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Resource
Panel

OPTIONS FOR DECOUPLING ECONOMIC GROWTH FROM WATER USE AND WATER POLLUTION

*A report of the Water Working Group
of the International Resource Panel*

UNITED NATIONS ENVIRONMENT PROGRAMME



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OPTIONS FOR DECOUPLING ECONOMIC GROWTH FROM WATER USE AND WATER POLLUTION

*A report of the Water Working Group
of the International Resource Panel*

Preface

Growing demand for water from households, industry, agriculture, and to maintain the health of our environmental services poses rapidly growing challenges for the rational management of this resource. Uncertainty regarding the future availability of water and universal access to it is increasing on all continents. Water (availability/scarcity/management) is one of the top global risks according to the 2015 World Economic Forum Global Risk Report. By 2030, the world could face a 40% shortfall in water supply if no changes are made in how water is managed. The total demand for agricultural products in 2030 is expected to grow by around 60% to meet the demands arising from growing populations and higher incomes.

Water resource management problems are multi-faceted, and cover a wide variety of economic, political and social issues. Some of these challenges can be addressed through sustainable, equitable and efficient governance, which optimizes water use between different sectors and ecosystems and balances current and future needs. This calls for governments, businesses, consumers and other sectors to step up and play an active role in improving management of water resources. In this context, the Sustainable Water Management Working Group of the International Resource Panel (IRP) seeks to offer an original and sustainable approach to water management.

This manuscript is the second IRP report on sustainable water management. The first report in the series provided a detailed account of how a decoupling policy can be measured. It introduced and discussed the analytical methods needed to ensure that water use can be properly quantified over the life cycle and integrated into other measures within the green economy.

This second report draws on the conceptual frameworks developed by IRP research and the existing literature, to provide a conceptual and analytical basis and compelling case for decoupling policy and decision-making in water resource management.

The report explores innovative technological and policy instruments and opportunities to accelerate decoupling and achieve the environmental and economic benefits of increased water-use efficiency and productivity for both developing and developed countries. The possibilities and limitations of these tools and approaches are presented for agricultural, municipal and industrial sectors followed by larger scale system level approaches, e.g., the river basin.

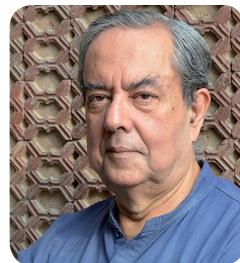
More broadly, it examines the interlinkages between consumption and production, analyzing among other issues, the ways in which global trade affects the geographical distribution of water use and water pollution. Resource and impact decoupling in the water sector is particularly important in areas where water resources are under pressure and pose threats to human and ecosystem health.

Decoupling human well-being from water use and impacts is at the heart of the recently -approved Sustainable Development Goal (SDG) for Water. The contributions of this report are particularly relevant for the implementation of the Water Goal and those Goals related to sustainable consumption and production, and resource efficiency.

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Foreword

Water is essential for healthy human societies and natural environments to thrive and prosper. Yet as the population approaches nine billion, nearly half of those people could suffer water stress by 2030 as a result of accelerating urbanization, new consumption habits and climate change. This report provides option for a viable and sustainable alternative; one that swaps economic growth fuelled by escalating water use and environmental degradation for a more durable model of social, economic and environmental resilience.

If the world continues on its current course, by 2030, annual demand for water in North America and Sub-Saharan Africa could increase by 42 and 283 per cent respectively, compared to 2005 levels. That is why the ambitious 2030 Agenda for Sustainable Development seeks to decouple economic growth from water consumption and pollution by integrating water related issues across each of the 17 goals and making a specific commitment that "*ensures availability and sustainable management of water and sanitation for all.*"

Therefore, this new report outlines the challenges to delivering these goals, while drawing on the many existing success stories to highlight some of the available solutions and provide a scientific assessment of technological and policy tools. Covering agricultural, municipal and industrial uses as well as water systems, these solutions have already proven to be practical and effective, with huge potential for scaling up. The report will help public and private sector decision makers to better understand the strengths and limitations of various approaches, which alone or in combination, could help break the link between escalating water use, economic growth and environmental degradation.

I would like to thank all of the experts at the UNEP-hosted International Resource Panel for the effort and cooperation behind this work. While I cannot mention everyone by name, I would like to say a particular thanks to Kevin Chika Urama, former Executive Director of the African Technology Policy Studies Network, Peter Koefoed Bjørnsen, Director of UNEP-DHI and Kalanithy Vairavamoorthy, Professor at the University of South Florida School of Global Sustainability for their commitment and leadership in this endeavor.



A handwritten signature in black ink, appearing to read "Achim Steiner".

Achim Steiner
UN Under-Secretary-General
UNEP Executive Director



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1 Introduction

This report is one of a series from the UNEP International Resource Panel (IRP) addressing how and whether economic growth can be decoupled from depletion of and damage to natural resources. The report addresses the issue of decoupling with respect to water resources.

The document begins with an explanation of what decoupling is and how it relates to water. It goes on to outline some achievements with regard to decoupling and makes a compelling case for further decoupling due to growing pressures on water resources. It also explores the ways in which global trade affects the geographical distribution of water use and water pollution, which is important for understanding decoupling at different spatial scales. The report then describes in more detail the water resources challenges in terms of drivers for change in demand and availability of water, the role of water uses in the economy, and the dependence on water for human welfare. This section aims to clarify the conditions and the context for potential actions and solutions moving towards decoupling. Finally, a collection of technical and policy tools to achieve decoupling is provided. The presentation of policy tools includes a treatment of equity considerations.

1.1 What is decoupling?

Decoupling refers to the ability of an economy to grow without a corresponding increase in environmental pressure. The terms “green economy” and “green growth” are also frequently used to describe this phenomenon. The 2011 IRP document, “Decoupling Natural Resource Use and Environmental Impacts from Economic Growth” (UNEP, 2011a), introduced the IRP’s position on decoupling. As part of the document, a definition of decoupling was provided that distinguishes between resource decoupling and impact decoupling (Figure 1.1) – and between absolute and relative decoupling.

Resource decoupling exists when economic growth exceeds the growth rate of resource use; in other words, when the economic productivity of resources is increasing. Resource decoupling is important when a specific resource is scarce and its further depletion could frustrate societal progress.

Impact decoupling occurs when the environmental impact of economic activities is reduced. Impact decoupling is important when the use of a resource poses threats to human and ecosystem health.

In the water sector, resource decoupling is important in areas where water resources are under pressure and further depletion poses obstacles to societal progress. In areas where land-use activities disrupt renewable supplies, limiting these activities can also be viewed as resource decoupling if the ease on

water resources is more significant than the loss of economic growth incurred by the land-use limitations.

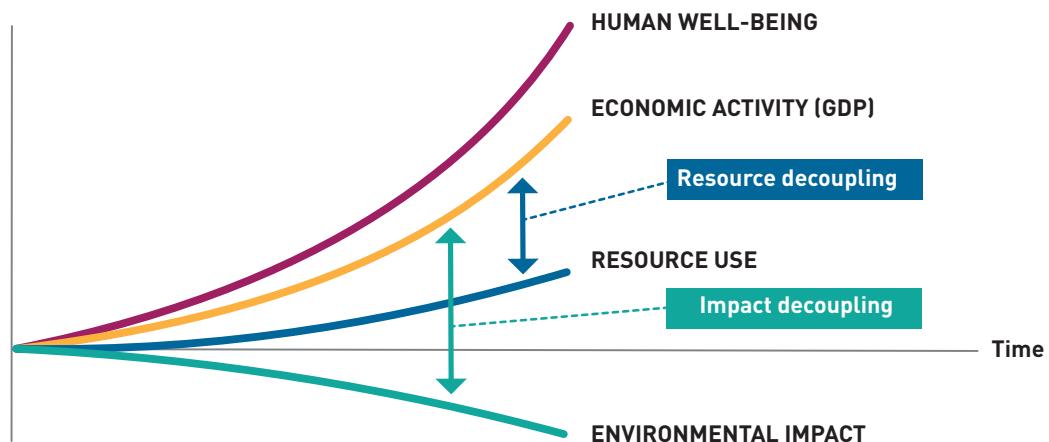
Impact decoupling is important when and where water use poses threats to human or ecosystem health. For example, water use can pose threats to human or ecosystem health both when water is abstracted from the natural environment, disturbing ecosystem functions, and when water is used as a contaminant sink or transport medium for contaminants.

The 2011 document also distinguishes between *relative* and *absolute* decoupling. *Relative decoupling* takes place when the growth rate of resource use or a relevant impact parameter is lower than the growth

rate of a relevant economic indicator (for example, GDP). The association is still positive, but the elasticity of this relation is less than one (Mudgal *et al.*, 2010). The example of resource decoupling presented in Figure 1.1 is an example of relative decoupling, as the rate of resource use is increasing, but at a slower rate than the rate of economic growth.

Absolute decoupling takes place when resource use or environmental impacts decline(s), irrespective of the growth rate of the relevant economic indicator. Absolute reductions in resource use are rare (De Bruyn, 2002; Steger and Bleischwitz, 2009), and can only occur when the growth rate of resource productivity exceeds the growth rate of the economic indicator.

Figure 1.1
The two aspects of “decoupling”



Source: UNEP (2011a)

1.2 Renewable and non-renewable water resources

The distinction between renewable and non-renewable water resources is important because it indicates to what extent resource decoupling with respect to water is needed. Although the hydrological cycle is a closed global mechanism linking all water in the world, the timescale of replenishment of water resources stocks is vastly different for different stocks of water, ranging from days for some lakes to tens of thousands of years for some groundwater stocks. And because water is costly to transport over large

distances, the geographical distribution and location of water resources matter. Therefore, the use of non-renewable water resources presents a more serious pressure and unsustainable use-pattern than the use of renewable water resources and hence makes a stronger case for decoupling.

In this report, *non-renewable* water resources are defined as large stocks of freshwater for which the rate of depletion is out of equilibrium with the rate at which stocks are renewed. In practice, all non-renewable water resources are groundwater resources; large stocks of surface water resources are comparatively rare, and those that do exist, such as large lakes, are generally not perceived as sources of water supply that may be depleted over time (there are exceptions, such as the Aral Sea). On the other hand, about 98% of the world's freshwater resource stocks are groundwater (UN-Water, 2009), excluding polar ice, and in many countries groundwater resources are being depleted at rates faster than they are renewed by the action of the hydrological cycle. When withdrawals are not replaced on a timescale of interest to society, eventually that stock becomes depleted. The water itself remains in the hydrologic cycle, in another stock or flow, but it is no longer available for use in the region originally found.

Renewable water resources include surface-water resources and groundwater resources where the rate of abstraction is in equilibrium with or lower than the rate of renewal through the hydrological cycle. It is important to note that the hydrological cycle and hence the amount of renewable water resources can vary over time and be impacted by a number of factors such as climate change and land-use change as described in a subsequent chapter.



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2 Making the case for decoupling

This chapter first examines the relationship between water use and economic growth in order to assess whether water use is increasing at a slower rate than economic growth in some countries (in other words, whether relative decoupling is already taking place) and which lessons can be learned from the development process. It then goes on to illustrate why we still need to do more and find new and additional ways to decouple water use from economic growth.

2.1 Status on decoupling – lessons learned

Despite the importance of water, many countries have a mixed track record in managing their water resources. With some exceptions, the integrated management of water resources has simply not been a top political priority, and in many cases water supply infrastructures are neither regularly upgraded nor adequately maintained. With few exceptions, many governments have often under-invested in their water resource systems; failed to put in place policies for integrated governance of groundwater supplies and their management and to establish effective market or pricing mechanisms; treated water resources as a public good; and struggled to enforce individual or communal property rights. Moreover, governance reforms to promote innovation

and new technologies for improving technical efficiency in water supply infrastructures and/or governance reforms to improve allocative efficiency and water productivity in different sectors have often been inadequate.

On average, national policy responses to the growing water scarcity have largely focused on expanding supply through substantive investments in water engineering infrastructure such as building large dams, canals, aqueducts, pipelines and water reservoirs. With a few exceptions, in the developed world these solutions are often inefficient and many of them are neither economically viable nor environmentally sustainable. The energy intensity of water, for instance, has been rising due to the lowering of the groundwater table in many areas, the increasing use of desalination processes, and the development of mega-projects for the surface transfer of water (such as China's South-North Water Transfer project, designed to move 45 billion cubic meters of water per year once fully completed in 2050). Water losses through evaporation from conventional water storage devices are also significant. The amount of water lost through evaporation from water reservoirs is higher than the total amount of water consumed in industrial and domestic uses (Shiklomanov, 1999).

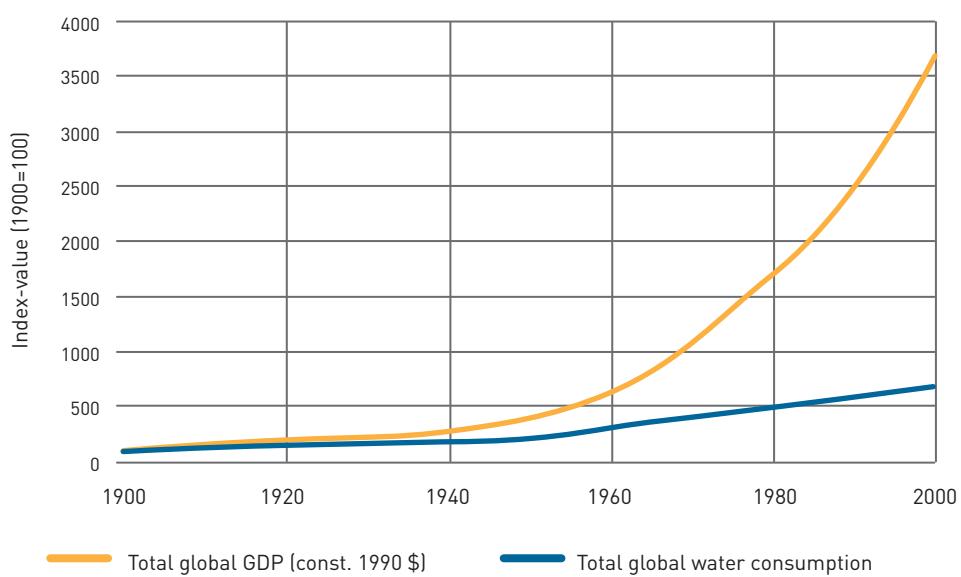
Despite these deficiencies there are indications that some countries have managed to decouple water use from economic growth, at least in a relative sense.

The ratio of domestic water use per GDP growth in most countries has declined since the 1980s (UN-Water, 2009). Between 1900 and 2000 the global economy grew approximately thirty-fold, while global water consumption grew six-fold, see Figure 2.1. By 1995, as a result of efficiency gains in water supply and demand management, total world water withdrawal was only about half what planners had predicted thirty years earlier based on historical trends (Gleick, 1998). Global water intensity of growth fell 1% per annum from 1980 to 2000 (Dobbs *et al.*, 2011). This suggests that, on average, there has been some level of relative decoupling in the water sector in recent times. However, increased rates of

growth in human populations, economic activities, water pollution and inefficiencies in the water supply systems have obscured the marginal efficiency gains in water uses per GDP growth at the global scale over the same period.

