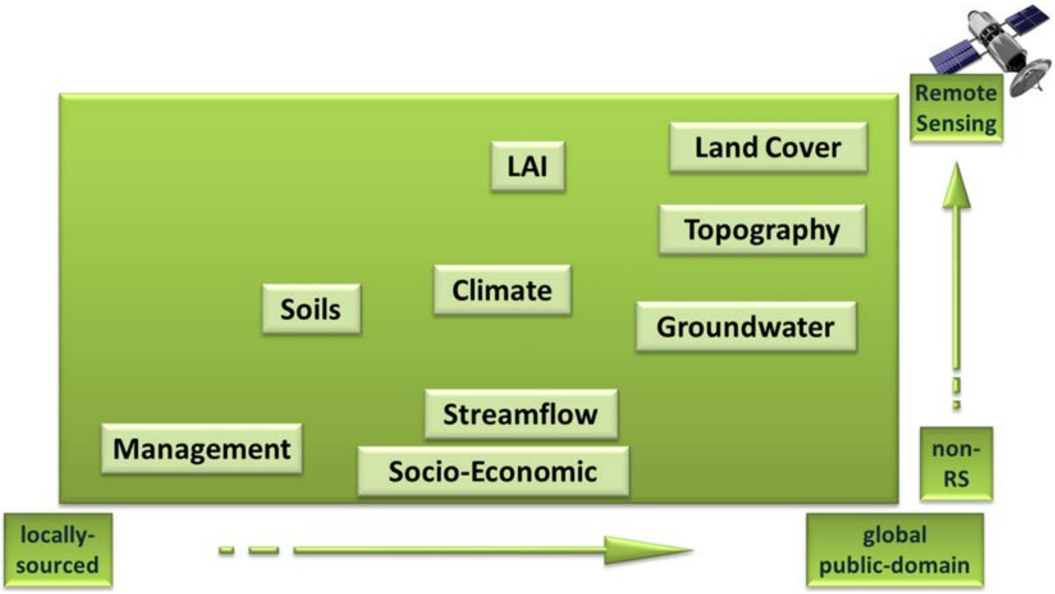

Figure 3: Development in data availability to support water allocation tools over the past 20 years.

groundwater, and atmosphere land surface interaction requires a lot of data and is computationally intensive and, therefore, can only be applied at the field scale. If one wants to study, for example, the impact of climate change at the continental scale, then different algorithms are used which are less data intensive. If we consider irrigation schemes, then more physical detail can be included on the water distribution and diversions than when modelling at the basin scale, but less detail on the water balance at the field scale.

Besides these important considerations there are a number of other factors influencing the appropriate choice of tool, such as the availability of source code, documentation, support, user friendliness, resources, price, data availability, and inclusion of crucial processes relevant to a particular study.

The sources of data to feed these water allocation tools have undergone a major shift over the last decades. The use of remote sensing in water allocation and hydrological tools is a growing field and provides a still increasing number of opportunities for water allocation purposes, especially in areas where data are scarce, unreliable or politically sensitive and hard to obtain. This situation is often encountered in many areas across the world in developing countries. Obviously, it is crucial to complement remote sensing data with ground truthing to obtain the desired output accuracy and the approval of the local decision-makers. However, remote sensing provides objective and continuous sources of information on many variables relevant to water allocation, and the number of applications is still increasing. Examples of the use of remotely sensed data include land cover classification, the inclusion of digital elevation models in catchment delineation, the use of vegetation indices to derive surface roughness, and the use of precipitation radar data as input to a model (figure 3).

There are principally two main approaches of using a water allocation tool for decision-making: (i) optimization; and (ii) scenario simulation. The first approach aims at identifying the decision-variable values that will produce the best allocation strategy directly, based on a set of assumptions. Optimization focuses on finding the optimal solution from millions of possible alternatives given certain constraints. An example of such an algorithm is linear programing. However, optimization is seen as a 'black box' approach, taking inputs, crunching the numbers, and presenting a solution. It's often hard for the decision-maker to fully understand the interplay of various factors and how the system works as a whole, and accept the outcomes.

The second approach, the scenario-based simulation, is generally preferred by stakeholders and policy-makers. This allows the decision-maker to see the behaviour of the system over time, as the inputs change. It may also allow bottlenecks to be identified that would otherwise be missed in an optimization programme that gives the best overall answer but misses crucial issues along the way. Such an approach does not drive to one unique optimal solution, but requires comparison of model output, interpretation and evaluation. This approach can also be implemented in web-based modelling in which decision-makers and other users are provided with a sort of virtual observatory that links data, models and expert knowledge in an interactive way.

Two case studies will be summarized to demonstrate these concepts where data and models are applied to assess the impact of a certain change. The first case study is from the MENA region where the impact of climate change and potential adaptation strategies are explored. The second case study describes the procedure to assess the impact of soil water conservation measures on upstream as well as downstream water users for a sub-basin in central Kenya.

Case Studies

Water outlook 2050 in the Middle East and North Africa

Water resources are under increasing pressure due to the world's growing population and economy, possibly intensified by the effect of climate change (Rosegrant, 2003). The relative contribution of different factors to water shortages is largely unknown, so are the options available to overcome these water shortages and, more importantly, at what cost. Moreover, many countries in the region are depleting their non-renewable water resources, putting even more pressure on future water resources. The costs of adaptation to climate change are an important input to negotiations regarding the Green Climate Fund (Donner et al., 2011) and in the mitigation debate (Landis and Bernauer, 2012). This funding, which may reach US$ 100 billion per year by the year 2020, is necessary to 'address the needs of developing countries' to adapt to climate change.

One of the regions that will potentially suffer most from climate change is the MENA region (Terink et al., 2012; Trieb, 2008). The MENA region, consisting of 21 countries, is the home to more than 300 million people, or about 5% of the world's population, with an average annual population growth rate of 1.7% (World Bank, 2011). MENA is the driest and most water scarce region in the world and this is increasingly hindering the economic development of most countries of the region (Khaled and Abdel, 2006). The agricultural sector is under severe pressure in the region given the enormous amount of water consumed by this sector and the need to feed a population which is projected to double by 2050 (Godfray et al., 2010; Rosegrant, 2003). However, adaptation in the agricultural sector requires a multidisciplinary approach where water for irrigation needs should be considered in the context of all water users (Howden et al., 2007).

Two water allocation tools were combined: the hydrological model Spatial Processes in HYdrology (SPHY) and the water allocation framework Water Evaluation And Planning System (WEAP) (Droogers et al., 2012). The study combined an evaluation of the projected impact of changes in climate, irrigation water demand, urban water demand, and industrial water demand. A combined physical hydrological and water allocation model was used to develop marginal costs curves of adaptation options on the impact of climate change up to 2050.

Projected total internal renewable water resources show a significant decline under climate change (figure 4), due to the combined effect of a reduction in precipitation and a higher evaporative demand. However, the total external renewable water resources show a small increase, mainly attributed to the Nile, owing to the projected increase in precipitation over East Africa by the majority of climate models. Projected total water demand is estimated to increase by 132 km^3/yr by 2050, while total water shortage will increase by 157 km^3/yr (figure 5). This increase in shortage is the collective impact of the increase in demand by 51% combined with the decrease in supply by 12%. Even under the wettest climate projection, water shortage will increase from 42 km3/yr currently to 85 km^3/yr by 2050, showing that increase in demand by socio-economic factors outweighs projected change by climate.

The water allocation (WEAP) and hydrological (SPHY) tools were also used to isolate the effect of climate change by assuming climate in 2050 would remain similar to current climate conditions, but all other changes would occur as projected. Comparing these results with the original analysis showed that only 18% of the increase in water shortage in the region is a direct result of climate change. 82% of water shortages originate from changes in socio-economic factors.

When trying to match future water supply and demand, three broad strategies can be considered: (i) increasing the productivity of existing water use; (ii) increasing supply; and (iii) reducing demand by shifting the economy towards less water-intensive activities. A total of nine different adaptation options belonging to one of these three strategies were tested. Figure 6 shows the effect of a single adaptation option when applied to its full potential in the entire MENA region. Clearly, improved agricultural practice and desalination are the preferred options, where unmet demand can be reduced by 55 km³, 63 km³ and 53 km³ respectively. Increasing reservoir capacity in the MENA will not be very effective given that reductions in precipitation are projected.

Total annual costs to close the entire water demand-supply gap are estimated to amount to US$ 147 billion per year by 2050. The contribution of climate change to this figure is US$ 48 billion (3% of current GDP of all countries), increasing the costs of adaptation by 48%, a result that is caused by the non-linear relationship between water shortage and the costs of adaptation; in other words additional water savings are increasingly expensive.

The results of this case study indicate that future water shortages in the MENA region are predominantly caused by socio-economic developments and to a lesser extent by climate change. Given the incremental costs of additional measures, climate change is likely to have a substantial effect on the overall costs of adaptation. Mitigation measures to reduce emission of greenhouse gases as an alternative to adaptation in the long-run is not a feasible option given the almost irreversibility of the impact of carbon dioxide on climate change (Solomon et al., 2009).

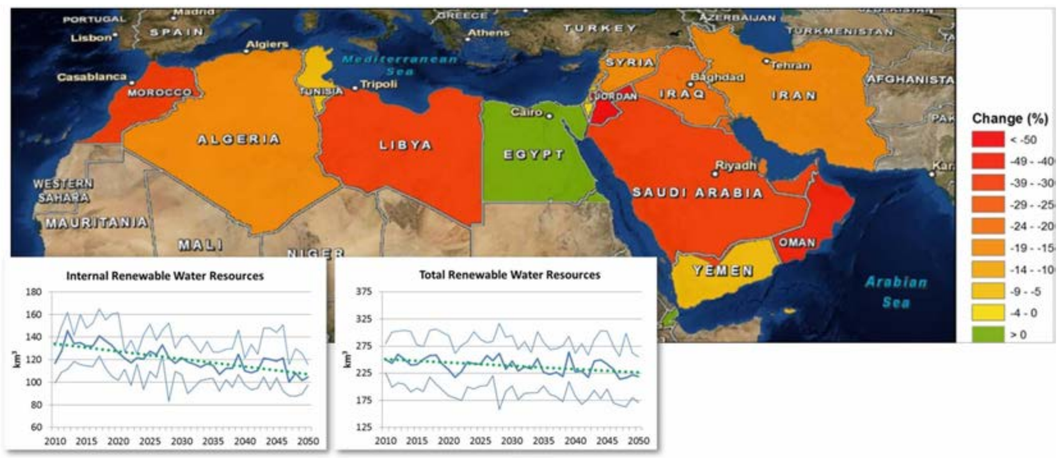

Figure 4: Internal and total renewable water resources from 2010 to 2050 for the MENA region (graphs), and change per country between 2010 and 2050 (map). The bold line is the average of the nine GCMs and the thin lines show the second wettest and second driest GCM. Renewable water resources are defined as the 'average annual flow of rivers and recharge of aquifers generated from precipitation'. This is from within the region under study (Internal) and from outside the region (External), adding up to the 'Total'.