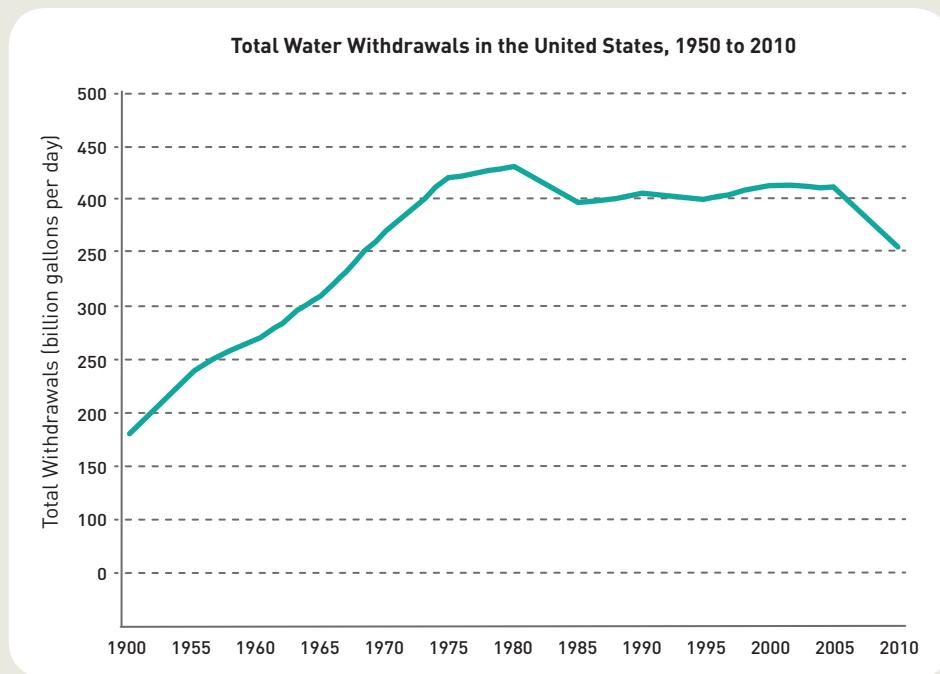
Earlier studies, including Hawken *et al.* (1999) and Gleick (2003), had suggested that some level of relative decoupling was occurring within cities, countries and economic sectors, without factoring in virtual water flows in the analyses. For example, in the USA, total water withdrawals have been almost constant since 1975 (Figure 2.2), despite population growth in the same period, and the economic productivity of water doubled between 1980 and 2005 (Figure 2.3), leading in fact to both relative and absolute decoupling with respect to water use (this does not factor in any changes in pollution of water).

Figure 2.1
Decoupling achieved at global level, 1900-2000



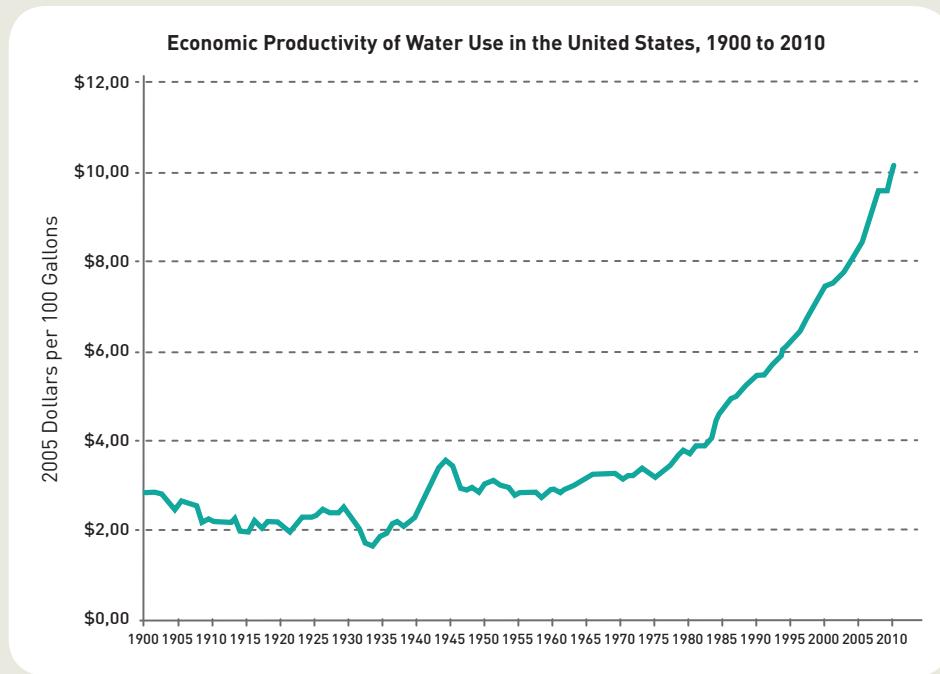
Source: UNEP (2011a)

Figure 2.2
Total water withdrawals in the United States, 1950-2010



Source: Figure prepared by PH Gleick; data from USGS and USBEA, 2014.

Figure 2.3
GDP per volume of water used in the United States, 1900-2010



Source: Figure prepared by PH Gleick; data from USGS and USBEA, 2014.

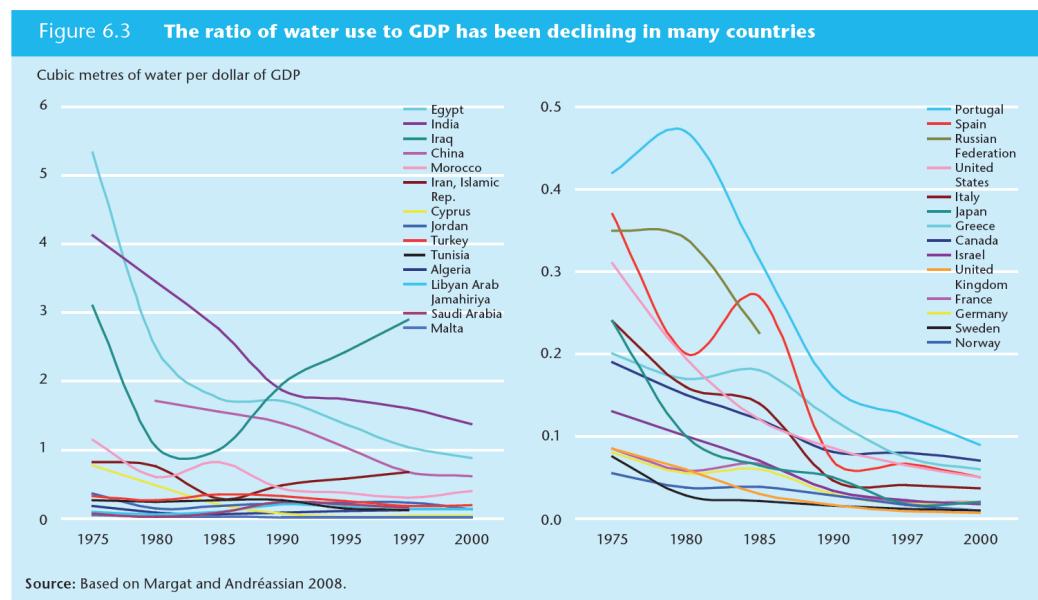
Similar trends are observed in other industrialized countries and some developing countries (Gleick, 2002). Most OECD countries increased their water abstractions over the 1970s in response to demand by the agricultural and energy sectors. Since the 1980s, some countries have stabilized their water withdrawal rates through more efficient irrigation techniques, the decline of water-intensive industries (e.g. mining, steel), increased use of cleaner production technologies and reduced losses from pipe networks (OECD, 2010). In Australia, total water consumption declined by about 40% between 2001 and 2009 while GDP grew by over 30% in the same period (Smith, 2011d); and in China, the rate of water consumption levelled out in the 1980s while GDP growth continued to increase significantly (Gleick, 2003). However, these

achievements in relative water decoupling do not take into account the implications of virtual water trade, including the export/import of water intensive products between countries and regions.

Some developing countries (e.g. Iran, Pakistan, Egypt, Kazakhstan,) have high water consumption rates per unit of GDP, i.e. a high water intensity ratio of their economies. Other developed countries (e.g. Austria, Japan, Norway, Switzerland,) and many developing countries (including Romania, Chile) have a low domestic water consumption rate per unit of GDP.

Over time, the ratio of domestic water use to GDP has been declining in many countries and most significantly in the developed world (Figure 2.4) – a clear sign of the

Figure 2.4
Ratio of domestic water use to GDP in different countries in the period 1975 - 2000



viability of a relative decoupling of water use from economic growth.

There are many success stories from around the world indicating that, if appropriate measures are taken, it is possible to contribute to the decoupling of water use from economic growth. The World Water Council *et al.* (2012) presented lessons learned from 26 case studies (see Figure 2.5) on water and green growth from all parts of the world, selected by an expert committee and focusing on various thematic aspects, viz:

- Ecosystem recovery and water quality improvement;
- Watershed management;
- Policy, planning and governance;
- Financing and public–private partnerships;
- Innovation and technology;
- Infrastructure.

Some of the lessons learned from analysing the case studies include:

- Each country or region needs to select the appropriate tools and policies for its own situation;
- Healthy ecosystems, sufficient water and biodiversity play a critical role as

infrastructure in rural as well as urban areas, where the population and the economy are growing the fastest. The maintenance or restoration of ecosystems should be considered a priority for both public and private investments;

- River or water basin planning is the foundation for designing water policy that reconciles economic growth, the protection of freshwater ecosystems and the creation of jobs linked to the green economy;
- Payment for ecological services (PES) has been identified as a tool used by many sectors, notably agriculture and forestry, to promote the management of land and water resources and provide the necessary incentives for restoring rural livelihoods and for rehabilitating damaged ecosystems. Most of the case studies indicated a high level of cooperation among public and private interests;
- Involvement of communities in green growth programmes will improve the environment and livelihoods, and will encourage social cohesion;
- Good governance in a river basin requires an authority that can coordinate stakeholders with competing demands and allocate water equitably among them, including agriculture, energy, urban water supply and industry.

Figure 2.5

List and categorization of case studies on water and green growth analysed by the World Water Council



A Ecosystem Recovery & Water Quality Improvement

- A1 Green Growth-Based Integrated Water Management
Indonesia (Citarum River Basin)
- A2 Development of Lake District
Republic of Korea (Lake Sihwa)
- A3 Rehabilitation of Urban Estuary as a Green Growth Project
Turkey (Golden Horn, Istanbul)
- A4 Water Quality Management & Wastewater Services
USA (Tualatin River Watershed, Oregon)

B Watershed Management

- B1 Integrated Natural Resources Management in Watersheds (INRMW) Programme
Georgia
- B2 Regional Development & Canal Project
Japan (Aichi Canal)
- B3 Rural Electrification Project (AHREP)
Nepal (Andhikhola River)
- B4 River System Rehabilitation
The Philippines (Las Piñas-Zapote River)
- B5 Basin-Scale Approach to Balancing Power Generation & Ecosystem Restoration
USA (Penobscot River, Maine)

C Policy, Planning & Governance

- C1 Green Growth & Integrated Water Resources Management
Brazil
- C2 Water Planning Towards a Green Economy
Spain (Ebro River Basin)

D Financing & Public-Private Partnerships

- D1 Public Policy of Payment for Environmental Services: A Financial Instrument to Improve Water Quality
Brazil
- D2 Rewards for Watershed Services
Indonesia (Sumberjaya Watershed)
- D3 Payment for Environmental Services Pilot Project
Kenya (Lake Naivasha Basin)
- D4 Public-Private Fund Mechanism for Watershed Protection: Water Funds
Latin America & the Caribbean (Columbia & Ecuador)
- D5 Eco-Compensation for Watershed Services
People's Republic of China

E Innovation & Technology

- E1 Integrated Urban Water Management: Modelling Human Behaviour
Australia
- E2 Recycled Water Scheme: A Best Practice for Industrial & Potable Supply Augmentation
Australia (Western Corridor)
- E3 Role of Technology in Water Quality Improvements
India (Gujarat State)
- E4 Photovoltaic System Floating on Reservoir
Republic of Korea (Hapcheon Dam)
- E5 Nutrient Recovery and Conversion to Fertilizer
USA (Tigard, Oregon)

F Infrastructure

- F1 Sanitation Plan
Chile (Santiago Water Basin)
- F2 Logistical Hotel: A River Transport Project
France (Quai d'Austerlitz, Paris)
- F3 Urban Water Sector Improvement Project
India (Karnataka State)
- F4 Four Major Rivers Restoration Project
Republic of Korea (Han, Nakdong, Geum & Yeongsan Rivers)
- F5 Participatory Irrigation Management
Turkey

Source: World Water Council *et al.*, 2012

2.2 Why further action is needed

The landmark study “Charting Our Water Future” by the 2030 Water Resources Group (2009) argues that if ecosystem water uses are taken into account, a 40% gap exists between projected water supplies and demands in 2030. The projection assumes a so-called “business-as-usual” scenario in which current approaches to water supply development and water management continue. Continuing with the current demand and supply-side efficiency measures such as desalination, irrigation scheduling, reduced waste in the mining sector, and other typical groundwater supply

management approaches will not sufficiently address the gap. Even maintaining historical efficiency improvement levels in the agricultural sector would meet only about 20% of the projected global supply-demand gap. Similarly, business-as-usual supply build-out, assuming constraints in infrastructure rather than in the raw resource, will address only a further 20% of the gap. This leaves a remaining 60% gap to be filled. Therefore, if ecosystem water uses are to be sustained, it is important that further measures be taken to reduce water use and decouple water use from economic growth. Highlights from the 2030 Water Resources Group report include the examples in Box 2.1 below.

Box 2.1 Examples of projected future gaps in water supply/demand and how decoupling could help close the gaps

- India's projected base case water demand-supply gap across 19 major river catchment areas and basins show cost curves ranging from US\$5.9 billion (including annualised capital and net operating expenditures) if the cheapest options are selected, while an infrastructure-only solution would reach an annual expenditure of about US\$23 billion and meet only 60% of the gap. However, 80% of India's water resource gap by 2030 could be addressed by measures to increase crop yields of individual fields, offsetting the need for additional land and irrigation.
- The least-cost conventional option for filling China's water supply/demand gap of 210 billion m³ would cost up to US\$21.7 billion. On the other hand, adopting industrial efficiency measures in water resource use in China would close up to 25% of the water demand gap and lead to labour savings of US\$24 billion by 2030. However, current incentives to adopt water efficiency are low. Hence, China faces the trade-off between diverting businesses' resources to water efficiency measures that may impede growth in the short run yet sustain growth in the longer term, versus supporting unsustainable use of water resources in the longer term, but allowing for greater growth in the shorter term. While the whole of China faces water scarcity challenges, solutions will have to be crafted at the river basin scale. For example, curbing demand and leveraging supply may be sustainable solutions in the Daging basin, while technologies for harvesting green water could be ideal in the Yangtze basin.
- In Sao Paulo, Brazil, the water supply/demand gap by 2030 is up to 2.6 billion m³. The least-cost solution to close the gap requires a net annual expenditure of US\$285 million by 2030. However, Sao Paulo can potentially achieve a net annual savings of US\$28 million by 2030 through a mix of cost effective interventions to improve municipal and industrial water efficiency.
- In South Africa, the water supply/demand gap is up to 2,970 million m³. The analyses show a need for a more integrated approach to closing the gap: investing in cost-effective supply infrastructures (50%); agricultural efficiency and productivity improvements (30%); and improving efficiency in industrial and domestic uses (20%). Overall, improving water productivity could lead to savings of US\$150 million per year by 2030.

On the global scale, historical government expenditure for upstream water supply has been between US\$40 billion and US\$45 billion per annum, excluding distribution costs. However, as demand outstrips cheaper forms of supply, this bill could increase to around US\$200 billion per annum by 2030 (Dobbs *et al.*, 2011). Exacerbating the challenge of finding sufficient supplies of water to meet demand is the fact that water shortages are usually a highly specific local problem affecting areas within a country or even an individual river basin. The costs of transferring physical water resources between river basins are often very high.

To head off looming water resource constraints over the next 20 years requires a package of responses based on decoupling. This could start with improving technical efficiency, enabling production of greater output from the same amount of water resource inputs and pollution, or producing the same output with less water resource inputs and pollution, without increasing the amount of other inputs. This needs to be matched by allocative efficiency to generate a larger total welfare from the available water resources, so that some people can be made better off by reallocating the water resources, without making others worse off. Both these potential responses are discussed in more depth later in the report, taking into account potential rebound effects.