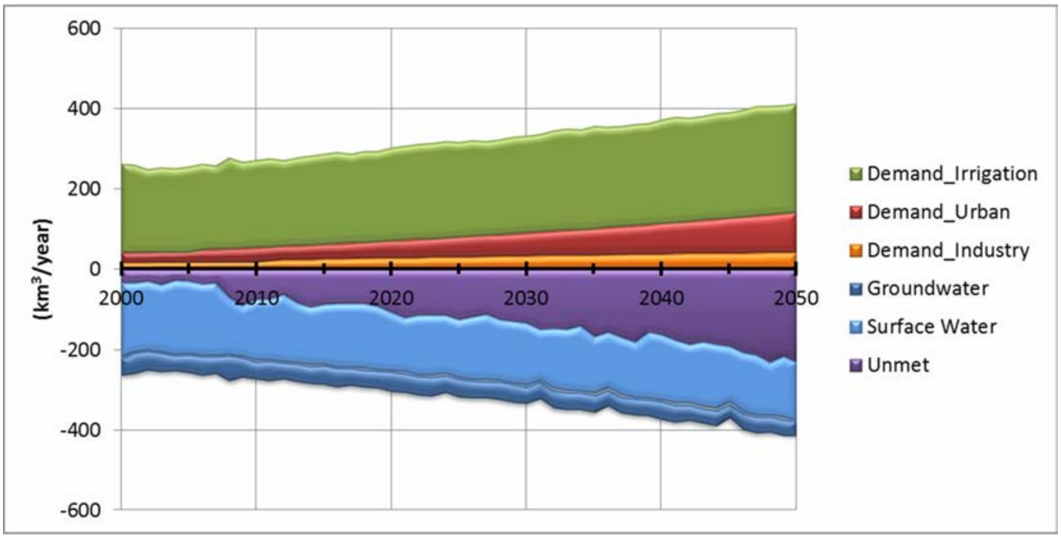

Figure 5: Water demand and supply for the MENA region based on the average climate scenario.

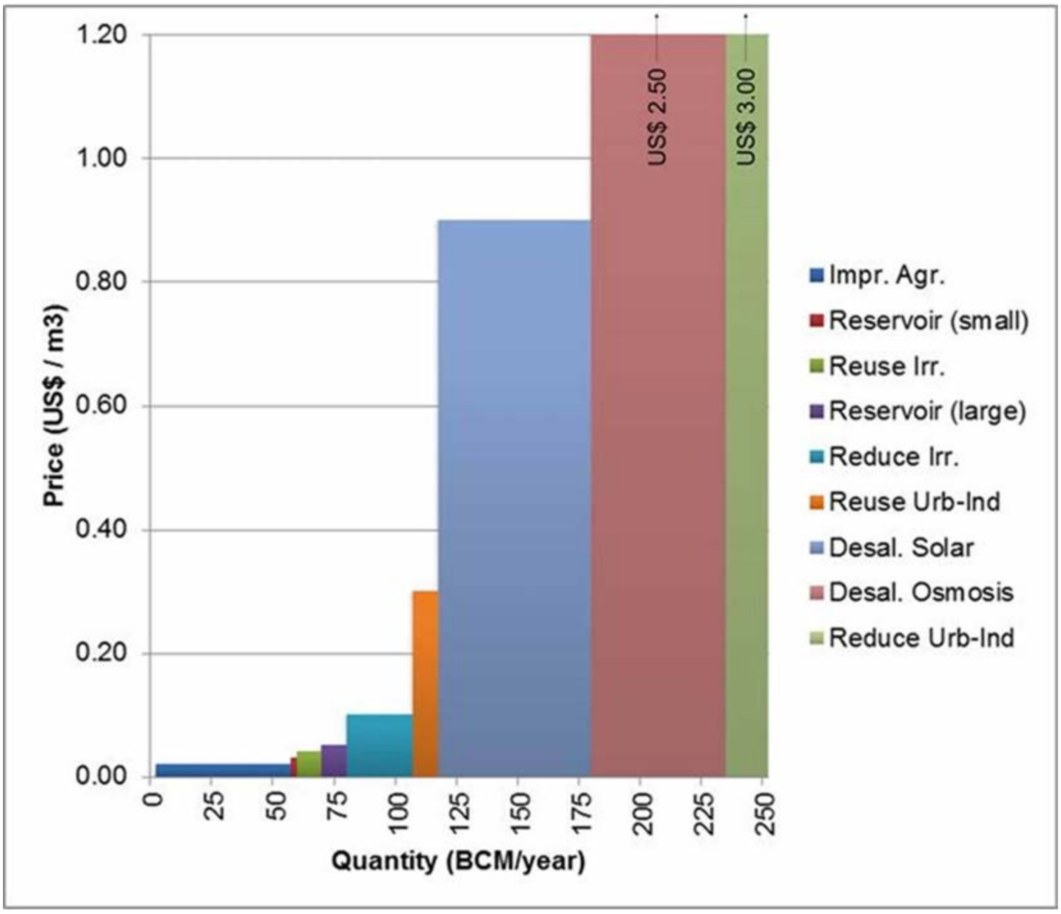

Figure 6: Water marginal cost curve for the average climate projection. The water-marginal cost curve shows the cost (Y axis) and water saving potential (X axis) of a range of different strategies - spanning productivity improvements, demand reduction and supply expansion – to close the water supply-demand gap.

Green Water Credits in Kenya[1]

Increasing pressure on land and water resources might lead to tension among inhabitants in many basins in the world because activities in one area of the basin can have major and often negative impacts in other areas. This interrelationship is particularly relevant for soil and water conservation (SWC) practices that may result in clear benefits upstream, while impacts downstream might be positive or negative. For example, upstream terracing reduces surface runoff, thereby enhancing infiltration, soil moisture storage and groundwater recharge. This, in turn, results in less erosion, less sediment in surface waters, and a more consistent streamflow, enabling water in rivers and reservoirs to be managed better. A lower surface runoff and, simultaneously, increased crop transpiration may, however, lead to less water downstream. The use of mulching in agricultural land may reduce soil evaporation and weed growth. Fewer weeds will limit unbeneficial transpiration, which in turn may contribute to more groundwater and streamflow.

Many efforts have already been made to enhance cooperation within basins, linking upstream and downstream activities related to water use (Blackman and Woodward, 2010). To facilitate this cooperation, the Green Water Credits (GWC) concept is being developed, linking the interests of upstream farmers and downstream water users. The term Green Water refers to water in the unsaturated zone of the soil which is available for crop growth and transfers to the atmosphere through evapotranspiration, whereas Blue Water refers to free water in streams and aquifers (Falkenmark and Rockström, 2010). GWC promotes the use of specified conservation practices to generate both on-site, upstream, as well as off-farm downstream benefits.

However, it is unfeasible to estimate the quantitative impact of GWC measures on such a large scale and across the different uses

1 Based on: J.E. Hunink, P. Droogers, S. Kauffman, B.M. Mwaniki and J. Bouma (2012) Quantitative simulation tools to analyze up- and downstream interactions of soil and water conservation measures: Supporting policy making in the Green Water Credits program of Kenya; in: *Journal of Environmental Management*, vol 111, pp 187–194.

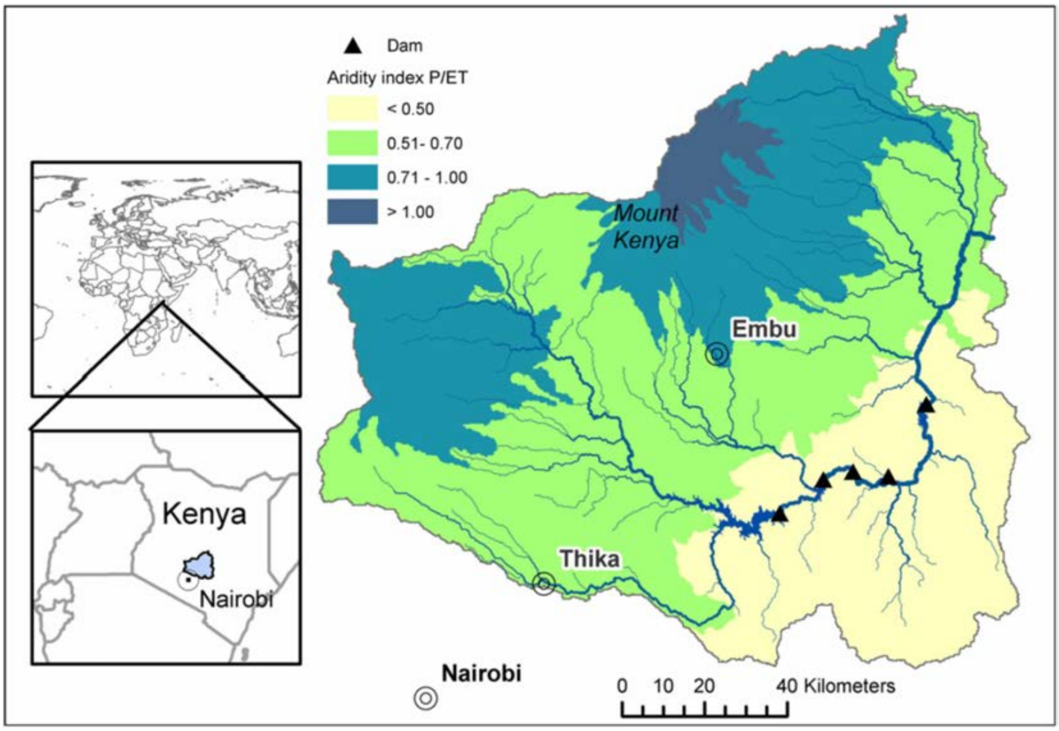

Figure 7: Location of the Upper Tana Basin in Kenya, main reservoirs, drainage network and climatic zones according to the P/ET aridity index.

and sectors purely based on data extrapolations. Water allocation tools are necessary to assess upfront the effects of land management practices on processes of interest, in space and under different climatic conditions. For this case study in the Upper Tana Basin in Kenya (figure 7) the Soil and Water Assessment Tool (SWAT) in combination with the WEAP was used. SWAT is a distributed hydrological model providing spatial coverage of the entire hydrological cycle including atmosphere, plants, unsaturated zone, groundwater and surface water. The model is comprehensively described in literature (Neitsch, Arnold, Kiniry, and Williams, n.d.). WEAP enables to link upstream to downstream allocations in terms of water, sediments and financial terms.

Based on discussions with stakeholders and policy-makers, 11 land management measures were selected that could be realistically implemented in the upstream rainfed areas of the Tana Basin and of which the WOCAT (Liniger and Critchley, 2007) database provides experimental data in catchments with similar physiographic conditions.

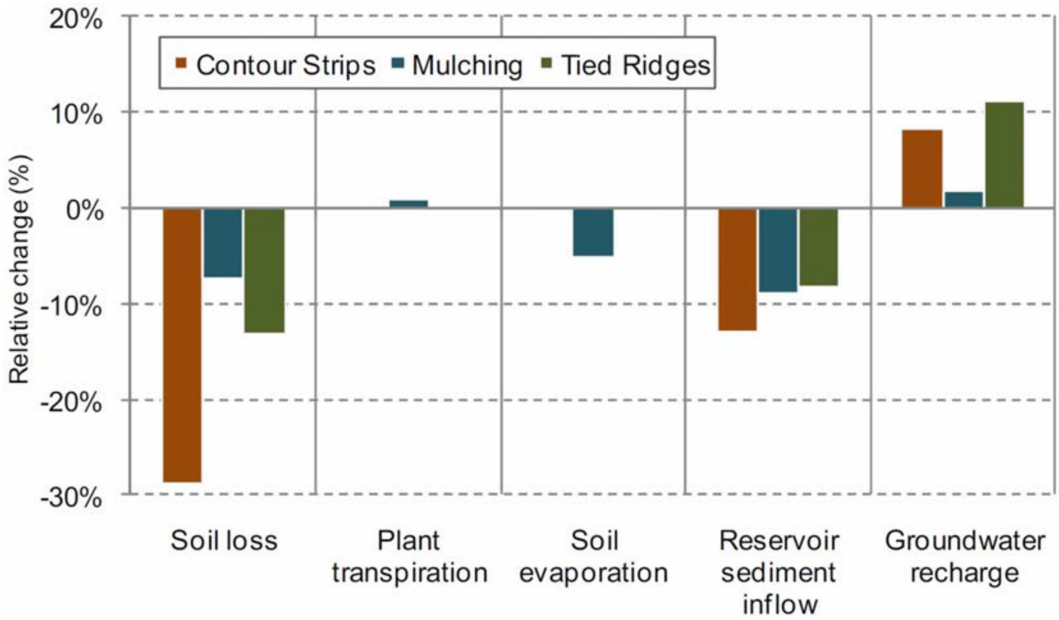

Figure 8: Relative changes of the five key indicators for the three scenarios compared to the baseline situation, based on yearly averages. Some changes are (near to) zero.

The model results confirm that changes in erosion on the agricultural fields match with changes in reservoir sediment inflow, affecting positively the reservoir storage capacities and the allocated water for hydropower and irrigation. Figure 8 shows the average changes to 4 key indicators for 3 of the 11 measures studied (permanent vegetative contour strips, mulching, and tied soil ridges), based on the annual means of the 10-year simulation period. Reductions in reservoir sediment inflow are all comparable (around -10%), while basin-scale reductions of soil loss are much more divergent among the three scenarios (between −7% and −29%). The main reason for this difference is that hydrological processes related to the different scenarios vary. The spatially distributed model routes the sediment to the basin outlet taking into account the spatial distribution of the erosion-prone surfaces and the corresponding changes in land management. Therefore, the location where the changes take place affects the processes in the channels controlling its sediment transport capacity (deposition and entrainment), something SWAT accounts for by using methods described in (Neitsch et al., n.d.).

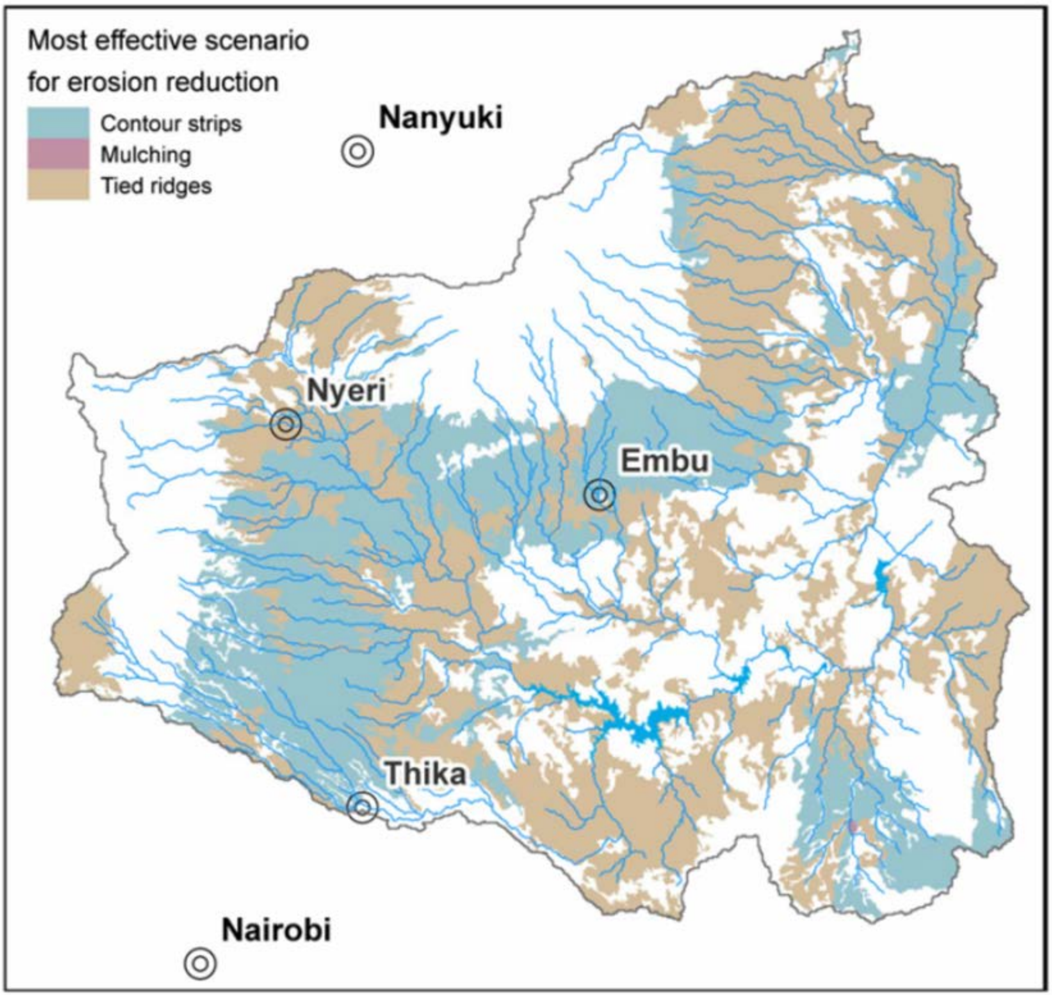

Figure 9: Map showing which practice is most effective in reducing erosion.

The SWAT tool can also be used to assess the impacts, flows and water allocations spatially, in order to determine the preferred GWC measure at each site. Figure 9 shows an example of a comparison of the effectiveness among different measures in the area. In this case, for some regions contour strips are more effective to reduce soil erosion while for other locations tied ridges are the preferred GWC measure. The spatial differences are the combined effect of factors such as crop, soil, slope, location from stream, farmer practice, etc.

Finally, the WEAP tool is used to quantify financial benefits on GWC measures where upstream (higher crop yields) and downstream (less sedimentation and regulated flows) impacts are assessed. Based on a total of 11 GWC measures it is clear that the water allocation tools are able to compare and evaluate the meas-

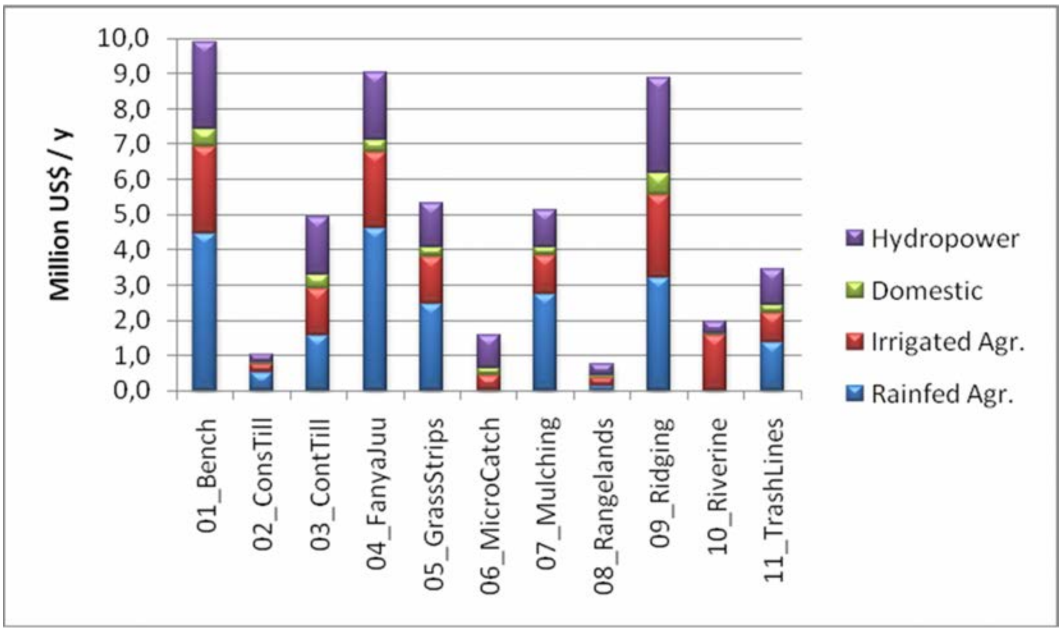

Figure 10: Increase in revenues for the 4 main sectors presented as changes compared to baseline for the 11 intervention measures.

ures and the potential economical benefits from each measure (figure 10).

Conclusions

Water allocation tools have been developed by researchers over the past decades and, since the beginning of this decade, these tools have been used increasingly by policy-makers to support their decision-making process. The main reasons for this uptake by policy-makers are: (i) uncertain future because of climate change; (ii) more demanding societies; (iii) development of well-tested allocation tools; and (iv) enormous increase in availability of data (often from satellites) to support tool development.

The case studies as presented here are just two amongst many others where water allocation tools are applied in practice to support decision-making processes. The MENA case study provides clear guidelines of adaptation measures and costs to climate change and other changes in 2050. The Green Water Credit study supports decisions regarding practical water management interventions, where upstream-downstream interactions are essential.