Many countries that have embarked on measures to improve efficiency in water supply and water demand management have also seen significant decoupling in the rates of GDP growth and productivity gains from water withdrawals and water pollution, as described in the previous section. Other studies also show that by using water more efficiently and utilizing the full array of water recycling options, it is possible to reduce the need to construct more dams and

other major water infrastructure such as desalination plants (Avakyan and Lakovleva, 1998). It is of paramount importance, though, that decoupling is seen from a life-cycle perspective (section 5.5.3) in order to avoid 'burden shifting' between the life-cycle stages, the environmental impact categories or geographic regions (see for example: Mekonnen and Hoekstra, 2011; Hoekstra and Mekonnen, 2012).

2.3 International trade and decoupling

The data presented above do not include the impact on water consumption from trade flows of 'virtual water' - water embedded in products and used in their production, particularly in the form of imported agricultural commodities. Due to water's heavy weight relative to its value, it is usually not economically feasible to transport it in bulk over long distances, with the exception of limited schemes for drinking water. Economic growth and increasing international trade in goods and services in the last decades has resulted in increasing amounts of water being traded between countries through flows of virtual water.



Table 2.1 Global water use and virtual water export per sector from the domestically produced goods for the period 1996-2005

Global water use per sector				
	Agricultural sector	Industrial sector	Domestic sector	Total
Global water use (km ³ /yr)	945	38	42	1025
Virtual water export (km ³ /yr)	213	14	-	227
Virtual water export compared to total (%)	23	37	-	22

Source: Mekonnen and Hoekstra, 2011

It is therefore important to assess whether or not the decoupling that may be experienced in domestic consumption is counter-balanced by increased virtual water in the imported goods. Some nations may have achieved a reduction in the domestic water consumption rate per unit GDP through virtual water trade (i.e. by shifting water-intensive production activities onto other countries).

The concept of virtual water (Allan, 1998; 2011) is closely related to the notion of water footprint, which is defined as the amount of water required to produce a product; it is termed 'virtual' because most of it is not physically contained in the final product. Hoekstra and Hung (2002, 2005) began to quantify and calculate virtual water flows and expressing them as water footprints. The methodology evolved to differentiate "blue water" (abstracted from water bodies for human consumptive uses), "green water" (soil moisture evaporated by plants), and "grey water" (a theoretical volume of water required to assimilate pollutants to safe levels) (Hoekstra *et al.*, 2011)¹. Water footprint shares the systems perspective with Life-Cycle Analysis (LCA, section 5.5.3), which makes them useful approaches to highlight the "hidden" burdens of a product, with a focus on water in the case of water footprints

(Boulay *et al.*, 2013). Calculating the water footprint provides the required information, which enables an assessment of the virtual water of products or services that occurs through trade.

The 2012 IRP document, "Measuring Water Use in a Green Economy" (UNEP, 2012), provided a summary of reviews of the virtual water concept. Positive reviews of the concept note that it helps track the export of scarce water resources from water-scarce countries to countries with more abundant water resources, which could be interpreted as a kind of environmental injustice if the loss of abstracted water resources is causing damage to human health or ecosystems in the exporting country. However, more critical reviews note that the export of water embedded in products is compensated by export income, which may have considerable benefits for the exporting country.

In any case, data and information on virtual water and water footprints can be used to inform strategic decision-making on water resources management. Depending on the characteristics and origin of the virtual water involved in traded products and services, trading virtual water may sometimes contribute to decoupling, for example when virtual water involves the sustainable use of a renewable source in the exporting region substituting the unsustainable use of a non-renewable source in the importing region, or it may counteract decoupling efforts under other circumstances.

1. WWDR 3 (2009) defines blue and green water as follows: *Blue water* is liquid water moving above and below the ground and includes surface water and groundwater. As blue water moves through the landscape, it can be reused until it reaches the sea. *Green water* is soil moisture generated from rainfall that infiltrates the soil and is available for uptake by plants and evapotranspiration. *Green water* is nonproductive if evaporated from soil and open water.

3

The water resources challenge

In order to properly address the challenge of reducing water consumption to sustainable levels and achieving decoupling it is necessary to understand what drives the development in water demand and use. This section describes the drivers of water use and how these are expected to lead to increased pressure on water resources in the future. The impacts of water use are then described, including depletion and other associated environmental impacts. Depletion impacts are relevant for resource decoupling while other environmental impacts are relevant for impact decoupling.

3.1 Drivers of the growing water resource challenge

Freshwater withdrawals and water pollution result from human activities in economic sectors, including agriculture, industry and energy, as well as from municipal uses. These are in turn driven by population and economic growth. Government policies, including food and energy security policies, and other factors such as consumption patterns and trade globalization, also contribute to changes in water use (UN-Water, 2015). On top of this comes the added challenge from climate change, which is likely to lead to changes in demand as well as availability of water. Crop water demand, for example, may increase due to increased temperatures, and availability of water may change in a complex geographical pattern, not necessarily coupled to local temperature changes.

3.1.1 Demographic and economic drivers

The following excerpt from the UN World Water Development Report (UN-Water, 2015) describes in a nutshell some of the major drivers of water demand and use emerging from projected growth in population and economic output:

Global water demand is largely influenced by population growth, urbanization, food and energy security policies, and macro-economic processes such as trade globalization and changing consumption patterns. Over the past century, the development of water resources has been largely driven by the demands of expanding populations for food, fibre and energy. Strong income growth and rising living standards of a growing middle class have led to sharp increases in water use, which can be unsustainable, especially where supplies are vulnerable or scarce and where its use, distribution, price, consumption and management are poorly managed or regulated.

Changing consumption patterns, such as increasing meat consumption, building larger homes, and using more motor vehicles, appliances and other energy-consuming devices, typically involves increased water consumption for both production and use.

Demand for water is expected to increase in all sectors of production. By 2030, the world is projected to face a 40% global water deficit under the business-as-usual climate scenario.

Population growth is another factor, but the relationship is not linear: over the last decades, the rate of demand for water has doubled the rate of population growth. The world's population is growing by about 80 million people per year. It is predicted to reach 9.1 billion by 2050, with 2.4 billion people living in Sub-Saharan Africa, the region with the most heterogeneously distributed water resources.

Increasing urbanization is causing specific and often highly localized pressures on freshwater resource availability, especially in drought-prone areas. More than 50% of people on the planet now live in cities, with 30% of all city dwellers residing in slums. Urban populations are projected to increase to a total of 6.3 billion by 2050. Developing countries account for 93% of urbanization globally, 40% of which is the expansion of slums. By 2030, the urban population in Africa and Asia will double.

Excessive water withdrawals for agriculture and energy can further exacerbate water scarcity. Freshwater withdrawals for energy production, which currently account for 15% of the world's total, are expected to increase by 20% through 2035. The agricultural sector is already the largest user of water resources, accounting for roughly 70% of all freshwater withdrawals globally, and over 90% in most of the world's least-developed countries. Practices like efficient irrigation techniques can have a dramatic impact on reducing water demand, especially in rural areas.

Many of the pressures that impact water sustainability occur at local and national

levels, and are influenced by rules and processes established at those levels. Increasingly, however, the rules and processes that govern global economics – investment of capital, trade, financial markets, as well as international aid and development assistance – influence local and national economies, which in turn dictate local water demand and the sustainability of water resources at the basin level.

3.1.2 Climate change as a driving force

A number of changes to the hydrological cycle observed in the recent historical record have been attributed to climate change and these changes are expected to intensify in the future. Although these changes are not a direct result of human use of water resources, it is important to understand the impact of these changes because they will affect the availability and quality of water resources in the future.

The Intergovernmental Panel on Climate Change (IPCC) coordinates the activities of scientists and other researchers around the world to prepare projections of future climate changes and associated impacts. The IPCC releases assessment reports periodically that describe the current state of science regarding projections of future climate and its impacts. The fifth and most recent assessment report (AR5) was released in stages between September 2013 and November 2014 (IPCC, 2014), and projections described in this chapter are based on AR5.

AR5 (Jiménez Cisneros *et al.*, 2014) provides an overview of changes to the hydrological cycle that have been observed in the recent historical record and may be due to climate change. Many of the changes that have been attributed to climate change in the recent historical record include the following:

- Changes in mean surface flows
- Increased flood potential
- Increased evaporation losses due to temperature increase
- Changes in the seasonality of flows, especially in snowmelt basins
- Changes in flows from glaciers due to their retreat
- Decreasing snow and permafrost
- Changes in soil moisture

These changes are predicted to continue under most likely and realistic climate change scenarios. Most of the changes result from temperature increases. Temperature increases impact the hydrological cycle through the following five



mechanisms: changes in the seasonality of precipitation and runoff; increased evapotranspiration; increased moisture-holding capacity of the atmosphere; changes to the buffering capacity of groundwater and glaciers; and changes to the Hadley circulation (the circulation of air from the tropics to the lower latitudes and then back again to the tropics).

AR5 provides projections of future climate change impacts on the hydrological cycle. Because of changes to the Hadley circulation and other causes, climate change is projected to reduce renewable surface water and groundwater resources significantly in drier lower-latitude regions. These changes will impact a substantial proportion of the world's population; for each degree of global warming, approximately 7% of the global population will be confronted with a decrease of renewable water resources of at least 20%. In contrast, AR5 projects that the increased intensity of rainfall events associated with increased temperatures will increase renewable water resources in higher-latitude regions not directly affected by the Hadley circulation.

AR5 also makes projections about climate change impacts on droughts and water quality. Climate change is likely to increase the frequency of droughts in presently dry regions by the end of the 21st century under more pessimistic emissions assumptions. However, there is no evidence of an increase in the frequency of drought in the recent historical record. Climate change is projected to affect water quality through increases in surface water temperatures; increases in sediment, nutrient and pollutant loadings due to heavy rainfall; reduction of dilution of pollutants during droughts; and disruption of treatment processes during sewer overflow events.

3.1.3 Land-use change impacts as a driver

Although surface waters are renewed independently of human actions, many ecological and economic water uses depend on the timing of surface water flows, and land-use changes can disturb natural systems that regulate this timing. For example, land-use changes can disturb runoff patterns when landscapes that retain moisture and delay runoff, such as forests and grasslands, are converted to uses (such as urban land uses) that impact these functions. Land-use change may also disrupt groundwater recharge and therefore contribute to the conditions where groundwater depletion takes place. Continued population growth and urbanization are factors that are likely to act as drivers for land-use changes that in turn are going to impact the hydrological cycle and water availability.

3.2 Impacts of water uses

This section describes the resource impacts of water uses in various sectors. These are the impacts that will be felt and exacerbated if decoupling water use and economic growth is not properly addressed.

In the discussion that follows, it is important to note the difference between total water withdrawals and water consumption. Water demand is measured in two ways: withdrawal and consumption. *Water withdrawal* is actual water abstracted for agricultural, industrial, or municipal use. However, some of the water withdrawn flows back to the basin (return flows) and could be available for downstream use. *Water consumption* refers to uses of water that make that water unavailable for immediate or short-term reuse within the same watershed. Such consumptive uses include water that has evaporated, transpired, been incorporated

into products or crops, heavily contaminated, or consumed by humans or animals. Less than 5% of total water withdrawals for the municipal sector are for consumptive uses, while consumptive use rates are much higher in the agricultural sector.

3.2.1 Municipal water use

The municipal sector describes water use for consumption in households and other domestic settings. Municipal water use also includes water use in commercial settings such as offices and restaurants. According to the 2015 World Water Development Report (UN-Water, 2015), municipal withdrawals account for about 12% of total withdrawals worldwide.

Considerable amounts of water are abstracted by the municipal water supply sector to meet household needs, including drinking, washing, cleaning, bathing, flushing toilets and landscaping. Although much water that is abstracted for domestic purposes is returned to natural waters, it is not always practical to reuse domestic return flows because of water quality concerns or because of costs associated with conveying return flows to entry points to the supply system. In addition, in areas where a considerable portion of domestic water use is used for landscaping, return flows can be significantly smaller than abstracted amounts due to evaporation and transpiration. Population growth will increase water demand in the municipal sector, and urbanization and economic growth without decoupling will also contribute to changes in municipal demands.

In addition to anticipated growth in population, rapid urbanization will aggravate the problem of water scarcity. By 2050, approximately 800,000 new urban residents will be added every week to existing and new cities around the world (USCB, 2011). The ratio of the world population living in cities is expected to increase from 50% in 2010

to 60% by 2030, while population in urban centres will grow at an average of 2.3% per annum with a doubling time of 30 years. This growth will take place particularly in smaller cities and towns in lower- and middle-income countries (USCB, 2011).

With urban centres as catalysts of economic growth, it is expected that urbanization and the associated increase in standards of living may increase the demand for water (UNFPA, 2007; World Bank, 2009). Changing consumption patterns associated with economic growth, such as larger homes, can increase municipal water consumption. Economic growth can also increase demand for water-intensive agricultural and industrial products, as described in the next section.

3.2.2 Agricultural water use

Water use in the agriculture sector includes water for irrigation and livestock, although water use in the sector is overwhelmingly for irrigation of agricultural crops. The agriculture sector accounts for 70% of water use worldwide. Irrigation plays an important role in food production; irrigated crop yields are estimated to be on average 2.7 times rainfed crop yields (UN-Water, 2012).

Although the agricultural sector accounts for the largest percentage of water abstraction worldwide, part of the water abstracted for use in the sector returns to surface water bodies as return flows or else percolates to groundwater (Rogers *et al.*, 2006). However,



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Figure 3.1

Global distribution of land equipped for irrigation, percentage of cultivated land and percentage of groundwater irrigation

Continent / Region	Equipped area (million ha)		As % of cultivated land		Of which groundwater irrigation (2009)	
	1970	2009	1970	2009	Area equipped	As % of total irrigated area
Africa	8.4	13.6	4.7	5.4	2.5	18.5
Northern Africa	4.4	6.4	18.4	22.7	2.1	32.8
Sub-Saharan Africa	4.1	7.2	2.6	3.2	0.4	5.8
Americas	26.6	48.9	7.2	12.4	21.6	44.1
Northern America	20.0	35.5	7.5	14.0	19.1	54.0
Central America and Caribbean	0.9	1.9	7.8	12.5	0.7	36.3
Southern America	5.7	11.6	6.3	9.1	1.7	14.9
Asia	116.2	211.8	23.3	39.1	80.6	38.0
Western Asia	11.0	23.6	17.8	36.6	10.8	46.0
Central Asia	8.1	14.7	15.3	37.2	1.1	7.8
South Asia	45.0	85.1	22.8	41.7	48.3	56.7
East Asia	42.9	67.6	37.7	51.0	19.3	28.6
Southeast Asia	9.1	20.8	12.5	22.5	1.0	4.7
Europe	15.1	22.7	4.6	7.7	7.3	32.4
Western and Central Europe	10.8	17.8	7.4	14.2	6.9	38.6
Eastern Europe and Russian Federation	4.3	4.9	2.3	2.9	0.5	10.1
Oceania	1.6	4.0	3.5	8.7	0.9	23.9
Australia and New Zealand	1.6	4.0	3.5	8.8	0.9	24.0
Pacific Islands	0.001	0.004	0.2	0.6	0.0	18.7
World	167.9	300.9	11.8	19.7	112.9	37.5

Source: FAO, 2010b

a significant portion of water abstracted is used for transpiration by crops or else is lost through evaporation from the soil surface. The next chapter addresses ways to reduce long-term groundwater depletion through technological solutions that reduce evaporation and transpiration.

FAO projects that global food production will need to increase by 40% by 2050 (FAO, 2009). In many parts of the world, irrigation makes an important contribution to agricultural productivity; irrigated agriculture provides

40% of the world's food from 20% of the cultivated area. For example, in Pakistan, China and India, irrigated land covers 80%, 35% and 34% of the cultivated area respectively (FAO, 2010a). For a regional distribution of land equipped for irrigated food production, see Figure 3.1. Because of the role of irrigation in food production, projected increases in demand for food production highlight the importance of resource decoupling in areas where dwindling resources of groundwater are the primary source of irrigation water supply.