The study ensures that all stakeholders are provided with independent information on which decisions will be taken.

It is clear that policy-makers will increasingly use these water allocation tools to support their decision-making processes. Therefore, the linkage of data and observations (to understand past and current water resources) to models (to assess future options and developments) is essential. The following issues are essential for their applications and further development to researchers:

- Proper selection of the most suitable tool(s) for the questions to be answered. A trade-off between required physical detail (spatially and temporally) and data availability should always be made;
- Public domain tools are increasingly becoming effective and are often better choices than commercial packages;
- Application of water allocation tools still requires a high level of expertise and substantial time, but new opportunities are arising related to web-based scenario analysis tools for water allocation, which will make the decision-making processes much more robust and accepted;
- An all-inclusive sector analysis is necessary and possible nowadays.

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The test of time

Finding resilience across climate boundaries

John Matthews

Introduction

How long will the Three Gorges Dam stand on China's Yangtze River? As one of the world's largest dams on one of the world's largest rivers, the Three Gorges Dam seems likely to have a marked influence on the ecosystems, human communities, and economic assumptions about energy production, navigation, and urban and agricultural water supply of the region for generations. If history is a guide, this Dam's lifetime may even extend several centuries (Turpin, 2008; Ortloff, 2009). The Dam's chief engineer reportedly said that his team was 'endeavouring to assure' that the Dam would hold 'forever'.

Freezing allocations in concrete (in a warming climate)

In many ways, the presence of long-lived infrastructure spanning decades or centuries crystallizes economic, allocation, ecological and climate assumptions through the medium of concrete and steel. Such infrastructure also bears the promise of reliable, stable services that are expressed through the large and small investments of governments, corporations and individuals. A city such as Las Vegas, United States, would not have attracted so many investments and people since 1950 without the 'promise' embodied in the Hoover Dam for cheap, abundant water and energy. As the regional climate has become more arid, the Dam's promise has become increasingly tenuous. As a result, Las Vegas is now spend-

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ing an estimated $US 1 billion on a new water intake channel to deliver two to three additional decades of water from Lake Mead's reservoir.

Neither Three Gorges Dam nor Hoover Dam is unusual. The lifetime of water infrastructure signifies the challenge of maintaining a coherent approach for managing water resources sustainably over periods relevant to both ecosystems and economies. The scope of the problem is enormous. About 50,000 large dams exist worldwide (>15 m tall), out of a global total of about 850,000 (some 80,000 of which are in the US) (World Commission on Dams, 2001; Vörösmarty et al., 2005; Vörösmarty et al., 2010). And the developing world has effectively entered a new era of aggressive dam building. While India has almost 300 hydropower dams planned for the Himalayas (Grumbine and Pandit, 2013), in 2011 China announced a 10-year plan to enhance water security through more than $US 600 billion in investments, largely in new or modified infrastructure (Yu, 2011). The temptations for additional 'investments' in new infrastructure are strong, particularly given new incentives for 'clean energy' and reliable water supplies. While the US has approximately 70 % of its hydropower potential developed and about 6000 m3 of storage per capita, Africa has roughly 7 % of its hydropower potential developed, with Ethiopia (a relatively wealthy country by east African standards) stores about 60 m3 per capita (Grey and Sadoff, 2007; IJHD, 2010). The pathway for development often runs through a river's blocked channel. And the long-term risks for making poor assumptions are high.

Sustainable water resources management has long presented significant challenges, but climate change heightens these concerns. An evolving climate may leave a dam unable to operate within its designed parameters: high and dry from an unexpected drought, potentially failing catastrophically from an unprecedented flood, or eroding in efficiency and reliability — and impoverishing a weakening economy as a result. Built water infrastructure is often difficult to modify or adjust to shifting hydrological conditions. The 'bathtub ring' from the 80-year-old Hoover Dam's 'missing' water in the US testifies to the high risk of divergence between the conditions engineers and planners assume and the rapid evolution of the eco-hydrological setting. In many cases, the resulting climate-infrastructure gap means that ecosystems must pay the difference through additional diversions, lower environmental allocations and a competitive stance relative to developing and developed economies (Matthews et al., 2011). Can the interests of emerging economies and dynamic but embattled ecosystems find confluence in a changing climate?

Who has the knowledge for climate-sustainable water management?

A common vision for sustainable water resources management must be grounded in both shifting eco-hydrological realities and in the capacity to design and operate adaptive water infrastructure. In effect, we need a coherent basis for resilient water resources management that combines aquatic ecology with infrastructure engineering that can be translated into operational and policy guidelines and realistic and flexible allocation decisions. Green growth and sustainable development must emerge from effective science and good engineering.

The water community is diverse and complex, with deep ravines between disciplines as well as between researchers and practitioners (figure 1). These disciplinary relationships are also unequal: economists are generally far more capable of influencing policymakers or finance arrangements than the scientists who are most aware of shifting conditions. Two scales are most relevant for successful allocation: (i) water planning, which sets directions across sectors and institutions and over large spatial and temporal scales (often national or transboundary in the developing world), and (ii) resource management, which typically operates at local scales, such as individual pieces of infrastructure, cities, or protected areas, and 'freezes' assumptions about eco-hydrological and socio-economic demands as water infrastructure within a narrow operational range. Particularly in the case of infrastructure design and operations, these assumptions can alter the landscape and constrain resource management options for long periods. Both approaches – socio-economic and natural science – and both scales – planning and local resource management – are critical to integrate in order to create an effective social-ecological resilient decision framework. For more resilient water resources management, these disciplines need to work together. But they must also recognize their relative strengths. Sustainable water management rises from the springs of eco-hydrological science.

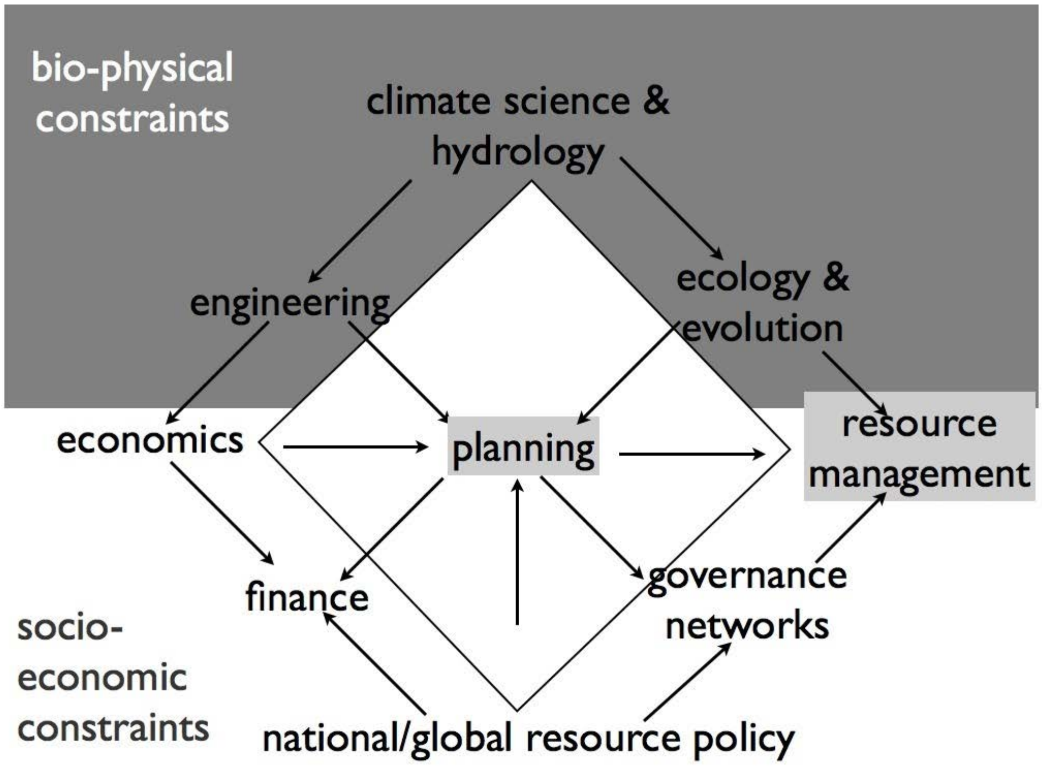

Figure 1: Bio-physical constraints.

Paradigm shifts: eco-hydrology and sustainability

Until the twentieth century, the dominant water management paradigm focused on managing for water supply and demand, with an additional focus on water quality beginning with the emergence of major urban water treatment facilities. Water in this conception was identified primarily as a social, human good. Water management plans often reduced flow variability drastically. Beginning roughly mid-century, management techniques that formally defined an 'environmental flow' for ecosystem health began, though these flows had little in the way of ecological underpinnings to determine flow needs (Arthington, 2012).

The definition of the natural flow regime as a 'master variable' for freshwater ecosystems in the late 1980s and 1990s marked a major departure in science, management, allocation, and design. The natural flow regime embodies the recognition that variability – within and across years – is critical for the health and integrity of aquatic ecosystems (Poff et al., 1997). Hydrologists typically represent the flow regime as an annual hydrograph, and the natural flow regime (sometimes referred to as water timing or water seasonality) is now understood to be a major driver for both water quantity and water quality. Ecologists have long recognized the role of 'disturbance' as a dynamic pulse in ecosystems, such as fires in the forests of western North America. The natural flow regime is the freshwater equivalent. Moreover, the natural flow regime could be translated into a few key eco-hydrological traits that could facilitate the process of managing for disturbance and eco-hydrological variability, which could then be applied across infrastructure networks at a basin scale. Perhaps the most comprehensive framework to this approach was the ecological limits of hydrologic alteration (ELOHA), which described a comprehensive, robust process for determining a sustainable environmental flows process (Poff et al., 2010; Kendy et al., 2012). Ideally, these approaches enable ecologists to maintain biological complexity while allowing engineers to focus on simple, reductionist operational variables.

Although many adherents of both paradigms could be found globally by 2008, a growing number of researchers and practitioners in hydrology, engineering, ecology, economics and other water-related disciplines became concerned about the widespread assumption of a stationary climate in water resources management decisions with the palpable quickening of climate change (Poff et al., 2002; Milly et al., 2008; Palmer et al., 2008; IPCC, 2008). Even approaches such as ELOHA lack a feedback loop that could detect and update shifting eco-hydrological parameters. And there was abundant evidence globally that these parameters were already shifting in many regions. A number of inter- and intra-disciplinary efforts have attempted to define the practice of non-stationary water management, but no clear consensus has resulted. Methodologies have been developed that attempt to apply institutional or legal mechanisms that create new allocation schemes periodically based on reanalysis periods, such as in the Pangani Basin (Tanzania) or through the EU Water Framework Directive. However, these methodologies are governance mechanisms and do not have a good basis in eco-hydrological science. Climate change remains a conceptual impasse. But an incomplete picture can still provide insights.

Constructing resilience

'Resilience' has associations with climate change and the management of social-ecological systems (whether or not climate is considered with those systems) (Hansen et al., 2003; Folke, 2006; Nelson, 2010). In both cases, the maintenance of ecological 'health' in the context of dynamic change — driven by climate, urbanization, demography, economics, or other forces — is important. Resilience is ultimately a social construction rather than a directly assessable metric for species, populations, communities, or ecosystems.

While we can wait for ecologists and engineers to come to some form of shared vision around resilience, the focus on types of change inherent in the concepts represents a useful approach to resilient allocation as a relatively predictable process (Figure 2) (Wickel and Matthews, 2013). Most non-stationary change is approached as a smooth, steady process, as shown in Figure 2a. In most parts of the world, however, climate variability is increasing, with little or no change in 'mean' climate (figure 2b) (IPCC, 2008). Thus, the frequency and severity of droughts and/or floods are increasing. Resilience in this case is relatively simple to define:

how can an economy, ecosystem, community or piece of infrastructure return to the mean state quickly and efficiently?

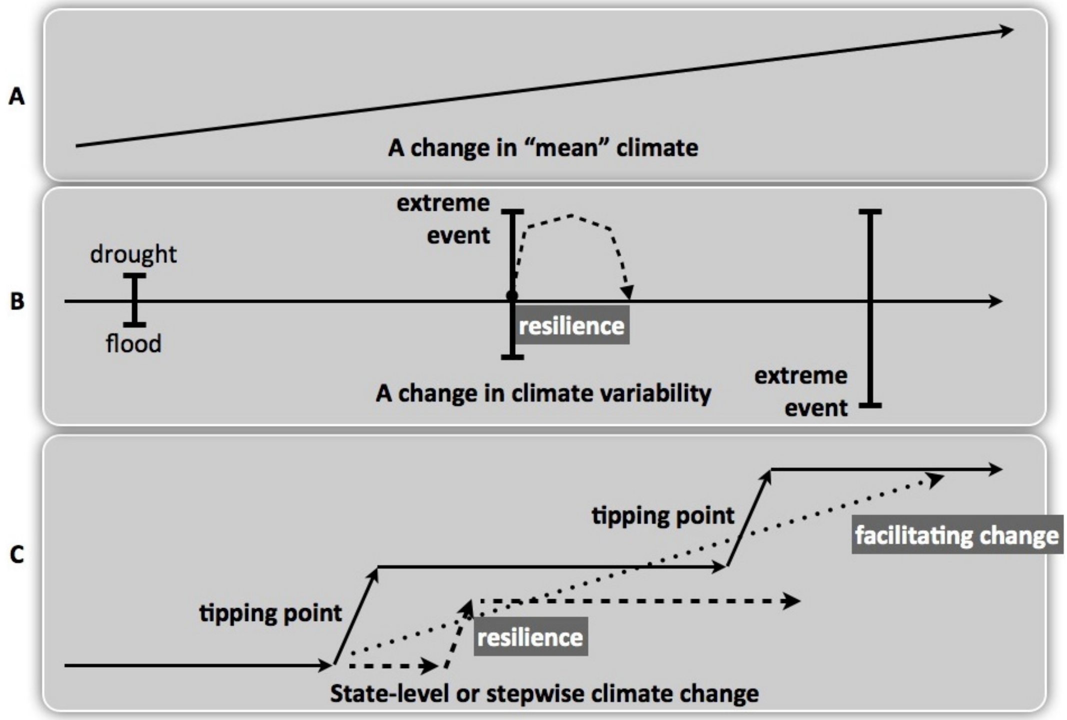

Figure 2: Three types of change, three types of resilience.

Looking over thousands of years of paleohydrological and paleoecological data, however, we can see many examples of what can be called 'state-level' or 'transforming' change (figure 2c). In these cases, a long period of relative stability is followed by a short period of rapid change to a new (and relatively steady) state. These interim periods are often referred to as tipping or transition points. Resilience in this context is different than for shifts in variability. Resilience here could be delaying the onset of a tipping point, reducing the ultimate degree of transformation, or (potentially) facilitating the process of change to some other, future state.

Variability and state-level shifts are not mutually exclusive. Indeed, the paleohydrological record suggests that the former becomes the latter, given enough climate change (e.g. Matthews, 2011). And in some cases shifts in the frequency and severity of hydrological variability can actually fuel state-level change in ecosystems, communities and economies. How many severe floods can a business owner withstand before closing down? How many failed efforts at reproduction before a fish population disappears?

Currently, much of the focus on resilient water management is almost exclusively about buffering or redirecting impacts relative to some past, reference state. As a single strategy, these efforts are unlikely to be successful. We need many types of resilience.

Conclusions

Climate change ultimately represents a new set of choices about how we manage allocation, using aquatic ecosystems as a signal or 'scorecard' for how well we are making both balanced (short-term) and resilient (long-term) choices. Indeed, there may be several types of resilience necessary. For instance, for some types of species or communities, resilience may need to focus on buffering shocks to the system by using water infrastructure as the means of limiting the impacts of extreme events such as super-droughts or super-floods beyond the historic record of variability (Shanahan et al., 2008). For other species or communities, however, the theory and practice of resilience may need to explore transition states such as tipping points and 'flickering' (Taylor et al., 1993; Lenton, 2011; Boettiger and Hastings, 2013). Resilience in these situations may be more focused on delaying tipping points, reducing the extent of transitional states, or even facilitating transitions by building ecological-infrastructure adaptive capacity. A growing body of research suggests that human physical, cultural, and social evolution is driven by shifts in the water cycle, which in turn are driven by climate change (Magill et al., 2012; Tipple, 2013). Where will climate change take us now?

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Economists owe ecology an apology

David Zetland

Back in 2008, I got into a rather heated debate with a fellow economist over US government subsidies to corn ethanol. Ben had graduated from Stanford and worked for the President's Council of Economic Advisers before moving to Cornell University. I had just graduated from UC Davis, and held a postdoctoral position at UC Berkeley. Ben assured me (and the readers of my blog) that "while the environmental benefits from corn-based ethanol are arguably small today, they will only grow in the future." I disagreed on the simple principle that price subsidies distort behavior and produce unintended consequences. Ben's response to my fear was "you are certainly entitled to your opinion, so long as you are comfortable with the fact that yours is based on gut reaction and faith rather than empirical analysis" (Zetland, 2008).

Well it turned out that Ben's empirical analysis was wrong in its estimation of impacts from chosen variables and wrong in its failure to consider missing variables. Corn ethanol may or may not have lowered carbon output, but it's definitely contributed to groundwater depletion, surface water pollution, an enlargement of the dead zone at the mouth of the Mississippi, distortions in global food prices, deviations in land use, and – most recently – claims of engine damage. Today, perhaps the only remaining defenders of America's corn ethanol programme (the subsidy lapsed at the end of 2012, but other laws continue to support production) are agribusiness companies and presidential candidates praising Iowa corn farmers while they eat pie and kiss babies.

How was it that Ben could be wrong about ethanol subsidies, even after he had "spent much of 2006 along with the help of several interns trying to calculate the benefits" of ethanol? How was it that he had come out in favor of a policy, the claimed benefits of which even he was unwilling to give "too much credence"?

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More importantly, was his failure – and the ongoing failure of the ethanol program – a small misstep on the road of 'green growth' or a warning that we may be striding over a cliff?

In this essay, I will expand the discussion beyond corn ethanol and green growth (an increase in economic activity that does not materially harm the environment) to address two substantial defects in how we understand and impact our economy and the ecology. The larger defect arises from a human tendency to simplify the world into 'sensible' concepts that may be inaccurate. Although we might laugh at past versions of this mistake (a flat Earth at the centre of the Universe, the spread of malaria from 'bad air', woman springing from the side of man, and so on), we continue to make this error today when we underestimate the complexity of our human and natural worlds. That miscalculation leads to the second defect in which economists promote theories, observations and prescriptions that fail to include this complexity (or a humble acceptance of it), a problem that worried Adam Smith over 250 years ago:

> *The man of system...seems to imagine that he can arrange the different members of a great society with as much ease as the hand arranges the different pieces upon a chess-board. He does not consider...that, in the great chess-board of human society, every single piece has a principle of motion of its own, altogether different from that which the legislature might choose to impress upon it...[Failure to take this motion into consideration means that] society must be at all times in the highest degree of disorder.*
>
> (Adam Smith, 1759)

This disorder does not just manifest in human affairs (via Stalin, Mao and others); it shows up in natural systems that we neglect and misunderstand. Climate change's unprecedented threat to humans, for example, may have forced our eyes open, but we're not yet wise (Peters et al., 2013; Marcott et al., 2013).

Clever like a fox – or too clever by half?

Over 2,000 years ago, the Greek poet Archilochus wrote that "the fox knows many things, but the hedgehog knows one big thing." This thought can be interpreted to mean that a clever fox changes his strategy with the situation or that a not-so-clever fox may choose an exact – and exactly wrong – strategy when a more general one will do.

In the case of Ben and ethanol, I was the hedgehog who worried that a 'green' subsidy was going to produce unintended but predictably bad consequences. My fear was based on my prior study of agricultural subsidies, all of which delivered failure before promise. Ben, as the fox, thought that he could calculate the benefits of ethanol subsidies amidst many confusing signals, but he was missing the flashing red warning: a lopsided distribution of costs and benefits meant that ethanol subsidies would help some but harm others.

Ben's mistake was – and is – common among economists, and I'm here to apologize for them. Nobody appointed me to this task, and many will object to me talking for economists, but we need to acknowledge that our work has justified and overlooked the substantial preventable harm inflicted on natural systems in pursuit of economic activity – harm that ended up costing us far more than we gained. I'm also no trailblazer in issuing these apologies: a minority of economists have dissented from the orthodoxy of the past 150 years. I'll draw on their theories, observations and critiques before ending with some suggestions of how to attain green growth.