3.2.3 Industrial water use

The industry sector includes water uses that are part of the production of industrial products. The industry sector also includes water uses in energy production, such as for thermal cooling. The sector accounts for 19% of water use worldwide, although the percentage can be much higher in industrialized countries.

In many developed countries, the industrial sector is responsible for the largest percentage of freshwater abstraction (up to 59%). In developing countries, industry is the second largest water user after agriculture, accounting for 10% of freshwater abstraction (2030 Water Resources Group, 2009). Industries

use freshwater from both surface and groundwater sources. In the USA, for example, the majority of industrial water abstraction is from freshwater sources of which 83% comes from surface water sources and 17% from groundwater (Kenny *et al.*, 2005). The Pan American Center for Sanitary Engineering and Environmental Sciences (2003) reported that in the last 100 years freshwater abstraction by industry and commercial sectors grew forty-fold, a higher rate than GDP. Industrial water use is often characterized by linear flows in which water is extracted, used and then disposed. Water use in each industrial production line is considered separately, resulting in very low rates of water reuse and recycling. This, in turn, leads to high rates of abstraction creating gaps between abstracted amounts and actual water needs.

About 22% of supplied water is used in industries (though this is as high as about 60% in industrialized countries and less than 10% in some developing countries), and about 8 -11% is for domestic use (averaging about 50 litres/person/day, though with great variability) (Comprehensive Assessment of Water Management in Agriculture, 2007; Gleick, 2010).

Water is also consumed indirectly in the form of water embedded in products, also referred to as virtual water, as mentioned earlier. Virtual water is then considered in the context of nations responding to domestic water scarcity by importing water-intensive goods (e.g. food) from regions where water is less constrained. A big part of this virtual water is already accounted for in the figures mentioned above (e.g. 70% of the water used in agricultural irrigation), although rainwater used by crops is also accounted for, and this is not usually included in the national statistics.



3.3 Dependence on water

In addition to using water as a commodity in various sectors, as described above, human societies depend on water being present in adequate quantity and quality in many complex and interlinked ways. When addressing water resources management and decoupling challenges, it is important that those dependencies are known and considered before choosing the technological tools or policy measures to address the issue at hand. This section highlights some of the key dependencies between human welfare and water resources that need to be considered.

3.3.1 Water use and welfare

As described in the introduction, water use can impact human welfare in two ways: 1) through the depletion of non-renewable water resources and 2) through human health and ecosystem impacts resulting from water use. The first type of impact results in the need for resource decoupling, while the second results in the need for impact decoupling. Water use can impact on human or ecosystem health both when water is abstracted from the natural environment, disturbing ecosystem functions, and when water is used as a contaminant sink or transport medium for contaminants.



On a global scale, water withdrawals have grown from about 600 billion cubic meters in 1900 to 4,500 billion cubic meters in 2010, almost twice the growth rate of the human population. According to 2030 Water Resources Group (2009), under an average economic growth scenario and if no efficiency gains are assumed, global water demand would grow to between 6,350 and 6,900 billion cubic meters by 2030. This represents a 40% demand gap compared to currently accessible water resources, including return flows.

The expected increases in demand for water withdrawal for human activities by 2030 show significant regional differences. The highest incremental demand between 2005 and 2030 is expected to occur in sub-Saharan Africa (283%) and the least in North America (43%) (Table 3.1).

Table 3.1
Increases in Annual Water Demand, 2005 – 2030

Region	Projected Change from 2005
China	61%
India	58%
Rest of Asia	54%
Sub-Saharan Africa	283%
North America	43%
Europe	50%
South America	95%
Oceania	109%

Source: 2030 Water Resources Group, 2009

The demand for water to increase agricultural output is likely to account for 65% of incremental water demand; growth in water-intensive industries for an additional 25%; and domestic demand for the remaining 10%. Scenarios suggest that agricultural demand will be most intense in

India and sub-Saharan Africa, while China may account for the greatest growth in industrial use (Dobbs *et al.*, 2011).

Water scarcity can be induced by an interrelated mixture of economic, social, institutional and environmental factors that will be discussed briefly in subsequent sections of this report. Lakes in many parts of the world, including Naivasha in East Africa, Chad in Central Africa, Balkhash in Central Asia and Superior in North America, are shrinking or losing much of their water (UNEP, 2015). Rivers such as the Colorado in the United States and the Yellow in China often fail to reach the ocean because of overconsumption of their water (Dobbs *et al.*, 2011). Reports already show that river basin closure (i.e. when supply of water falls short of commitments to fulfil demand in terms of water quality and quantity within the basin and at the river mouth, for part or all of the year) is an anthropogenic process and manifests at societal as well as ecosystem levels (Molle *et al.*, 2010). Humans are also overexploiting groundwater in many large aquifers that are critical to agriculture, especially in Asia and North America (Gleeson *et al.*, 2012).

It is now estimated that up to one third of the world's population is currently subject to water stress (those with less than 1,700 cubic meters of renewable water per capita annually), and if nothing is done to change present levels of water consumption and water pollution about half of the global population will live in areas of water stress by 2025 (UN-Water, 2009, Commission on Climate Change and Development, 2009). The majority of the water-stressed population in 2025 will be in sub-Saharan Africa and South Asia (UNDP, 2006). The OECD estimates that by 2030 nearly half of the world's population (3.9 billion people) will live under conditions of severe water stress (i.e. when the ratio of total water use to renewable supply exceeds 40 per cent) (Figure 3.2).

When people do not have access to water, either large amounts of their disposable income have to be spent on purchasing water from vendors or large amounts of time have to be devoted to carting it, in particular by women and children. This erodes the capacity of the poor to engage in other activities necessary to escape poverty (e.g. attending school or employment) (UNEP, 2011b). Something similar happens when water is available but of poor or non-secure quality, and bottled water is introduced taking a significant amount of domestic income.

3.3.2 Water pollution and welfare

Deterioration in water quality due to pollutant loadings in water bodies is already limiting available water resources for economic activities and sustainable ecosystem services in many river basins.

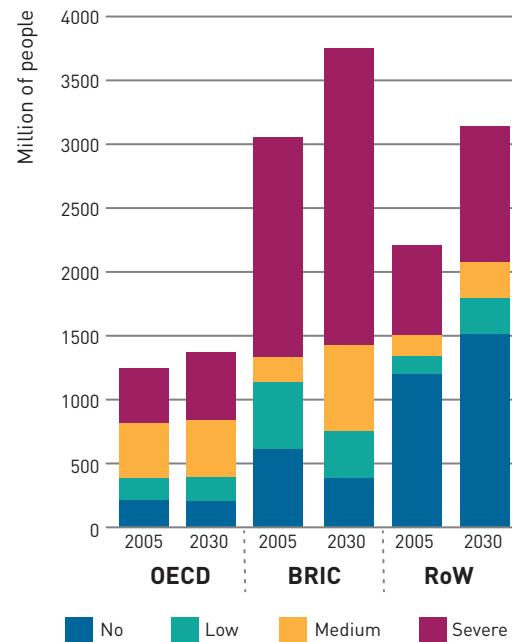
Major water bodies in various parts of the world are now seriously polluted due to a large variety of pollutants. A few examples are: eutrophication in the Baltic Sea, Aral Sea, Yellow Sea, Bohal Sea, Congo basin, Gulf of Mexico and Lake Victoria, caused largely by nitrogen and phosphorus runoff from agricultural lands; suspended solids in the Caribbean Sea, Aral Sea, and Lake Victoria; radionuclides in the Benguela Current and Pacific Islands; oil spillages in the Caribbean Sea, Bohal Sea and the Benguela Current; solid wastes in the Congo Basin, Benguela Current and Pacific Islands; dangerous chemicals in the Aral Sea and the Benguela Current; and microbial organisms in the Gulf of Mexico and Lake Victoria.

Agriculture, mining activities, landfills and industrial and urban wastewater effluents are the most relevant sources of water pollution. Agricultural activities contribute the largest quantity of pollutants to water bodies in the United States and in many developing countries (UN-Water, 2009).

The main pollutants from agriculture include pesticides, nutrients (from fertilizers) and organic compounds that end up in water bodies (Schwarzenbach *et al.*, 2010). Excess runoff of nitrogen fertilizers from croplands is leading to eutrophication and ultimately to extensive “dead zones” around many of the major river deltas of the world, where aquatic life cannot be supported due to depleted oxygen levels. A recent study by Perlman (2008) recorded 405 dead zones in the coastal zone worldwide, representing a more than 100% increase over the past 5 years.

In the industrial sector specifically, 70% of industrial wastes are dumped untreated into waters (UN-Water, 2009). In Karachi, the Lyan River, which runs through the city, has become an open drain of sewage and untreated industrial effluent from some 300 large, medium and small industries; in Shanghai about 3.4 million cubic meters of

Figure 3.2
Number of people living in water-stressed areas in 2030 by country type.
The colour scale shows the degree of stress.



OECD, 2008 in UNEP, 2011b



Hanoi Photography/Shutterstock.com

industrial and domestic waste has resulted in the Suzhou Creek and Huangpu River becoming lifeless water bodies (Helmer and Hespanhol, 2011). Mining industries are also major sources of pollutants, producing about 35.4 million metric tons of waste per year (Schwarzenbach *et al.*, 2010). Large-scale mining industries are regulated in many countries. However, significant amounts of pollutants from artisanal mines end up in water bodies, especially in developing countries where regulatory institutions are weak and the law is not correctly applied.

In urban areas of developing countries, the lack of adequate attention to sanitation and wastewater treatment are major sources of water pollution. In many countries, 85%–95% of sewage is discharged directly into rivers, lakes, and coastal areas (UNFPA, 2007). In China, the percentage of surface water declared to be of non-useable quality increased from 18% in 2002 to 22% in 2006. The percentage of surface water of sufficient quality for use as potable drinking water also declined from 65% in 2002 to 58% in 2006 (2030 Water Resources Group, 2009).

Globally, water pollution and the increasing amount of water withdrawal have constrained the potential of the water bodies to properly function as sinks and/or sources of the ecosystem services required for sustainable livelihoods on earth. Polluted groundwater is causing significant health problems for millions of people in both developed and developing countries (Twarakavi and Kaluarachchi, 2006; Mukherjee *et al.*, 2006; Moe and Reingans, 2006). About 1.4 million children under five die annually as a result of lack of access to clean water and adequate sanitation (UNICEF, 2004).

Water-related agents make up 4% of the global disease burden (Ezzati and Lopez, 2003); and water-borne diarrhoea is the third most common cause of child mortality in West Africa. These have far-reaching implications for labour productivity in the agricultural sectors (Urama, 2003; Urama and Hodge, 2007). Examples of the annual economic impact of inadequate sanitation include approximately US\$6.3 billion in Indonesia, US\$1.4 billion in the Philippines, US\$780 million in Viet Nam and US\$450 million in Cambodia (World Bank, 2008; Tropp, 2005). When water supply and sanitation services are inadequate, large amounts of revenue are spent dealing with the impacts of water-borne disease rather than generating new wealth (Tropp, 2005). These call for a far greater effort to promote impact decoupling.

3.3.3 Flooding and welfare

While water shortage is a major problem, excess water can sometimes be more damaging, at least in the short term, with floods causing a significant and growing economic and social problem in many parts of the world. Floods and

droughts are increasing in frequency in every region (UN-Water, 2009; Dirmeyer, 2011). Of all observed natural and anthropogenic hazards, water-related disasters are the most recurrent and pose major impediments to achieving human security and sustainable socio-economic development. During the period 2000 to 2006, the EM-DAT database recorded a global total of 2,163 water-related disasters (EM-DAT, 2005), killing more than 290,000 people, affecting more than 1.5 billion people and inflicting more than US\$422 billion in damages. Comparing data for scarcity-related disasters (i.e. droughts) with flood-related disasters during the period 1986-2006 indicates that 41% of fatalities came from drought, 20.1% from windstorm, 19.9% from wave and surge and 13.4% from flood (Adikari and Yoshitani, 2009).

Factors such as climate variability, inappropriate land management policies, population growth and inadequate human settlements have led to increased water-related disasters. The number of people affected by such events increased substantially between 1980 and the end of the twentieth century, and water-related economic costs increased even more (UN-Water, 2009). The number of those affected by water-related disasters globally dropped from 1 billion to about 420 million between 2003 and 2006. This is attributable to the increased capacities of early warning systems in water-disaster prone regions during the past decade. On the other hand, the total damage went up sharply from 2001-2003 (approx. US\$90 billion) to reach US\$300 billion in 2004-2006. Unless preventive efforts are stepped up, the number of people vulnerable to flood disasters worldwide is expected to reach two billion by 2050 (Bogardi, 2004).

4

Technological innovation and decoupling

This chapter provides an overview of how technological innovation may contribute to decoupling in the water sector. Technological solutions with the potential to contribute to decoupling are described for the agricultural, industry and municipal water-supply sectors. Systems-level technological solutions are also presented. Obviously, the tools described here are not an exhaustive collection of all those available (such a list would be constantly changing as new technologies are developed), but they provide a broad introduction to some of the best-known and documented tools.

4.1 Agricultural sector

This section describes technological solutions with the potential to reduce depletion of non-renewable water resources and to reduce the environmental impacts of water use.

4.1.1 Efficient rainwater management

The largest source of water for agricultural production is rainfall, not irrigation. Precipitation, which is part of “green water”, accounts for about 80% of agricultural water use, and rain-fed agriculture systems (which do not make use of irrigation) account for 60% of the world’s food production (FAO, 2007). Rainwater-use efficiency in agricultural systems is 35–50%, up to 50% of

the rainwater falling on crop fields being lost as non-productive evaporation, which entails evaporation of free water from soil and leaf surfaces (Rockström and Barron, 2007).

Innovations that improve rainwater-use efficiency in agricultural production include micro-dams, terracing, rainwater tanks and flood diversion approaches. These technologies are used to collect surplus water falling as rain and channel runoff to areas where it can be applied to crops. These techniques can also contribute to groundwater recharge. Efficient rainwater management systems can provide additional benefits by helping to reduce losses of plant nutrients and soil organic matter through erosion.

Efficient use of rainwater in agriculture can have impacts on surface water hydrology. For example, along the Yellow River, water conservation structures have been effective in conserving rainfall and reducing erosion, but these practices have also reduced river discharge (Falkenmark and Rockström, 2004).

4.1.2 Efficient irrigation delivery systems

Efficient water distribution technologies, such as sprinklers, can reduce water abstraction by 30% compared to the conventional irrigation technologies (Weizsäcker *et al.*, 2009). Field experiments in India, Israel, Jordan, Spain and the United



States have shown that drip irrigation systems that deliver water directly to crop roots can reduce water abstraction by 30% to 70% and raise crop yields by 20% to 90% (Qadir *et al.*, 2007). Some of the reduction in water use achieved using sprinkler and drip irrigation systems is the result of reduced surface evaporation. These systems can also be automated and monitored using computerized systems, ensuring maximum efficiency with precise water application (Weizsäcker *et al.*, 2009). Installation costs, operation costs (mostly energy consumption) and other technical operations requirements have limited the application of drip irrigation technologies; for example, India and China use drip irrigation on just 1% to 3% of irrigated land, while the United States incorporates drip irrigation on only 4% of its land (Weizsäcker *et al.*, 2009). However, water savings are often used in certain cases to expand irrigated acreage instead of releasing water to the environment. A decrease in infiltration of return irrigation flows also reduces water availability to other farmers downstream previously dependent on them. Finally, if water use is not optimized, the return irrigation water may be saline and heavily loaded with nutrients.

4.1.3 Deficit irrigation

Deficit irrigation can be used to increase water productivity in water-scarce areas. Deficit irrigation describes an irrigation strategy in which water application is reduced to an amount that is less than the amount required to meet full crop transpiration requirements. Because the resulting reduction in crop yield is often less than the reduction in applied water, this can be an efficient strategy for reducing consumptive water use in some situations. For example, supplying 50% of full crop water requirements may reduce yields by only 10% to 15% for some crops. Deficit irrigation is carried out using various strategies including reducing the depth of irrigation, refilling only part of the root zone, increasing the interval between successive irrigations, and wetting furrows alternately or placing them farther apart (Ali and Talukder, 2008). In rice cultivation, as an alternative to maintaining 3-5 cm standing water continuously in the field, application of irrigation after 3-4 days of disappearance of ponded water (also termed as alternate wetting and drying) leads to 20% to 30% water saving without significant yield reduction (Ali and Talukder, 2008).

Optimal sequencing of water deficits reduces the impact on yields and increases water productivity. These irrigation strategies are broadly applicable to many crops.

4.1.4 Irrigation scheduling

So-called “smart” irrigation scheduling provides a means to evaluate water needs in real time and then schedule irrigation applications to maximize yield benefits (McCready *et al.*, 2009). The California Irrigation Management Information System (CIMIS) is an example of using such irrigation systems to provide timely information to growers and landscape irrigators about the water demands of their plants and the likely climatic conditions facing them. With this information, farmers can make better decisions about when, where and how much to irrigate, reducing overall irrigation water needs, increasing crop water productivity and saving money. A recent independent assessment of the programme suggested that growers using CIMIS have reduced water use on their lands by an average of 13% and have increased yields by 8% (Weizsäcker *et al.*, 2009).

4.1.5 Drainage infrastructure

Drainage infrastructure systems are used in irrigated agriculture to collect, treat (if necessary) and dispose of applied irrigation water that has percolated through the root zone and into the groundwater table. Drainage systems are used to prevent waterlogging of soils, which can take place when irrigation water that percolates to the root zone causes the underlying water table to rise. Drainage systems also assist with salinity control. Because all irrigation water contains some dissolved salts, these salts accumulate over time in the root zone and must be removed by applying excess irrigation water in what are called leaching operations; drainage systems are then needed to remove leaching water, which would otherwise accumulate

in the underlying groundwater. This water, however, is generally disposed of into rivers or infiltrated, which may lead to loss of usable water resources. Improved drainage can increase the efficiency of leaching, reducing the need to abstract water to carry out these operations.

4.1.6 Agricultural land management

Changes to agricultural land management can improve crop yields, thereby improving water productivity. Land management actions can also increase soil moisture storage capacity, raising the efficiency of rain-fed agriculture. Improving soil fertility, such as by increasing soil organic matter (involving the application of more organic-rich fertilizers and mulches, less or no chemicals, artificial fertilizers and pesticides), is an effective way of improving soil water-holding capacity. The organic matter also results in more efficient water use by releasing water slowly, which facilitates proper crop growth and thus increases yield and water productivity (Evans and Sadler, 2008). Other land management practices, such as improved or suitable crop rotation, crop density, mulching, weed control, pest and disease control and water conservation measures (Raza *et al.*, 2011), will also enhance the soil productivity. In sub-Saharan Africa, doubling or tripling yields is quite feasible with improved tillage and supplemental irrigation (Rockström *et al.*, 2003).

The 2030 Water Resources Group’s report “Charting Our Water Future” (2009), presented evidence that much of the projected increase in agricultural water demand in India could be eliminated simply through efforts to improve crop yields. Up to 80% of the projected gap between supply and demand in 2030 could be addressed by measures to increase crop yields of individual fields, offsetting the need for additional land and irrigation.

4.1.7 **Hydroponics**

Another system of arable agriculture with growing applications includes hydroponics, the art of growing crops in water surfaces or saturated sand. The concept was re-discovered in 1930 at the University of California, Berkeley, but there is evidence that this growing method was used by ancient cultures, including Babylon, and also around mountain lakes like Titicaca in Peru and Inle in Myanmar. Proponents suggest that this helps to optimize productivity by regulating nutrients and water inputs in keeping with optimal crop requirements.

4.1.8 **Crop varieties with reduced transpiration requirements**

In addition to soil fertility, water consumption and productivity are dependent on crop species or varieties. Steady improvements in genetic engineering are providing less water-intensive crop varieties. This can reduce irrigation water requirements. For example, improved varieties are now planted on 80% of the cereal area in India, only about half of it irrigated (World Bank, 2007). Newer generations of improved wheat varieties have provided an annual increase in yields and globally the area planted with them has more than doubled since 1981, largely in rainfed areas (World Bank, 2007). Crop selection can enhance water-use efficiency and productivity, if farmers perceive an advantage in switching from low-value, high water-use crops such as cotton to high-value, low water-use crops such as vegetables or fruit (Ali and Talukder, 2008). Similarly, selecting alternative low-value crops that use less water (i.e. wheat instead of rice, or sorghum instead of corn) may also enhance crop water productivity.

4.1.9 **Wastewater reuse**

Using recycled wastewater for irrigation can reduce pressure on groundwater resources. In addition to supplying conventional



irrigation operations, recycled wastewater can be used in urban and peri-urban farms. According to FAO (2005), urban and peri-urban farms, those within or immediately adjacent to a city, currently supply food to 700 million urban residents. Across 50 countries, 20 million hectares are already directly or indirectly irrigated with wastewater (FAO, 2005), close to 10% of the total irrigated area. In addition, it is worth noting that treated wastewater can contribute to irrigation supplies when used to recharge groundwater aquifers.

Wastewater reuse is high on the agenda in water-scarce countries across North Africa and the Middle East. In the Syrian Arab Republic, 67% of sewage effluent is reused, in Egypt 79% and in Israel 67%, mostly for irrigation and for environmental purposes (FAO, 2010a). Similarly, in the mid-1990s, California residents relied on more than 2,460 million cubic metres of reclaimed water annually for irrigating landscapes, golf courses and crops, recharging groundwater aquifers, supplying industrial processes and flushing toilets (Weizsäcker *et al.*, 2009). The Californian agriculture sector is now exploring innovative uses of recycled water in peri-urban agriculture, such as secondary treated wastewater reuse on fodder and fiber crops and tertiary-treated water for vegetable and fruit crops (Weizsäcker *et al.*, 2009). Such a

strategy provides an opportunity to shift from a focus on urban wastewater as a problem to treating it as a resource for market gardens and farming in and around cities. However, the existing regulations and restrictions for exporting the products may make this use difficult. Another factor is the cost of wastewater treatment, which is generally expensive or very expensive if tertiary treatment is compulsory.



Table 4.1 Estimated Leaks from Urban Water Supply Networks

Country	Estimated Leakage in Urban Supply Networks	Year
Sweden	35%	1999
Denmark	10%	1997
Italy	30%	2001
Slovenia	40%	1999
Bulgaria	50%	1996
Israel	10%	2010
Nigeria	80%	2010
Germany	5%	2011
Finland	15%	1999
United Kingdom	25%	2011

Various Sources, Compiled by Authors, 2011

4.2 Municipal sector

This section addresses ways to reduce abstraction for urban water use and improve the collection and treatment of urban wastewater.

4.2.1 Leakage reduction and non-revenue water in domestic supply systems

Water supply infrastructures in some cities are old, poorly maintained, obsolete and complex (Sharma and Vairavamoorthy, 2009). These factors are associated with high rates of leakage in the domestic water supply distribution systems.

Currently, water losses through leakages and unaccounted flows in water supply systems are estimated at between 5% and 80%, varying significantly by country and town (Table 4.1).

These variations depend on the level of infrastructure development as well as operation and maintenance practices. Every year, more than 32 billion cubic meters of treated water leaks from urban water supply systems around the world (Kingdom *et al.*, 2006).

Water that is abstracted for domestic use but not observed to reach a household customer is called non-revenue water (NRW). In addition to water lost to leakage, non-revenue water includes water lost to illegal connections and water that is not accounted for because of dysfunctional meters.

Distribution system losses provide opportunities for reducing domestic water abstraction through simple measures of leakage control. For instance, in Malta leakage control policies reduced leakage rates from 67,200 cubic meters per day in 1995 to 29,400 cubic meters per day by 2001 (EEA, 2003). About 100 billion to 120 billion cubic meters of water can be saved in 2030 by reducing leaks in the supply of bulk water in commercial, residential

and public premises. Some utilities have also made significant progress in reducing NRW. For example, Phnom Penh reduced NRW from 50% in 1999 to less than 10% in 2008 and Manila reduced NRW from 55% in 1999 to 20% in 2008. Pressure management can also significantly reduce water loss in distribution systems. For example, a 50% reduction of the pressure results in the reduction of water loss by 50% (Farley and Trow, 2003).

Globally, over US\$18 billion worth of water annually is considered as non-revenue water (NRW) (Miya Arison Group, 2010). NRW is the difference between water that is put into the distribution system and the volume that is billed to the customers. NRW comprises three components: (i) physical losses – leakage from all parts of the distribution system and overflows of the utility's storage tanks; (ii) commercial losses – customer meter under registration, data-handling errors, and theft of water in various forms; and (iii) unbilled authorized consumption – water used by the utility for operational purposes and water provided for free to certain consumer groups (Kingdom *et al.*, 2006). According to the World Bank, improving the water distribution system through a 50% reduction of the current non-revenue water levels could increase annual revenues in developing countries by US\$2.9 billion in cash per year (from both increased revenues and reduced costs) and potentially serve an additional 90 million people without any new investments in production facilities or further abstraction of scarce water resources (Kingdom *et al.*, 2006).

4.2.2 Improvements to household water use efficiency

Water conservation through improvements to household water-use efficiency is probably the least expensive way of reducing abstractions for urban water use (Haddad and Lindner, 2001).

Efforts to reduce water consumption using 'water-wise' fittings/water saving devices and restrictions during drought are some of the measures that are being implemented (Chanan *et al.*, 2003). New South Wales, for example,

introduced new regulations in 2004 that required all residential developments and renovations to existing buildings to submit a BASIX (Building Sustainability Index) certificate that shows potable water use reduction by 40% (Burgin and Webb, 2011). Some examples of household water-use efficiency measures are listed in Box 4.1.

Box 4.1 Some measures for efficient use at the household level

Low-consumption toilets: can save up to 50% of water per flush for example ultra-low-flush or dual-flush toilets, air-flushing urinals, urine separation systems, dry urinals;

Low-flow showers: low-power devices can be installed in the shower, such as reducing the flow or low-energy showers, high-pressure low-flow shower heads. USEPA (1998) reported that an average household (in the USA) could save more than 8694 L/yr by installing WaterSense labeled showerheads. At the same time these will reduce demands on water heaters (energy savings of 300 kilowatt hours of electricity annually);

Water-saving sinks: water reduction in kitchen and bathroom sinks can be accomplished by using aerators which inject air and boost water flow, increasing the coverage area and improve washing efficiency. Public bathrooms commonly have valves or sensors that only allow water out when the hands are placed beneath them;

Efficient laundry: significant savings are achieved by using appropriate loads of clothes or equipment that uses little water. In addition, reuse of water from them is also feasible and can be used for washing floors in the house and yard or recirculation *into the toilets*;

Repairs in water and sanitation facilities: breaks and leaks in water pipes and water and sanitary fittings can waste plenty of water. A dripping tap wastes 80 L/d, equivalent to 2.4 m³ per month; a stream of water of 1.6 mm in diameter loses about 180 L/d and a jet twice as big loses up to 675 L/d;

Optimum watering of gardens: this is best done in hours of low sun and without rainfall, to prevent evaporation and to better utilize soil absorption capacity; in addition the use of non-conventional water sources such as rainwater or reclaimed water is recommended.

4.2.3 Improved collection, treatment, and reuse of urban wastewater

Improved collection and treatment of urban wastewater can help reduce domestic water-use abstraction if the treated wastewater is used to augment domestic supplies.

The collection, treatment, and reuse of wastewater have considerable potential to reduce the need for domestic water abstraction in developing countries, where wastewater collection and treatment rates are low. Only a few cities in African countries (such as South Africa, Namibia and Senegal) have sewerage coverage of up to 80% (WSP *et al.*, 2009). The majority of Africa's urban residents depend on on-site sanitation such as pit latrines and septic tanks with the highest coverage rate of about 44% (WSP *et al.*, 2009). A similar scenario exists in Latin America and Southeast Asia. Wastewater treatment rates are also low. Only about 35% of wastewater is treated in Latin America, 14% in Asia, and wastewater treatment is almost non-existent in Africa (WHO/UNICEF, 2010). In the BRICS countries (Brazil, Russia, India, China and South Africa), water supply

infrastructures in urban settlements have improved significantly over the past decade, but sewerage services and wastewater treatment facilities are still inadequate. For instance, 122 of the 571 cities with populations greater than 150,000 did not have a sufficient standard of urban wastewater treatment by 2003, and 17 cities had no treatment standard at all (EEA, 2005).

Reuse of reclaimed water is already practised in many urban areas in countries such as Singapore, Israel, Australia, Spain, the United States, Namibia, South Africa and others (OECD, 2009). Technological innovations available to facilitate wastewater reuse are presented in Table 4.2. In addition to these technical alternatives, separation of grey water, which is wastewater that does not contain human waste (from laundry, wash basins, etc.), can also reduce domestic abstractions. Grey water, which accounts for up to 55-65% (Morel and Diener, 2006) of domestic wastewater, can be reclaimed and used for potable and non-potable purposes. In Australia, for example, more than half of the households are reusing grey water in some form to help meet irrigation demand (Maheshwari, 2006).

Table 4.2 Innovative technologies to enhance decoupling in domestic water use

Innovative technology	Benefit to decoupling
Nano technology and microbial fuel cells	<ul style="list-style-type: none">Improve possibilities to recover resources and minimize waste disposal. For example, energy can be generated from organic waste. Reclaimed water can be reused for different purposes.
Membrane bioreactors (wastewater)	<ul style="list-style-type: none">Enhance wastewater treatment performance and safe disposalEnhance wastewater reuse potentialReduce plant footprint
Membrane technologies (both water and wastewater)	<ul style="list-style-type: none">Promote decentralized systems that minimize the environmental footprintEnhance contaminants removal and water reuse possibilitiesEnhances the use of alternative sources
Source separation	<ul style="list-style-type: none">Promote water reuse and nutrient recoveryAvoid wastage and reduce complications and cost of dealing with mixed wastes
Natural treatment system	<ul style="list-style-type: none">Improve environmental qualityMinimize the use of chemicals and energyPromote water reuse and nutrient recovery

Jacobsen *et al.*, 2012

Israel has a very rich experience of reusing domestic wastewater for irrigation purposes. Out of the 467 million cubic meters per year of wastewater collected, 395 million cubic meters per year (about 84%) is reclaimed mainly for irrigation purposes (Hoffman *et al.*, 2005). In Tunisia, the Ministry of Agriculture estimated that in 1996 accessible reclaimed wastewater and desalinated water were about 120 and 7 million cubic meters per year, respectively. These figures are expected to grow to 340 and 49 million cubic meters per year by 2030 (Bahri, 2002). In Windhoek, Namibia, reclaimed wastewater accounts for about 26% of the drinking water supply (Lahnsteiner *et al.*, 2007). In Singapore, the brand name "NEWater" has become an icon of water supply, which is reclaimed wastewater that is used both for potable and non-potable applications such as in industries. Currently "NEWater" constitutes about 30% of the water requirements in the country and it is intended to increase this to 50% by 2060 (PUB, 2010). Rainwater harvesting practices in many countries have shown significant potentials for water demand savings and spared some scarce water resources.