The rise of the machines

Modern economics began with Adam Smith's explanation of market function and the benefits of free trade in The Wealth of Nations (1776). His ideas were strengthened by David Ricardo, whose 1817 explanation of comparative advantage (every person – and every nation – is relatively better at some activity) clarified how trade was both attractive and inevitable. Ricardo showed, for example, that it was better for the English to trade their wool for Portuguese wine than for the English to make wine and the Portuguese to raise sheep. His example contains one explicit and one implicit idea. The explicit one is that the Portuguese could also raise sheep, but they could trade wine for more English wool than they would get producing wool themselves. His implicit point (and perhaps my wishful thinking) is that advantages are only comparative when they reflect the real cost of an activity. It makes no sense for the English to sell their wool at prices that leave their workers unpaid or sheep unfed, just as it makes no sense for the Portuguese to produce wine by draining their lakes or turning their forests into barrels. This short elaboration on comparative advantage leaves us with the knowledge that trade helps people enrich each other 'as if led by an invisible hand' and that traders consider all costs when making deals – including costs that are difficult to measure. Free trade, in other words, can produce sustainable wealth.

The Industrial Revolution that began in the era of Smith and Ricardo put their ideas into widespread use. Markets deepened, trade expanded, and the true nature of costs attracted greater attention. Dickens, Marx and others described the impact of industrialization on workers, London was renamed 'The Smoke', and fossil fuels were burned at record rates, but most people – rich and poor – were too busy pursuing wealth to care about to environmental or social costs. The relative and cumulative impacts of those costs started to bite around World War I, when societies were transformed by total war, the assembly line, Soviet industrialization, and the Great Depression. The fingers of growth no longer caressed the surface of ecosystem and resource reservoirs; they lunged for the heart.

World War II broke new ground in the transformation of society: countries mobilized entire populations, alliances shipped raw and finished materials around the world, and communication networks sped up the beat. National leaders and their minions pushed and pulled levers from the Commanding Heights, and they were aided by the new economics of optimization (Scott, 1998).

Economists had spoken of gains from trade, utility maximization and decreasing marginal returns for decades, but the rise of the mathematical economists with their theories of general equilibrium, game theorists with their closed-form solutions, optimizers with linear programming models, and macroeconomists with their national accounts meant that leaders could now ask economists to design programmes and implement actions that would push economies towards their potentials. They turned to economists like John Maynard Keynes, John von Neumann, Paul Samuelson and others whose theories explained how to use people as interchangeable, calculating 'homo economicus' gears in the national machine.

The trouble was not that these economists were wrong in their understanding of people or their optimizations of production. They admitted as much themselves. The trouble was that they did not anticipate the dramatic consequences of politicians and bureaucrats pushing their ideas to full throttle.

The first unexpected and unwelcome results appeared in the command and control economy of the USSR, where forced industrialization and collectivization led to misery and starvation for millions (Remnick, 1994). The turmoil of the Great Depression and World War II made it difficult to know whether 'scientistic' economic management was helping or hindering nations (debate continues today), but the post-war boom appeared to justify the vision of nations as machines (Hayek, 1942). Americans and Soviets shared that vision as they raced for world domination. Yes, there was prosperity of a sort, but the engine of scientific progress started to shudder and crack – just as some people had predicted for a long time.

Nature bats last

> *When we try to pick out anything by itself, we find it hitched to everything else in the Universe.*
>
> (John Muir, 1911)

> *The economic problem of society is [...] a problem of the utilization of knowledge which is not given to anyone in its totality.*
>
> (F.A. Hayek, 1945)

John Muir and fellow conservationists, environmentalists and ecologists understood the Earth not as a machine to bend to man's will but as a life-supporting organism that reckless humans could damage. They worried about the conversion of wetlands to farmlands, of forests to timber, of rivers to ditches of industrial effluent. Their worries were not based on simple calculations of costs and benefits; they were based on countless observations of the delicate, surprising and endless connections among flora and fauna, rocks and rivers, air and light. They worried that we were harming the ecosystems that supported our prosperity under the dual influences of ignorance and hubris. Economists sympathetic to these views worried that complex human interactions could be mismanaged and damaged like ecosystems. F.A. Hayek, Ronald Coase, Elinor Ostrom and other institutional economists argued against oversimplifying complex systems into reduced-form models and suggested simple policies and limited actions when it came to managing society.

Their humility did not appeal to politicians who liked to direct, bureaucrats who liked to push and pull, or industrialists whose machines rested at the centre of (calculated) national wealth – all of them active managers when it came to manipulating factors and adjusting accounts in a quest to achieve the optimal mix of visible costs and benefits. Machine managers disliked fuzzy, vast conceptualizations of biomes that evolved in chaotic directions; they preferred the mechanisms and flow diagrams of industrial consultants who bestrode the world delivering a future of logic uncluttered by doubt. Sure, they added columns and rows to 'internalize the externalities' in their ledgers, but they could not add what they could not measure.

It was soon clear that the absence of evidence of problems does not equal the absence of problems; unexpected damages pulled expected outcomes off course. Although trouble could be blamed on techno-optimism, national security, consumerism and other forces, economists deserve blame for promoting accounts, models and theories that promised (but failed) to quantify quality of life, optimize human action, and integrate the environment. Not all economists should be blamed for these failures – we'll hear from them below – but the mainstream majority can be. Their dominance and influence drove the process and created a reputation which only some of us deserve but all of us bear. Let's review the charges.

These numbers don't add up

Gross Domestic Product (GDP) was invented during the Great Depression for politicians who wanted to know if their policies were working. GDP as a measure of production has several flaws. First, it only counts payments for goods and services. It does not reflect our work – and pleasure – in the home. A home-cooked meal contributes less to GDP than Happy Meals from McDonalds. Second, its measures are based on prices, not values. An innovation that lowers the price of phone calls, for example, appears to reduce the benefit from calls – and totally misses the greater value of calls on Mother's Day. Third, GDP ignores the benefits of functional ecosystems and grows when unpriced environmental inputs become priced outputs – when water moves from rivers to irrigated fields, for example. Economists know about these measurement problems (Stiglitz et al., 2009), but they cannot prevent the widespread abuse of GDP statistics.

Goddert's Law states that "a measure that becomes a target ceases to be a good measure", and that's what happened with GDP. Politicians claim they will increase GDP – and thus prosperity, happiness and national pride – while their opponents will destroy it. Those claims lead to policy. Why protect an unpriced wetlands when you can convert it into a housing subdivision and boost the economy? Why promote walking to work in 20 minutes when people can buy cars and use gasoline to drive for an hour on highways whose construction costs boost local GDP? There is no GDP value in the unpriced time people spend commuting or the air pollution that results, but there's plenty of GDP value in the (priced) resources burned on the way.

Economists' attempts to improve GDP (adding up the negative impact of excessive congestion delays, for example) failed to clarify costs or improve understanding because those adjustments to GDP – a measure of the flow of goods and services – did not account for the capital depletion of burned fuel that might be valuable in the future, the negative impact of pollution on the capital stock of local and global air quality, and the socially and psychologically relevant fact that an hour spent in congestion free traffic is still an hour lost from either work or leisure. Reasonable people know that the flow of our economic activities is bound to affect stocks – it's not possible to live (or enjoy life) without taking water from streams, cutting a few trees or taking fish from the sea – but there's a difference between reasonable and excessive taking. We may disagree on the appropriate size of these takings, but we can't discuss 'appropriate' without an accurate measure of their level, and GDP doesn't include levels. GDP doesn't help us understand where we are or where we're going – it sows confusion and scrambles priorities

Your inefficient grandmother was onto something

The Folk Theorem of behavioral economics is not named after Professor Folk. It refers to the 'obvious' fact that people are more cooperative when they interact over time – negotiating, trading, rewarding and punishing – instead of just once. This theorem is not, unfortunately, taught to most economics students; even worse, it is ignored in economic research that relies on simple models to 'prove' how people will interact. The Prisoner's Dilemma and Tragedy of the Commons, for example, are related in their dire predictions of how self-interested people who should cooperate will defect, leaving prisoners and the environment worse off (Madani, 2013). These models are often used to justify policies, actions or inactions that make the common man shake his head in wonder. Cooperation on climate change? Nope. Regulation of high seas fishing? No. Sustainable groundwater management? No sir. Starving the poor by sending corn into gas tanks. Sure – they'd do it to us if they could!

I could fill a book with examples of failures to coordinate and address problems that have pushed our lives back towards brutish, nasty and short. These examples cannot be blamed on economists or their theories – humans have suffered from similar problems for ages – but we can blame economists for promoting the idea that miserable outcomes are logical or inevitable. It was Keynes, after all, who spoke of our potentially misleading power:

> *The ideas of economists and political philosophers, both when they are right and when they are wrong, are more powerful than is commonly understood. Indeed the world is ruled by little else. Practical men, who believe themselves to be quite exempt from any intellectual influence, are usually the slaves of some defunct economist. Madmen in authority, who hear voices in the air, are distilling their frenzy from some academic scribbler of a few years back.*
>
> (John Maynard Keynes, 1936)

Economists' focus on single transactions over repeated relations means that we design systems and incentives that emphasize short-term advantage over long-term cooperation, whether it be with other humans, beasts or ecosystems. The irony of these misplaced theories is that humans lacking the wisdom of clever economists often have better relations with each other and their surroundings (Polanyi, 1944; Lansing, 1991). They may have fights and they may be superstitious or poor, but they usually find ways to cooperate in building robust institutions for managing their natural, social and environmental resources (Axelrod and Hamilton, 1981; Lansing, 1991; Ostrom et al., 1994; Henrich et al., 2001; Dietz et al., 2003).

But they were not as rich as we were, right? Didn't that mean that their cultures and systems were inferior and simple? Perhaps, if we compare discrete purchases, disposal and recycling of products but not if we pay attention to the streams of continuous value provided by natural processes and social relations. Should we quantify and monetize ecosystem services and social networks? That cure may be worse than the disease.

Which brings us to a difficult junction. A few people think that humans should do the planet a favor by turning our entire population and civilization into an elaborate compost pile, but most people agree that we should use resources and the environment to improve our lives. The question the majority wants answered, then, is 'how much can we take without harming ourselves?' Economists

– as specialists in getting the most benefit out of scarce resources – have certainly spent a lot of time trying to answer that question. But our tendency to push for efficiency using faith-based numbers and models has led us to use concepts like 'maximum sustainable yield', 'optimal exploitation' and 'the economics of extinction'. These phrases should make us all pause.

What if optimal exploitation turns into unexpected extinction? Should we allow private profits from exploiting a resource that belongs to us all? Will people be smart enough to include a safety margin? If the financial crisis has taught us anything, it's that we should not bet on forbearance over greed. Economists, unfortunately, have sometimes invited greed to join us.

Internalizing externalities but falling off the sustainable path

A.C. Pigou, writing in 1920, proposed that a tax could be levied on activities producing pollution to align private and social incentives. His theory underpins taxes on gasoline, pesticides, cigarettes and other goods that come with negative externalities, but it has problems. First, Pigouvian taxes may be set at the wrong level – the case with gasoline taxes that do not reflect the costs of road damage, local pollution, congestion or climate change. Second, taxes that go to the treasury don't help the victims of pollution. Pigou himself complained that British road taxes were subsidizing new roads instead of maintaining existing roads. Economists, trapped by their limited 'complete' perspective, may have condoned 'socially efficient' levels of hyperactivity.