4.2.4 Disaggregated urban water supply infrastructure

Despite the large capital costs associated with urban water supply development, decentralized community-based clusters of scalable supply systems may be more efficient in some cases than centralized systems. In decentralized systems, different streams can be managed separately to maximize the potential outcomes of reclamation, while in the conventional, centralized approach this may be more difficult as it may be more expensive to separate waste streams (Bieker *et al.*, 2010; Otterpohl *et al.*, 2003).

4.2.5 Integrated urban water supply systems

Integration of the different elements of the urban water cycle (water supply, sanitation, storm water management, waste management) with the city's urban development and the management of surrounding catchment areas may also help reduce water abstraction for domestic use. A few cities (for example, Singapore, Curitiba, and Melbourne) have embraced the full concept of integrated urban water management and are showing some positive results. Opportunities exist for cities, towns, and villages in developing countries without major water infrastructure to implement integrated but scalable urban water management. The main characteristic of the resulting integrated urban water system is that water supply, sewerage system and storm water drainage are no longer described as independent and linear systems but rather as an integrated total water cycle with several interactions and feedback loops (Lekkas *et al.*, 2008).

4.3 Industrial sector

4.3.1 Industry water saving schemes

Some examples of technical measures to reduce industry water use and increase reuse within industrial processes are presented in Box 4.2 and Box 4.3. Significant water savings within industrial facilities are possible. External reuse is more complex but offers significant potential for reducing water abstracted for industrial purposes. Reducing water use often results from other drivers such as efficient energy use and closed material flows in overall industrial processes. The metals and mining, pulp and paper, textiles, and chemicals industries provide huge potentials for water recycling and reuse (Gavrilescu *et al.*, 2008). Water savings potentials commonly range from 20 to 8% (UNEP, 2010).

Box 4.2 Some technological measures for efficient water use in industries

Heating and cooling

Optimization of the heating and cooling needs: this requires estimation of the right level of heat transfer and consideration of cascade use of the heat in different processes (use of the same water for multiple cooling or heating purposes depending on the temperature needs).

Use of water-free heat transfer systems: by exploring options of heat transfer means such as air, minerals, oils or specialty chemicals, the need for water to carry heat can be significantly reduced. For example, air-based transporting means can reduce water requirements.

Enhancing water quality: in order to avoid losses of heat transfer, it is important that the water quality is of a high standard that does not interfere with the heat transfer capacity. By maintaining the desired water quality (in terms of pH, hardness and biofouling), the efficiency of energy transfer is improved and the quantity of water needed thereby reduced. Moreover, it is possible to reuse the same water in an increased number of cycles such as multiple-pass cooling/heating instead of single-pass systems.

Optimizing water use in cooling towers: major water conservation measures in cooling towers include controlled evaporation, minimizing splash losses (water that escapes from the cooling tower, damaged louvers or wind), minimizing drift losses by installing drift eliminators or arrestors and use of alternative water sources (such as reclaimed wastewater).

Rinsing and cleaning of products

Counter-current washing: water-use efficiency in washing and rinsing can be achieved by implementing an optimized configuration of washing cycles. For example by using counter-current rinsing, the same water can be used to wash several products as the water flows in an opposite direction to the product flow. This is similar to the cascade use approach where the same water is used multiple times to wash several products.

Alternative washing/rinsing methods: draining options such as air blowing, gravity or centrifugation can significantly reduce the amount of water needed for rinsing. Alternative methods of washing such as chemicals or energy can also be used to reduce the water needs. However, tradeoffs between water, energy and chemical costs need to be made to ensure sustainability of the approach.

Equipment and space cleaning

Mechanical cleaning: the amount of water required can be substantially reduced by removing as much of the substances as possible by mechanical means – such as brushes, scrappers, rubber wipes, or pucks (for pipes). While reducing the water consumption, in certain cases the use of mechanical cleaning methods can also allow for the recovery of products that would otherwise be washed away by the cleaning water.

Pressurized cleaning: by applying a pressurized stream of water, or an air-water mixture, flowing at a high-velocity, cleaning can be achieved with reduced water flows. These systems can provide the same or an even better cleaning effect by using as much as 50% less water. Similarly, by using chemicals or high-temperature water, significant savings can be achieved. However, cost-benefit analysis of the chemical/energy and water requirements needs to be made.

Transporting

Water used for transporting products and wastes requires different levels of water quality and in many cases reuse of the same water for transport purposes is possible. Other means of saving transport water include the use of proper valves to avoid losses and to shut off flows when equipment stops and the use of pneumatic and mechanical means of transport as an alternative to water.

Source: AFED, 2010

Box 4.3 Good practices in water decoupling in the industrial and commercial sectors

Sectors	Empirical examples
Steel Manufacture	Water consumption in the steel industry has fallen from 200–300 tons of water per ton of steel in the 1930s and 1940s to just 3–4 tons or even less water per ton of steel today (Gleick, 2002). For example, BlueScope Steel's Port Kembla Steelworks now uses 0.9 tons of freshwater per ton of steel. This Steelworks is aiming to use entirely recycled water or seawater for all processes and thus be completely independent of freshwater within five years.
Aluminum Manufacture	In the aluminum sector water is largely used for cooling and environmental treatment in the aluminum smelting process. Alcoa, in their European Mill Products (EMP) business, has achieved a 95% reduction in water consumption by installing a closed-loop system in 2007 that recycles process water. Alcoa has committed to 70% reductions in potable water use in all its global operations.
Petroleum Refining	Petroleum refining uses as much as 2.5 L of water for every 1 L of petroleum product. The separation of fractions of petroleum requires significant heating and cooling, which requires water. Yet, by combining water efficiency and use of treated recycled water, it is technically possible to reduce freshwater demand or even use totally recycled water. By implementing best practices in 1997, the BP Kwinana Petroleum Refinery, south of Perth, Australia, has been able to reduce the use of drinking water by 70% and wastewater flows by 40% (by 2004), with a saving of over US\$1 million a year. Chevron's El Segundo Refinery in California uses recycled water for 80% of the 1GL used each month in process applications.
Paper and Cardboard Manufacture	Since 1900 best practice in the amount of water used per kg of paper produced has improved from 500-1000 L/kg to 1.5 L/kg of paper produced. Visy Industry's Australian Tumut Paper and Pulp mill has achieved an 80% reduction in average water consumption. No water is discharged off the site, and all treated wastewater is used where possible in the industrial processes or for the irrigation of pastures. At their Cartonboard Mill in Petrie, Amcor Australia has achieved annual savings of more than 1000 ML, via a 90% reduction in the use of freshwater in the manufacturing process by using treated and recycled water.
ICT - Manufacture	Intel's operation in Arizona uses 75% less water than the industry average (down from 25 to 8 ML/d). Additionally, Intel treats and recharges more than 13.2 billion L treated wastewater into the aquifer since the plant's inception in 2000 (Cohen et al., 2009).
Glass Manufacture	Pilkington (Australia) Limited's Geelong glass manufacturing plant reduced its per piece water consumption by 61% in five years. In 2004, it was using 70 ML less water each year than in the baseline year, 1999.
Food – Poultry Processing	Inghams Enterprises, Australia's largest poultry processing company, has achieved 20% water-use efficiency savings and has reduced water usage by 72% in its major poultry processing plant in Brisbane through onsite recycling. This has reduced freshwater demand by 545 ML/yr, using an integrated approach to water efficiency and recycling. This has set a new and significantly improved global benchmark for best practice in this sector.
Brewery and Soft Drink Industry	Breweries use about 6–8 L of water per L of product, but best practice breweries in Australia now only use around 2 L of water per L of beer. In 2009, the Coca-Cola system achieved its seventh consecutive year of improved water-use efficiency. Across the system, 309 billion L of water were used to manufacture 130 billion L of product, with a water-use ratio of 2.36 L of water per L of product—a 13% reduction since 2004.

Source: Smith *et al.*, 2010; Smith, 2011a; 2011b; 2011c

4.4 System-level approaches

Some technological solutions to reduce water abstraction are not implemented at sector level but instead at a larger scale consistent with the hydrological cycle, such as the river basin scale. These approaches may require an integrated water resource management (IWRM) approach to implement successfully. A description of the IWRM approach is provided in section 5.5. Two examples of system-level technological approaches are provided below.

4.4.1 Natural water purification

Wetland and riparian ecosystems can provide wastewater and storm runoff treatment that can reduce the costs of investment in wastewater treatment facilities. Natural soil passage (such as river bank filtration or soil aquifer treatment) can significantly reduce water treatment chemical and energy costs (Sharma and Amy, 2010). The advantage of this approach is that the natural environment serves as a buffer for purification and storing of water. During the period of storage, the natural storage system also allows for subsurface run off for groundwater recharge, evapotranspiration, and subsequently sufficient condensation and precipitation required for maintaining environmental flows in rivers and lakes. Eco-hydrology is a cost-efficient technology of water and ecosystems management and can increase the reuse of water at the basin scale (Zalewski, 2007).

4.4.2 Multiple-use systems with cascading reuse of water

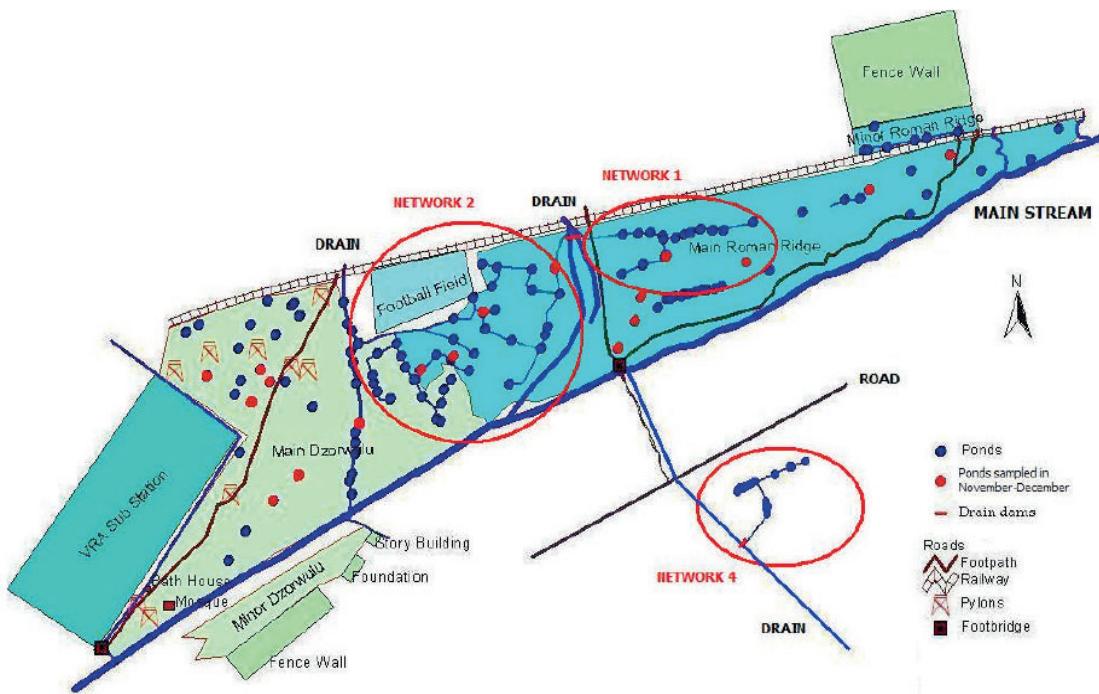
The multiple-use systems (MUS) with cascading reuse of water is based on the

assumption that it is possible to align water quality requirements and water-use locations from upstream to downstream within a river basin. Return flows from upstream uses may then have appropriate water quality for downstream uses and reduce the need for additional treatment or groundwater extraction by downstream users. Cascading from higher to lower quality makes water reuse more affordable than embarking on intensive water treatment at each abstraction point in a river basin. For example, domestic wastewater can be an important source of water for irrigating home gardens, lawns, etc. With minimal treatment, domestic wastewater could also provide a useful water source for the industry – e.g. for washing and cooling systems. A cascading water reuse system can also be designed with natural buffers (e.g. wetland, small ponds, rivers) to allow for water filtration, condensation, etc., before downstream users extract the water for reuse (Box 4.4).

An investigation of MUS in Bangladesh, for example, revealed that it meets the needs for water better than the conventional system with the benefits of increased productivity and incomes, reduced irrigation costs and easier access to domestic water (Fontein *et al.*, 2010). Other examples where MUS approaches have been implemented with positive outcomes are in Nepal and India (Mikhail and Yoder, 2008). In the implementation of multiple-use systems at any level (household, community or basin), it is important to recognize the existing traditional resource management systems that may integrate multiple uses of water resources, and which typically offer diverse and resilient livelihood strategies to poor groups (Nguyen-Khoa *et al.*, 2005). The MUS has been identified as one of the major opportunities to increase water productivity (Molden *et al.*, 2007; 2010).

Box 4.4 Cascading Water Use in Accra, Ghana

Accra, the capital of Ghana, with a population of 1.6 million and an annual growth rate of 3.4% (GSS, 2000) generates about 100,000 m³/d of wastewater. Irrigated urban vegetable production in Accra provides up to 90 % of the most perishable vegetable needs of the city - especially lettuce, which benefits around 250,000 people daily. Moreover it yields an average monthly net income of US\$40-57 per farm size. Most of the agricultural sites are located on valley bottoms along streams and drainage systems and the wastewater is used as the main source for irrigation (cascading water use). Nevertheless, it is associated with health and environmental risks of pathogens from the discharge of raw wastewater and consumption of contaminated vegetables. Hence the research project SWITCH developed guidelines for institutional as well as low-cost treatment systems (e.g. natural treatment systems) to facilitate a safe reuse of wastewater for irrigation purpose and minimize health risks. A demo project was established at the Dzorwulu-Roman Ridge Demo site (which covers an area of 8.3 ha in Accra) to use natural treatment systems to facilitate the treatment of domestic wastewater before it is reused for irrigation. Shallow ponds are extensively used to store wastewater and pipe water for irrigation of the agricultural land in the area. This project demonstrated the safety of the reuse of wastewater by reducing the pollution significantly. A site map of the study in the Roman Ridge farming area in Accra, Ghana, is shown in the figure below.



Reymond *et al.*, 2009

5

Policy innovation and decoupling

This chapter provides an overview of how policy innovation may contribute to decoupling. Because many of the policy innovations presented in this section involve the use of economic instruments, the chapter begins with a brief review of some of the characteristics of water that limit the extent to which the resource can be managed as an economic good. Policy solutions with the potential to contribute to resource decoupling are described for the agricultural, industry, and municipal water supply sectors. In addition, systems-level policy approaches with the potential to encourage efficient use across sectors are also described. The section concludes with an examination of equity considerations that should be included in the design of policy measures. Obviously, the tools described here are not an exhaustive collection of all the policy tools available, but they provide a broad introduction to some of the most well-known and documented ones.

5.1 Constraints on the economic management of water

The focus on economic instruments as policy tools for decoupling in previous reports (UNEP, 2011a; 2014) is based on managing water as an economic good. However, water has some unique characteristics that limit the extent to which economic instruments can function effectively as management tools. These

characteristics can be grouped in four broad categories: water exhibits properties of a public good in some of its uses; a number of externalities are associated with the use of water; the provision of water supply is a classic “natural monopoly” because of declining average costs of supply; and transaction costs associated with managing water are high relative to water’s value.

- **Public goods properties:** A public good is defined by two characteristics: use of the good is both non-rival and non-excludable. If the use of a good is rival, then use by one user precludes the use of the good by another. In many of its uses, such as consumptive uses by agriculture or industry, water use is rival. However, some uses, such as the aesthetic or recreational values provided by water, are non-rival; in these uses, use by one user does not preclude use by another. If the use of a public good is excludable, then it is possible to establish property rights for the good so that potential users of the good can be excluded unless they pay for use. Again, aesthetic and recreational uses of water provide an example of a use where it is difficult to exclude non-paying users. In addition, the nature of the water resource, which is dispersed in space, moving in time, and variable in supply at both seasonal and annual time scales, makes it challenging to establish secure, non-excludable property rights. For these reasons, water can be considered

a public good in some contexts. The economic management of public goods is complicated by the “free-rider” problem; if use of a good by one user does not preclude use by another and it is difficult to exclude use of the good, then it is possible that many users will use the good without paying for it. The general consequence is that the social value of the good is not reflected in prices that can be charged to firms and individuals for its provision.

- **Externalities:** An externality is a cost to others that is not included in the costs faced by the individual or firm responsible. In the water context, discharge of wastes and return flows are two examples of externalities. Discharge of wastes to water bodies impacts water quality, imposing costs on downstream users who must use degraded water supplies. Return flows impact downstream users by altering the hydrological regime in ways that may impact downstream water supplies or disturb the operation of hydraulic works such as canal intakes. Externalities require government or other administrative intervention in order to impose costs on individuals and firms that are responsible for them.
- **Natural monopoly properties:** A natural monopoly exists when the average costs of water supply are declining as supply increases. In this case, marginal costs of supply are lower than average costs. As a result, production costs are cheaper when a single producer supplies all customers and competitive pricing (marginal cost pricing) will not cover costs. Residential water supply is an example of a natural monopoly; because of the expense of building a conveyance and distribution network, it is more cost-effective for a single supplier to provide the service than to have two or more suppliers in

competition. Therefore, in many cases it is not cost-effective to have market competition in water supply, and prices paid by users often do not include the opportunity costs that would be included given market competition.

- **High transaction costs:** Water has a low unit value, which makes it expensive to transport and store. In addition, the dispersed and unpredictable nature of the water resource makes it difficult to monitor and control water supply. For these reasons, it can be challenging to apply economic policy incentives to water supply, as the costs of related monitoring and enforcement may exceed the benefits of economic management.

The presence of the above characteristics does not mean that economic approaches cannot be effective for water management. Indeed, the IRP notes (UNEP, 2011a) that China has succeeded in reducing per capita water use through a combination of regulatory and economic approaches, which stands out as a success for an economy that has struggled to decouple economic growth from the use of other resources. China has also reduced water pollution impacts, partly through the application of economic instruments. Another IRP publication, “Measuring Water Use in a Green Economy” (UNEP, 2012), credits the use of water markets in Australia for increasing agricultural water productivity.

However, the characteristics described above complicate the application of economic incentives as tools to improve resource productivity and reduce environmental damages associated with resource use. Some of these complications are outlined below for two economic approaches to resource management: the market and economic incentives such as taxes, subsidies and fees (as advocated in UNEP, 2014).

- **Markets:** Although the 2014 document does not make explicit recommendations about using markets to achieve decoupling, other publications, including UNEP (2012), credit the use of water markets with improving the resource productivity of water use. “Measuring Water Use in a Green Economy” (UNEP, 2012) highlights the use of water markets for allocating irrigation water supplies in Australia and argues that market allocation has resulted in significant gains in water-use efficiency. Similar conclusions were reported in Chile following the introduction of market allocation in that country. However, in both cases markets have not been able to provide for public goods, such as environmental flows, which have required government intervention to provide them. In addition, transaction costs and the dispersed nature of water use have made it challenging for market allocation to function efficiently.
- **Economic instruments:** Economic tools such as taxes, subsidies and fees can be used by governments or other authorities to supplement market transactions and account for the problems associated with economic allocation of water described above. For example, governments can provide for the provision of public goods such as aesthetic and recreational services by limiting consumptive uses or paying consumptive users to reduce water use. Governments can reduce pollution externalities by charging fees for disposal of wastes into water bodies. Water service providers are regulated by the government to reduce their monopoly power. Water service providers that subsidize water use (as is frequently the case with providers of irrigation water) can be charged abstraction fees that account for the opportunity costs of water use. However, it is not clear that these instruments can mitigate all complications. If the

governments pay for the provision of water for recreational and aesthetic services, it is uncertain whether the resulting price will reflect the actual social value of these services since they are not sold on a market. The same applies to pollution fees. Abstraction fees can help account for the opportunity costs of water use, but these types of fees lack the specificity and flexibility of a market, particularly in large river basins with dispersed uses. In all cases, the need for and costs of monitoring and enforcement limit the extent to which these tools can be used efficiently.

5.2 Agricultural sector

As described above, the agricultural sector accounts for the largest percentage of water abstraction worldwide. In areas where groundwater makes a significant contribution to irrigation water supplies, appropriate policy solutions could help to reduce the risk of long-term groundwater depletion (in cases where this depletion has the potential to frustrate social progress).

5.2.1 Volumetric water pricing

In many areas where irrigation takes place, water is either free, or farmers pay fees for irrigation water that are not linked to the amount of water used. Even if irrigation water users are charged using volumetric pricing, it may be that the prices charged do not cover the full opportunity cost of water use; in other words, if high-value alternative water uses are available, existing prices may not include this information and therefore not provide incentives to conserve. Finally, prices may not reflect the long-term costs of resource depletion. Properly designed volumetric water policies have the potential to provide financial incentives for farmers to conserve water for the future and reduce inefficient irrigation practices.

5.2.2 Water markets and trading

As an alternative to water pricing, water markets and water trading can be used as a policy tool to encourage efficient use. Water trading and markets are already used in the agriculture sector in a number of water-scarce regions including Australia, Spain, Chile, and parts of the United States.. In a market system, water users hold rights to water that can be sold to others, either permanently or temporarily. The market system has the advantage of using the market to determine the opportunity cost of water use; under a market system, farmers will not use water for irrigation unless the value of water in irrigation exceeds the value of selling the water. Because future water users are not part of the market, however, market prices may not reflect the opportunity cost of future depletion.

5.3 Municipal sector

As discussed in Chapter 4, long-term groundwater depletion for municipal water supply can be reduced by policy solutions

that reduce abstraction and improve the collection, treatment and reuse of urban wastewater. Policy solutions include economic tools, such as volumetric water prices, as well as institutional and social tools, such as public awareness and education campaigns.

5.3.1 Appropriate water pricing

Volumetric water pricing can be used as a tool to reduce water abstraction for domestic use by giving domestic users a financial incentive to conserve water. However, water pricing may give rise to ethical concerns, particularly if the price limits the access of the poor to water needed for basic health and sanitary purposes. On the other hand, there is evidence that global subsidies to domestic use may be as much \$1 trillion per year, and these subsidies may encourage inefficient water use through artificially low prices (Dobbs *et al.*, 2011). Pricing policies should be developed to account for equity considerations (i.e., to ensure that the poor have access to a minimum amount of water needed for health and sanitation), depending on local contexts.



5.3.2 Public awareness campaigns

Public policy can play a useful role in raising awareness about the need for efficient management of water resources. Through such campaigns, households could be encouraged to embrace water-saving practices.

5.4 Industrial sector

The industry sector accounts for a significant percentage of water abstraction, particularly in developed countries. This section describes how policy solutions can be used to reduce rates of water abstraction by the industry sector.

5.4.1 Appropriate water pricing

As with the agriculture and domestic sectors, pricing can be used as a tool to encourage efficient water use. As many industry users have dedicated supplies (in other words, they are not supplied by a water utility or other domestic supplier), this requires a water resources management authority with the ability to implement a pricing policy (see section 5.5 on systems-level policy approaches). For some industries, water costs are a comparatively small part of overall input costs, and volumetric prices may not be sufficient to encourage conservation.

5.4.2 Corporate water reporting and accounting

The corporate world is becoming more aware of the need to account for water use, both in volumetric terms as well as in terms of risks to the business. The UNEP (2012) report on measuring water use in a green economy introduces the analytical methods

and policy frameworks needed to ensure that water use can be properly quantified over the life cycle and integrated into other measures within the green economy.

The corporate world is applying many approaches to quantify and assess water use and impacts. They include water footprinting; life cycle analysis, inventories and impact assessments; water management tools such as those developed by the World Business Council on Sustainable Development (WBCSD); and corporate reporting indicators such as those within the Global Reporting Initiative. Depending on the database, tool or framework, the information contained within the water inventories and accounts used by companies can differ considerably.

5.5 Systems-level approaches

Previous sections have discussed strategies for reducing water abstraction within different sectors. However, water supplies are delimited by natural boundaries associated with the action of the hydrological cycle (such as river basins), and policy solutions to reduce water abstraction should consider whether water use is distributed efficiently across sectors. In this context, the water cycle includes the movement of water from source (surface water, groundwater, rainwater, etc.), to its distribution to and utilization in economic sectors (agricultural, industrial, domestic, etc.), its treatment, recycling and reuse in these economic sectors, and return flows to the natural environment and vice versa (Figure 5.1).

The major hydrological interactions between the different components of the water cycle include the flow of water from

rivers, lakes and reservoirs to consumers, the excess flow from agricultural irrigation to receiving water bodies, wastewater and storm water flows from urban areas (domestic and industrial) to receiving water bodies, the cascading use of water between different consumers, and the interactions between surface water and groundwater (Mayer and Muñoz Hernandez, 2009).

The Integrated Water Resources

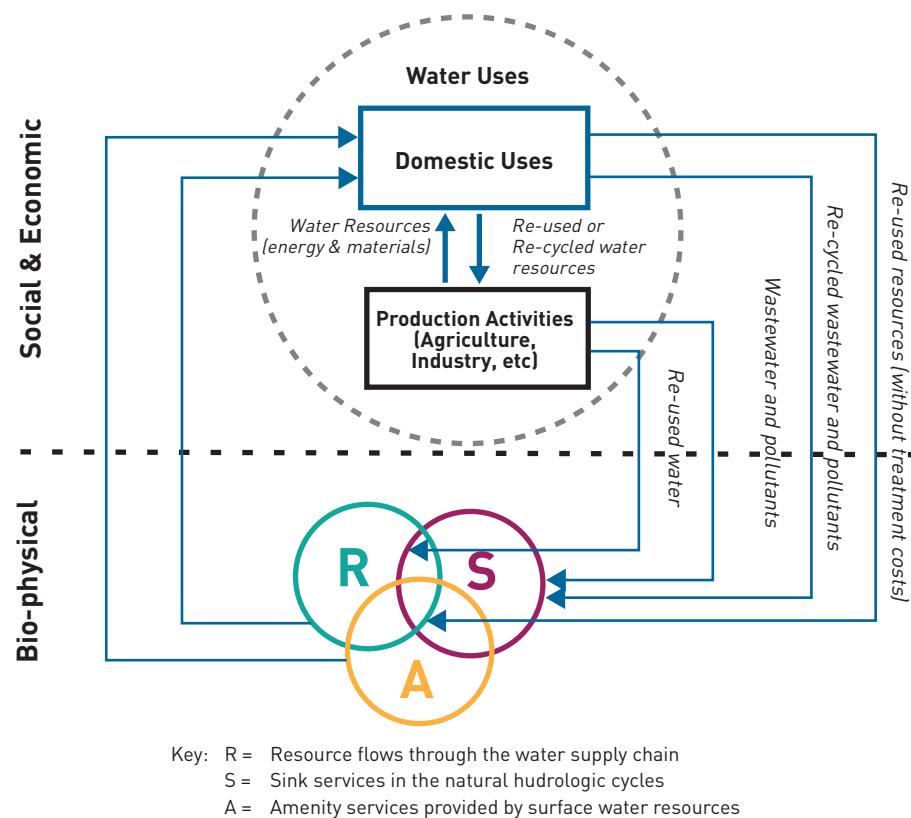
Management (IWRM) approach incorporates all parts of the overall water cycle and views the different water sectors as components of an integrated physical and institutional system (Mitchell, 2004). A hypothesis associated with the IWRM approach is that better water efficiency and water productivity can be achieved by integrated basin-wide management. If implemented properly,

the IWRM approach may help protect the environment, improve water efficiency, foster economic growth and promote democratic participation in water governance (GWP, 2010). IWRM is now widely recognized and practised in many countries following Article 26 of the World Summit on Sustainable Development (WSSD) in 2002 (ANEW, 2011). An overview of important components of the IWRM approach is given in Box 5.1.

5.5.1 Conjunctive management of surface water and groundwater

Conjunctive water management is the joint management of surface and groundwater resources at the river basin scale. It requires a comprehensive monitoring approach that is used to support management objectives and enforce local policies. Conjunctive

Figure 5.1 Functional Cycle of Water Resources in the Economy



Adapted from Urama *et al.*, 2006a

Box 5.1 Dimensions of IWRM

IWRM aims to achieve integration in relation to the following aspects:

- *Integration of all parts of the water cycle:* IWRM considers all systems in the overall water cycle such as storm water, water supply, wastewater collection, treatment system, irrigation system, ecosystem services, etc. The different parts and subsystems are designed and managed in an integrated manner for a more efficient and productive use of water, which maximizes synergies and minimizes negative impacts (van der Steen and Howe, 2009)
- *Integration of all water uses:* IWRM takes into account all water uses to provide water services to the community, such as water supply, public hygiene, flood protection and food production, while at the same time ensuring the ecological integrity of the natural environment (Maheepala *et al.*, 2010). Different anthropogenic uses like industry, agriculture and domestic are considered. IWRM attempts to efficiently allocate available water sources to the different uses and to maximise economic benefits.
- *Integration of all institutions, stakeholders and water users:* IWRM is characterized by complex and flexible governance arrangements, increased inter-organizational interaction and wide stakeholder participation. It aspires to institutional integration that enhances communication, collaboration, community participation and information sharing (GWP, 2010). Integration is recognized as a dynamic element as it involves both organizational patterns and the state of mind of participants (De Boe *et al.*, 1999). Bringing together a wide range of disciplines and skills is one of the critical features of IWRM.
- *Integration across time:* IWRM aims to balance the short-, medium- and long-term needs of water management by taking future pressures and related uncertainties into account. IWRM is based on strategic planning that addresses future pressures and global dynamics adequately, promoting the planning and design of flexible and adaptive systems that provide the capacity to adjust efficient and productive water management for expected and unexpected future changes.
- *Integration of different spatial scales:* IWRM considers different spatial levels from the whole region down to the single site (Mitchell, 2004), so that the concepts of the single sites have to fit as incremental parts in the IWRM strategy for the basin. The water management decisions on the upstream water cycle have to take into account the impacts downstream and vice versa. Furthermore the institutional arrangement may take different shapes and the scale may vary depending on whether the catchment boundaries fall within a basin or involve multiple basins.
- *Integration of innovative solutions:* IWRM promotes the implementation of innovative approaches to improve water efficiency and water productivity. Innovations may include: the utilization of non-conventional water sources, including rainwater, greywater and wastewater; the application of fit-for-purpose principles; storm water and wastewater source control and pollution prevention; the use of mixtures of soft (ecological) and hard (infrastructure) technologies; and non-structural tools such as education, pricing incentives, regulations and restriction regimes.

management is complex because of the associated monitoring and institutional requirements. Nevertheless, it has the potential to improve water efficiency, particularly in water-scarce regions and in times of drought. A successful example of conjunctive management is in Uttar Pradesh, India. Recent studies found that the application of a conjunctive management

approach there resulted in a 26% increase in net farmer income; annual energy savings of 75.6 million kilowatt hours and pumping cost savings of Rupees (Rs) 180 million (US\$2.7 million); an increase in canal irrigation from 1,251 hectares in 1988 to 37,108 hectares in 1998; a fifteen-fold increase in rice area; and a 50% reduction in conveyance losses in canals (IWMI, 2002).