The same holds for the Environmental Kuznets Curve (EKC) that supposedly describes an empirical (and causal) arc in which the people of poor countries have a limited environmental impact (due to their inability to exploit their environment), the people of middle income countries have a much greater impact due to growth and development, and the people of rich countries have a relatively lower impact due to their ability to spend money on protecting or restoring environments that they now want to enjoy (Grossman and Krueger, 1995). People like this theory because it promises a comforting resolution to the troublesome question of whether we can have both material possessions and a healthy environment and because it fits our images of pristine environments in Congo or Copenhagen and polluted wastes in India and China. But the evidence of an 'inevitable' decline in environmental impacts is weak. Over the past few years, I've read about the lack of improvement in water quality in the US, the EU's reduction in carbon outputs being more than replaced by increases in carbon embedded in imported goods, the increase in population growth (and consequent consumption of resources) in rich countries, and even the significant environmental impacts of delegates traveling to climate change conferences all over the world (Smith and Wolloh, 2012; Davis and Caldeira, 2010; Economist, 2009; Staff, 2012). The EKC is about as likely as a free lunch, but economists aren't getting the bill. Society is.

From razor's edge to Occam's razor

The common mistake in all the examples I've given – GDP, single transaction models, green taxes and the EKC – is economists' assumption that they are capturing and considering all relevant data. This assumption justifies the claim that economics is a social science. That claim is not just imperfect in the data, it's imperfect in its overemphasis on 'scientistic measurement' of complex social interactions that should not be stuffed into models, databases and theories of optimal action (Hayek, 1942). Some economists have tried to include those dimensions, and I'll get to their work in this section, but let's step back for three important observations.

First, we know that resource efficiency and environmental quality vary among places and peoples. Americans drive cars while Dutch ride bikes; there's more pollution in London than Zurich. Second, we should acknowledge that these differences result from past interactions between physical and cultural institutions (formal rules and informal norms). Growth is a priority in China, petrol is taxed highly in the Netherlands, and Americans have spread themselves over a vast area. Third, there's a difference between the 'cover price' and the actual cost of polices, actions and goods. Some choices – as coastal Americans found with Hurricane Sandy –

seem cheap until they are expensive. From the opposite perspective, some ‘free’ goods are worth a lot more than we thought, as we’ve found with the value of a low-carbon atmosphere.

These observations mean that differences in prices, policies and outcomes may just as easily result from calculated decisions as they do from accidental happenstance. We cannot assume that numbers are correct, expected or invited. Keeping this point in mind, is it then acceptable to pursue the growth in particular numbers over other goals? Should we agree with economists such as Simon (1980) who argue that we can solve all of our problems by getting rich first and then using technology to defend ourselves from the blowbacks of growth? It’s not hard to find short-term thinkers who have jumped out of the plane with that parachute, but they’ve taken us with them and the ground’s approaching fast.

Critics ranging from Malthus (1798) to Carson (1962), the Club of Rome (Meadows et al., 1972), and Stern (2007) have argued that the Earth’s ecosystems become unstable and dangerous for present inhabitants once they’ve passed a tipping point, and we’re keeling over from assaults on climate, water resources, biodiversity and other ecological networks in this Age of the Anthropocene (Economist, 2011). We have, in other words, gone beyond GDP accounts, outside the models and into an era in which humanity must live with an environment that’s diminishing and needy instead of thriving and giving.

Humans have made exceptional progress over the past few hundred years, but life is going to get harder for the majority of the world’s population that does not have the institutional, financial and technical resources necessary to replace lost ecosystem services or defend themselves against an increasingly hostile environment (Diamond, 2004; Ridley, 2010; Dolan, 2011). Life for the richer minority is going to be less pleasant: they will lose access to environmental amenities they’ve taken for granted, lose money to protection from natural calamities, and lose sleep over helping the less fortunate or defending themselves against the desperate. Those facts will define a ‘new normal’ for people everywhere, but we have the opportunity to reduce their impact.

Philosophers use Occam’s razor to shave an idea down to its simplest essence (‘salt to taste’, for example), but economists’ razors have been used to rationalize a move to theoretical maximum efficiency that has left us over a real world cliff, wondering if we can scramble back before we plunge into the abyss. Those razors need to be replaced – at least as far as everyday policy is concerned.

The last few sections will sketch out some ideas from economists who have spent time thinking of realistic ways to defend the environment and limit resource consumption while moving on a path towards the traditional economic goal of happiness. Is it the path of green growth or green shrinkage? Who cares what we call it if it's the only path we can take?

Stop counting GDP. Start measuring progress

Some people like GDP as a measure of economic activity, but when's the last time that you made a decision based on GDP? Have you planned a holiday to a country of a certain GDP? Did you quit your job – or get hired – because of a change in GDP? It's hard to think of any use for GDP statistics, other than measuring national pride, generating political noise, or helping traders churn the market. Perhaps those gains have value, but GDP is a costly indicator when it encourages governments to convert unmeasured natural capital into 'products' that raise GDP but impoverish society.

Should we try to make GDP better or just dismiss it? I'm with Bergh (2008), who says that we should give less attention to the narrow measures of growth in GDP and more attention to indicators of progress that matter to individuals: environmental quality, health and education performance, road quality, inflation, and so on. Such a change in focus would allow us to keep behavior within the limits of sustainability without pushing individual activity and growth choices into a framework built on the GDP fetish.

As an example, consider how people adapt and thrive once sustainable constraints are set and remaining resources are allocated by citizens using decentralized markets and price signals. Hayek (1945) argued long ago that such systems did not just move resources to those who can generate the most value from them; he explained how the resulting market prices would help others innovate and maximize benefits from scarce resources. These theories have done a lot more for the environment than any measure of GDP. They've been used to establish markets for SO_2 permits in the US, water in Australia, CO_2 in British Columbia, and so on (Joskow et al., 1998; NWC, 2011; Bauman and Hsu, 2012).

GDP does nothing for sustainability per se (as we saw with the EKC), but market transactions can be sustainable if they are constrained within ecological limits. Who should set those limits? Probably not politicians seeking headlines, businessmen pursuing quarterly profits, farmers maximizing yields, or consumers chasing bargains. Scientists are the natural choice, but they have the opposite bias: they want as much nature, flora and fauna as possible. That's why their recommendations and outcomes need to be compared regularly to socially-acceptable targets (Young et al., 2003). Why don't we do this now? Well, there's sure to be a few people who want to cut down all the trees, but you can bet that most people shy away from sustainable constraints because they've been taught that a fall in consumption hurts GDP and leads to misery, unemployment and national shame. That fall might improve our lives in unmeasured ways, but we wouldn't know, would we?

Weak models for a messy world

A change in accounting could be complemented by a change in the way we describe the underlying relations and actions that connect accounts. As we saw above, many economic models of calibrated, efficient systems are precisely inaccurate because they are based on 'homo economicus' – a stylized caricature of an individual that has been repudiated by psychologists (Kahneman and Tversky, 1979; Taleb, 2007; Ariely, 2009; Kahneman, 2011). Ariely (2012), in fact, shows how Becker's landmark paper on the economics of crime and punishment (Becker, 1968) matches neither the views nor the behavior of criminals and citizens. I know from a 2007 conversation with Becker that he'd probably concede such a point by noting that models are more about discovery than accuracy, but that advice is often forgotten in debates over policy design. We need to remember what Friedman (1953) said: models don't need to be realistic as long as their predictions match real outcomes. Mathematical economists often forgot his condition on the way to their conclusions.

The problem of misspecification within models is made worse by omitting relevant variables. Ecological economists such as Herman Daly, Paul Ormerod and E.F. Schumacher included environmental variables in their discussions of policies and outcomes, but their work did not penetrate mainstream economics. Environmental economists took another tack, to assign or estimate values for the environment and ecosystems, but their results were inaccurate and easy to dispute and ignore (Sagoff, 2012). The same can be said for the failure to properly integrate uncertainty into models (Knight, 1921). Many economists and (much to our regret) financial analysts pretend that unquantifiable uncertainties can be treated as risks whose known probability distributions can be used to calculate optimal (but incorrect) expected outcomes.

But even famous concepts from environmental economics have been abused. Pigouvian taxes supposedly internalize the externalities, but they do not usually correct the distributional imbalances between polluter and pollutee. Coase (1960) argued that polluters and pollutees could agree on compensation for a given level of pollution, while allowing that high transaction costs might prevent such an agreement. So it seems that Pigouvian taxes would be efficient in many-to-many scenarios and Coasian bargaining would be efficient on a one-to-one basis, but it's rare to see Coasian bargaining resolve environmental issues. Why? Coase's decentralized solution relies on property rights and negotiation between those with a material interest in the matter ('standing'), while Pigou's taxes fit within an existing administrative framework in which bureaucrats tax activities adverse to the public interest. This framework has been extended to smother Coasian solutions and abused: activities are not taxed according to their damages to those with standing but according to the power of those who claim to be stakeholders; revenues are spent according to industrial and political lobbying, not harm to individuals or the environment. Pigou's brilliant insights have been debased in support of third-best policies.

From precisely wrong to vaguely right

Some economists reject the idea of an apology, citing the useful contributions that economists have made and the necessity of making a few mistakes on the road to discovering new ideas and refining policies, but these go-getters may be unwilling to slow down and take stock. They may put effort into publishing academic theories (not matter how fragile) instead of explaining economic ideas or debating social progress in public.

Gun manufacturers claim 'guns don't kill people, people kill people', but that sophistry will not save a gunshot victim. Gun manufacturers can rationalize that they want to maximize profits, but economists cannot. We want to maximize utility – human happiness – and that goal requires an accurate and useful integration of human and ecological values. "Yes indeed," say some of the economists who read an earlier draft of this essay, "but why are you distracting people with our internal debates? Isn't it more important that we stop silly ideas from engineers, scientists, lobbyists and lawyers who ignore the tradeoffs and opportunity costs inherent to their hairbrained (or devious) plans for subsidizing corn ethanol, building solar cities in Germany, suing corporations for past legalities, and so on?" Yes, we need to stop these ideas, but we cannot if we lack a reputation for clear and objective evaluations of the social, monetary and environmental costs and benefits of various policies and actions. We need to admit our mistakes and clarify our caveats if we want to claim we are maximizing social welfare.

We've been right many times on the environment. Pigou was right to propose a tax on negative externalities, and modern discussions of carbon taxes descend from his ideas. Economists long ago proposed cap and trade programmes to reduce harmful activities at low cost and markets to move water from farmers to wetlands without the cost of court battles. Malthus and Ricardo worried about the consequences of Manifest Destiny before North Americans coined the phrase for colonizing their continent; they wrote about carrying-capacity and pricing land for its productive value. Where would we be today if early Americans had thought in terms of maximizing long-term yields instead of chewing through resources because there was always more free stuff beyond the horizon?

We've been right when we've kept our advice simple. Yes, it's necessary to coordinate people to resolve collective action problems, but it's not necessary for a central authority to coordinate every detail. Yes, it's important to stay within ecological limits, but it's not necessary to calculate the exact cost, technique or path that respects them. Yes, we need to encourage activities that make us richer, but we don't need to calculate which activities will deliver what wealth to whom.

Politicians and bureaucrats tend to favor large-scale solutions that are easy to describe and visible over smaller, uncoordinated actions that are neither, but their bias towards command and control can result in failure from imperfect planning or failure from corruption or rent seeking (ethanol subsidies helped big agribusiness instead of farmers, the environment or society, for example). Many economists know of these problems, but their unrealistically simplified accounting, modeling and theorizing has delivered false hopes – and dangerous tools – to the wrong people. We need to spend more time warning the public about weak and misused policies and less time pushing the frontiers of fancy econometrics. This change in emphasis may not please researchers, but economic ideas are more likely to justify ill-conceived, harmful policies than ideas from botanists, physicists or anthropologists. It's worth a little inconvenience if we can reduce or prevent harm.

In truth, we know very little about how complex systems work, so it's better to design and use policies that set simple constraints, leave space for mistakes, and leave numerous actors to make uncoordinated decisions with feedback that helps them adjust. Such a system allows politicians to set targets, regulators to prevent disaster, citizens to act freely, and society to progress.

What should we have said about corn ethanol subsidies? Many economists knew they were wasteful handouts to the agricultural lobby, but most of them kept silent as they worked on their academic projects (sometimes supported by the agricultural lobby). Economists like Ben who debated the issue got bogged down in technical discussions of elasticities, substitution effects, trade barriers and the like. We would have had a greater impact if we had spoken out in simple terms: these subsidies are going to cost taxpayer money, push farmers to plant different crops, distort food markets, and intensify the use of environmental and natural resources. And for what? People will drive the same or more; money will shift from large oil companies to large agribusiness companies; and our carbon footprint may fall – or not – because subsidies encourage consumption. Want people to use less carbon? Then tax it. Is that a bad message to send because people don't like taxes? Who cares. It's not our job to be popular. It's our job to be right (with apologies).

The bottom line is that our human economy and natural ecology affect each other. That's not just important for understanding that the economy impacts ecology, it's important for understanding that ecosystems provide invaluable benefits that we will lose in pursuit of short-term economic gains. Economists need to understand that; everyone does.

Acknowledgements

I thank Jeffrey Beall, Lynn Broaddus, Dennis Grzezinkski, Ben Ho, Gorm Kipperberg, Shaw Lacy, Carolyn Lowry, G. Tracy Mehan, Damian B. Park, Laer Pearce, Darius Roberts, John Rosenberg, Jenny E. Ross, Jim Roumasset, Timothy Shah, Alex Trembath, Gábor Ungvári, Michael van der Valk, Jane Wagner-Tyack, Adam Walker, Jay Wetmore and Joel Wood for their suggestions and improvements to earlier drafts. This work was supported by funding from the European Community's Seventh Framework Programme (FP7/2007-2013), grant agreement #265213, Project EPI-WATER 'Evaluating Economic Policy Instrument for Sustainable Water Management in Europe'. All opinions and errors are mine (with apologies to the economists who don't think they need to apologize).

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Things heard in Wageningen

Xavier Leflaive

Introduction

The OECD Environmental Outlook to 2050 establishes that rapidly growing water demands for electricity production, industry and urban supply are likely to come into increasingly acute competition with agriculture for available water in the coming decades. Even radical changes in the efficiency of current uses may not be enough to avoid a more fundamental appraisal of the allocation of water.

OECD governments are gaining experience with innovative approaches to water allocation (such as tradable water rights, smart metering), water reuse, or sustainable water pricing (which includes abstraction charges or licences that reflect scarcity). More needs to be done to properly assess and scale up the use of some of these instruments, to secure environmental values while meeting social and economic needs. Particular attention should be paid to the design and implementation of flexible water allocation mechanisms, which adapt to shifts in water availability and allocation priorities (e.g. by combining water rights reform and pricing policies).

The Wageningen Workshop on Water Allocation and Green Growth provided an excellent and lively setting to explore some of the policy challenges related to these issues, and possible responses.

A subjective selection of things heard in Wageningen

Presentations and discussions at Wageningen confirmed the relevance of allocation as a policy issue. It reinforced some of the

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assumptions on which OECD work relies. It challenged others. The reflections below are a subjective rendering of some of the information gathered during the Workshop.

Optimising vs satisficing

The way in which water is allocated within sectors (for instance, between low-value subsistence agriculture and high-value export-driven crops) and between sectors (ecosystems, agriculture, energy, industry, cities) affects the overall growth of a country and how the benefits of that growth are distributed. In principle, efficient allocation of water requires that the marginal value of water be equal across all uses. There is a range of mechanisms for determining these marginal values in a number of areas through, for example, the use of water markets. Such mechanisms have been implemented in a number of countries and their use is slowly expanding as governments become more familiar with their advantages and implementation challenges.

In practice, it is generally very difficult to define an optimal allocation strategy or purpose that encompasses the full range of water uses. For example, determining the marginal values of water in restoring environmental flows poses significant valuation challenges. As a result, allocation of water resources generally remains a bargaining process, fuelled with divergent and potentially conflicting values.

Two consequences derive from this observation.

First, because values are hardly assessed and compared, it is difficult to define optimal allocation. In a pragmatic approach, participants in the Wageningen Workshop proposed that good allocation is allocation that fits with a development strategy. The greener the strategy, the greener the allocation, as long as allocation mechanisms reliably and effectively translate the initial strategy on the ground. It follows that allocating water for green growth has two features: (i) it is in line with the development strategy; and (ii) it is effective.

Second, allocating water for green growth needs to be flexible, to reflect shifting priorities and to adapt to uncertain water futures.

This is a clear departure from traditional allocation policies, where water is allocated based on first appropriation or riparian rights. Flexible allocation means that water may have to be reallocated, especially in OECD countries, where water is already fully (or even over-) allocated. Workshop participants agreed that flexible allocation should depart from the widespread model of 'disorderly disallocation', which does not create the levels of water security necessary for food and energy security or for business development.

On flexible water allocation

Flexible water allocation brings a lot of operational challenges. In most cases, it works best with accompanying measures, tailored to local issues.

Flexible allocation mechanisms have to be backed by appropriate quality standards and specific infrastructure design and investment. Quality standards allow water to be reallocated where it is 'fit for use'. Infrastructure design for flexible allocation should maximize short-term benefits and minimize the potential sunk costs of infrastructures; infrastructures that scale to needs are a possible response. Such infrastructure design should be backed by investment processes, which postpone technically constraining decisions and the risk of generating sunk costs to the last moment, when reliable information is available on development priorities, future water demand and availability. For instance, real options are gaining increasing attention. However, practical experience with their application for water investment remains limited.

Some OECD countries are gaining experience with socially fair and politically acceptable approaches to water allocation. These include water abstraction licences that reflect scarcity; market mechanisms, e.g. tradable water rights; and information-based instruments (smart metering). Participants at the Wageningen Workshop agreed that, while water trading offers some benefits, it should not be seen as a panacea. Markets are expected to help get water to where it has best productive use, but they assume perfect knowledge and cannot fully account for the uncertainty of how much water will be available to trade in any given year. It is also difficult to accurately predict external costs and the real productivity of water in any given year. Markets can also result in some producers effectively being cut off from supply – stranding assets. Transactions must be legal and registered centrally to ensure the system works. Transparency is required to avoid over-allocation and a wide dispersion of water costs where no one knows how much others are paying. Certain preconditions to water trading also need to be in place, such as separating water rights from land rights. It should be remembered that only a small percentage of water will ever be traded (even in Australia, this only amounts to about 2% of all water) and real benefits will only be felt during periods of drought.

Tools and information requirements

More needs to be done to properly assess and scale up the use of allocation instruments, to secure environmental values while meeting social and economic needs. Experience from OECD and non-OECD countries indicates that process matters: building a strong constituency is an essential element of allocating water for green growth. It can bring coherence to policies that drive green growth and that impinge on water availability and use (land use, agriculture, energy, biodiversity, etc.). The role and limits of the participation of stakeholders need to be defined; some participants made the case for negotiated flow management.

Decisions (on allocation or investment, for instance) will be made under uncertainty. However, several tools (e.g. modelling, scenario development, planning, real options) can be developed, to move 'from uncertainty to confidence' (a phrase borrowed from John Matthews, Conservation International) that the path taken is the appropriate one.

The need to understand how much water is available and how much water is needed means modelling tools are an integral part of creating water allocation policies. Modelling tools for green and blue water will therefore be useful when making allocation decisions (even though modelling green water is intrinsically harder to do). The GTAP model is one such tool presented at the Workshop, which can be used to look at the economic cost of droughts, providing improved insights into the shadow price of water while being able to distinguish where the available water comes from. These models are also useful when adopting Payment for Ecosystem Services (PES) schemes, where monitoring of real impacts is often lacking. IMAGE was another model presented that helps policy makers carry out cost-benefit analyses.

A role for economics

Economic analysis plays a prominent role in allocation processes. It can make the bargaining process more transparent; reveal foregone benefits from misallocation, which are usually unnoticed; analyse distribution issues; and suggest ways to balance social equity, environmental performance, and economic efficiency.

Economic instruments can support dynamic allocation patterns. They are not a panacea, though: they work best in combination with command and control instruments and with voluntary arrangements.

Moving forward

The OECD Environment Directorate is completing a report on water management for green growth (to be released in 2013). The report argues that allocation or, more appropriately, reallocation of water is a major driver for green growth in OECD countries and beyond. More needs to be known on the policy instruments that contribute to this and on the accompanying measures that can facilitate reform of allocation policies and mechanisms.

This will be the topic of further analyses by the OECD over the next two years. The OECD considers building a knowledge base on how member countries allocate water; drawing lessons from the experience of OECD countries with the reform of allocation mechanisms; analysing the role of infrastructures to support flexible allocation mechanisms.

This work will be informed by the discussions that took place in Wageningen, and would benefit from continued cooperation and exchanges.

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