5.5.2 Water efficiency trading schemes and investment offsets

Investment in efficiency gains in one sector (e.g. domestic, agriculture or industry) can offset investment in other sectors, for example the natural environment, and vice versa. Thus technical measures and management approaches to improve water efficiency and water productivity in the agricultural sector could be cheaper than the strategies for water savings in domestic water supply systems, or vice versa. Implementing efficiency measures in sectors where these measures are more cost-effective can release water for use in other sectors. A life-cycle approach is essential to identify such opportunities and potential trade-offs (see section 5.5.3). The benefit of this approach is that the limited available financial resources are invested to achieve significant water efficiency gains with minimum cost. Rural water markets have resulted in a reallocation of water with significant economic and environmental benefits (Frontier Economics, 2008). This can result in a “water efficiency trading scheme” between sectors, countries or even regions in shared river basins. A key element for the success of these schemes is that the “winners” (those gaining water supplies) compensate the “losers” (those losing access to supplies). For example, cities could support farmers with water conservation measures such as improved irrigation technologies (e.g. installing drip and sprinkler irrigation) and improved on-farm water management practice (Molden *et al.*, 2007). To be effectively deployed, these practices must provide tangible water savings that can be transferred to other sectors so that the benefits are not lost elsewhere in the same sector (e.g. excess irrigation water used by other farmers).



5.5.3 Life Cycle Assessment

The Life Cycle Assessment (LCA) evaluates the environmental performance of products and services and quantifies all inputs (e.g. extraction and consumption of resource) and outputs (e.g. wastes and emissions) throughout a product's life cycle, from raw material acquisition through to waste disposal, also including manufacture, distribution and product use (UNEP, 2004). This whole-systems perspective provides the added value of avoiding burden-shifting between different life cycle stages or components of a product system. The LCA is a tool to trace water use and water pollution associated with different products “from cradle to grave”, thereby better balancing trade-offs and supporting decision-making. However, the inclusion of water-use related impacts (linked to scarcity and pollution) in LCA has been challenging

due to inconsistent terminology and lack of standardization in the measurement metrics (Berger and Finkbeiner, 2010; UNEP, 2012).

The main challenges to including the impacts from water use in LCA arise in the methods used to address the inventory and impact assessment. These have been the subject of intensive research in the past few years (see e.g. Frischknecht *et al.*, 2006; Milà i Canals *et al.*, 2009; Pfister *et al.*, 2009), recently under the auspices of the UNEP/SETAC Life Cycle Initiative (Kounina *et al.*, 2013). The development of a standardized methodology that includes water use and pollution in LCA has been the focus of work within the International Standardization Organization (ISO). The details behind these various methods and an evaluation of the key differences in relation to international standards setting are a key part of the first report of the Water Working Group (UNEP, 2012).

It is important to consider the whole-systems perspective provided by LCA and/or Water Footprint when assessing the resource efficiency of a technology, product system, lifestyle, etc., in order to prevent unintended burden shifts (e.g. if the water use is significantly reduced in one phase of the product's life cycle at the expense of a bigger increase in another phase).

5.5.4 Virtual water trading

Issues of water scarcity and environmental impacts from water consumption can be both aggravated or improved through trade of virtual water. The most water-scarce regions or nations could import water-intensive products from water-abundant countries and at the same time develop products or services that require less water (water-extensive products), thereby relieving pressure on domestic resources. On the other hand, through patterns of consumption and imports, countries can

aggravate water shortages and pollution of their water supplies.

Virtual water trading does not in itself lead to overall less use of water; it just determines where the water use takes place. It may thus contribute to increasing water consumption in one place (and thereby counteract decoupling in that place) while reducing the water consumption in another place (and thereby contribute to decoupling in that place). If virtual water trading is carried out wisely, it could thus relieve the water resources pressure in water-stressed areas at the expense of using the water where resources are more plentiful. Needless to say, a water footprint criterion cannot stand alone in policy development, as other needs (such as the need for foreign exchange) might dictate export policies; but virtual water calculations may reveal imbalances and patterns that need to be addressed. Perhaps more income could be generated by producing less-water-requiring but higher-value crops.

5.5.5 Water neutrality

Another integrated approach with the potential to limit increases in water abstraction is the concept of water neutrality. The basic idea of 'water neutrality' is that economic growth and associated development should not lead to an overall increase in water demand in a basin (Hoekstra, 2008; Hoekstra *et al.*, 2011). Water-neutral development is achieved when the water demand requirements of new developments are met through more efficient use of existing water resources by investing in water efficiency and water productivity, rather than through an increase in water abstraction. This can be accomplished by requiring developers of new agricultural and urban areas to invest in water efficiency and water productivity measures equivalent to their expected water consumption (Nel *et al.*, 2008).

Measures motivated by the water neutrality principle must consider the impacts of these measures on the natural hydrological system (e.g., if agricultural return flows are re-routed to another part of river basin, it may have consequences for aquatic ecosystems).

In general, the underlying principles of IWRM are inherently complex because multiple users (irrigation, domestic, fishing, livestock, industries, etc.) have to be taken into account (Meinzen-Dick and Bakker, 2001); but, in the long run, it is the most cost effective means of achieving water decoupling. In many basins the available water resources are already fully allocated to the key economic sectors, ignoring the environment. Such strategies have proved expensive in the medium to long term in countries where groundwater becomes depleted beyond sustainable thresholds and base flow in rivers and lakes are not maintained. This affects the hydrological water cycle with significant economic, social and environmental consequences. The IWRM approaches provide the possibility to analyze and understand water for ecosystem services in relation to the other sectors (Fischhendler and Heikkila, 2010). For example, it helps in understanding the impact of deforestation or afforestation on flows and water quality; the use of alternative land-use practices in mitigating damage; the design and impact assessment of dams on rivers (Acreman *et al.*, 2009); and the impact of rainfed agriculture discharges on ecosystems (Rijsberman and Silva, 2006).

5.5.6 Basin-scale water markets

Basin-scale water markets facilitate the trading of water between sectors and can contribute to the allocation of water to uses that maximize economic efficiency. However, unlike markets for other commodities, the establishment of water markets can be controversial because of the

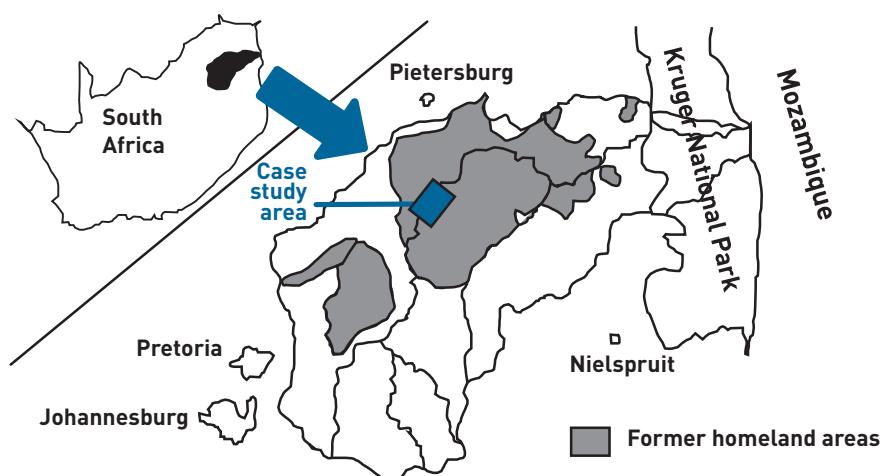
perceived social importance of water. The experience of two decades of basin-scale market transfers in Australia suggests that markets have helped re-allocate water to higher-value uses and resulted in significant economic, social and environmental benefits on the catchment scale (Frontier Economics, 2008). In developing countries, the establishment of water markets could play an important role in improving the efficiency, equity and sustainability of water use (Rosegrant and Binswanger, 1994). However, consideration of the ability of the poor to pay for water at its open market value prompts strong ethical concerns against optimal pricing of water. Water also provides other invaluable services to human welfare through the multiple ecosystem services that it provides. The political economy of defining the optimal price for water is therefore characterized by ethical consideration of the right to access, as distinct from the economic value of water. It is therefore challenging to determine the optimal solution for water allocation from an economic perspective alone (Spash *et al.*, 2006; Urama *et al.*, 2006b). To address these concerns, Dinar *et al.* (1997) suggest necessary criteria for optimization in water resource allocation: flexibility in the allocation of supply sources, security of tenure for established users, real opportunity cost of providing the resource, predictability of the outcome of the allocation process, equity of the allocation process, and political and public acceptability of the allocation process. An example from South Africa demonstrating some of the complications associated with implementing a market allocation scheme is provided in Box 5.2.

5.6 Equity considerations

Many of the policy measures discussed in this section involve the use of market mechanisms to allocate water. In addition to the limitations of markets discussed in

Box 5.2 Water Allocation, South Africa

South Africa is a lower middle-income country characterized by a two-faceted primary economic sector, with agriculture and mining. Agriculture represents about 3.5% of GDP and employs 9% of the total active population with irrigated agriculture and stock watering using about 52% of total water. Mining accounts for about 7% of GDP and some 3% of total water usage. It employs about 6% of the total active population (Forgey *et al.*, 2000). The two primary sectors are increasingly competing for natural resources, and especially water. South Africa adopted a water policy, represented in the National Water Act (RSA-NWA, Act 36 of 1998), that provides a framework for water markets. The legislation makes provision for water rights trading as an option for water allocation. For example, negotiation takes place in an area of Limpopo (former Northern Province) in the water-stressed basin of the Olifants River. Some mining companies are investigating the possibility of buying water rights from small-scale irrigation schemes, while others have launched proactive negotiations with communities and/or local, provincial and national authorities (Rouzère, 2001). The available water of the sub-basin, mostly stored upstream the Arabie dam, is already fully allocated (56 Mm³/yr). A smallholding irrigation scheme (Arabie-Olfants I.S.) lies downstream the Arabie dam. A total of 1650 smallholders' households partake in the scheme, mostly for food supply and subsistence purposes. A decision-making support model of water availability (56 Mm³/yr) versus demands in the area clearly reveals the difference in economic power between the two sectors. This means that a direct negotiation on water rights transfer between mines and smallholders is likely to end up with an almost complete transfer of water rights to the mining sector. On the other hand, such a transfer would challenge certain objectives of the government, which go beyond mere economic perspectives and include equity, sustainable rural development, environment protection, and the like. Certain economic or regulatory policy tools may be implemented, as alternatives towards a more balanced allocation of water. The figure below shows the case study area of Limpopo, South Africa.



Farolfi and Perret, 2002

Section 5.1, it is important to take account of equity issues when considering the use of market instruments to allocate water.

Market instruments allocate resources to users that are most willing to pay for them; in other words, to the users that value these resources most. This form of allocation is considered efficient because it is assumed that users willing to pay for the use of resources will go on to use these resources to produce other goods and services that are highly valued by society; otherwise, they would not be willing to pay as much.

However, water is more than a consumption good or input to production. It is also essential to human life, as well as an essential item for cleaning, cooking, and household sanitation. In many developing countries, the poor face limited access to water because of inadequate infrastructure, and the lack of financial resources in poor

communities means that these communities may struggle to develop and operate adequate water supply and sanitation facilities. In this case, market mechanisms are failing to provide a service that is important to human dignity and helping the poor to improve their economic position. Therefore, it is essential that governments and international agencies help marginalized communities to develop and maintain adequate water and sanitation infrastructure.

In addition, in areas where water scarcity exists, uneven power relations may pose obstacles to the efficient and equitable allocation of water. Individuals and other agents with privileged access to water resources may use these resources to extract resource rents without paying the full social and environmental costs of water abstraction. Such water uses could come at the expense of ecosystem uses or at the expense of marginalized communities.



6

Conclusions and recommendations

Decoupling pressure on water resources from economic growth is key to sustainable development because of the uneven geographical distribution of global water resources and the cost of transporting water. In regions where water resources are scarce and the rate of withdrawal higher than the rate of replenishment through the hydrological cycle, there is a danger of depleting the resource leading to unsustainable resource use.

Although several countries have already achieved some degree of relative or absolute decoupling of water use from economic growth in recent decades, the world as a whole needs to strengthen the efforts in this area in order to avoid a looming water resource crisis. And there are lessons to be learned from previous experience in a number of countries, as described in this report.

International trade in goods and services may mask the link between economic growth and water use for a country if virtual water (water embedded in goods and services where water is required for their production) is not accounted for. Although the applicability of the virtual water concept is debated, calculating virtual water content provides a tool to inform strategic decision-making on water resources management and decoupling. Depending on the circumstances and the nature of the water resources involved in virtual water, international trade may sometimes

contribute to decoupling and sometimes counteract decoupling efforts. This also demonstrates that, due to the uneven distribution of water resources, decoupling should not necessarily be pursued by all regions. In order to achieve decoupling where it is most needed (in water-scarce regions) it could be overall advantageous to achieve this through 'reverse' decoupling in other more water-rich regions and exchange through virtual water trade.

Continued population growth, increased urbanization, changed food consumption patterns and climate change are some of the key drivers that are likely to increase pressures on water resources in the future. Traditional supply fixes and continuing improvements in water use efficiency in agriculture will close less than half the projected gap between water supplies and demands in 2030. Under a business-as-usual scenario it is estimated that annual water demand will increase between 43% (North America) and 283% (Sub-Saharan Africa) from 2005 to 2030. By 2030, nearly half of the world's population may live under conditions of severe water stress, threatening the provision of basic needs to families and limiting their welfare and quality of life.

The pressure on water resources also impacts the quality of waters and makes larger proportions of the available water unfit for the intended use due to growing pollution and water quality deterioration.

Whereas water shortage and droughts are a major problem, excess water can sometimes be more damaging, particularly in the short term, with floods causing a significant and growing economic and social problem in many parts of the world. Of all observed natural and anthropogenic hazards, water-related disasters are the most recurrent. Drivers such as climate change, urbanization and land-use changes are only expected to make this tendency worse, with more frequent and more violent disasters hitting more people.

This gloomy outlook makes a compelling case for more decoupling of water use from economic growth – resource decoupling as well as impact decoupling. The problem is that there is an upper limit to the possible withdrawal of water, determined by the hydrological cycle; so that, although some decoupling has already been achieved as described, the future calls for more in order not to surpass nature's limits. Desalination is an option in some places such as coastal areas, but not in others such as continental and high-elevation situations; and it is still more expensive than what many communities can afford. Therefore, decoupling must be part of the efforts to avoid a water crisis.



A long list of technological tools and policy tools to help achieve decoupling with respect to water are presented and described in this report. The technological tools include techniques, solutions and approaches within the agricultural, municipal and industrial sectors, designed to reduce water consumption and use water more efficiently. System-level approaches to be implemented at larger scale, e.g. the river basin scale, are also included. Finally, policy (including economic) tools for the same sectors and different scales are presented and described, together with their known constraints and limitations where relevant.

These tools, which represent just a sample of the entire toolbox available, show that it is possible to act now and that there is a variety of tools available to address the wide range of circumstances and peculiarities that constitute the real-world challenges.

In order to further accelerate the achievements on decoupling with respect to water in recent decades, it is recommended that countries, decision-makers and researchers:

- *Invest more in research and development concerning improved and additional technological tools for water-use efficiency gains.* Technical water efficiency can help reduce wasteful use of the limited water resources, up to a point where the marginal cost of efficiency gains exceeds the marginal value of the water.
- *Consider and apply policy measures to curb water demand and re-allocate water between sectors and users according to where water produces goods and services* most beneficial to society, i.e. where it contributes to most economic output per drop. Water pricing and market instruments could be used to achieve this. However, water is a basic human need and such measures need to be balanced against measures to protect vulnerable groups, particularly the poor.

- *Consider ways to internalize current externalities*, i.e. removing disincentives to using water more efficiently. For example, if fines for polluting water resources are too low, it may discourage efforts towards water resources protection and hence decoupling. In other words, if ecosystem services are not factored in to the equation water may not be used in society's overall best interest.
- *Strengthen research into the value of ecosystem services* in order to better integrate those value elements into the economic growth equation. If we neglect or miscalculate the value of ecosystem services, we risk making sub-optimal use of scarce water resources.
- *Do more to document the efficiency and effectiveness of different measures.* The lessons learned on what does and does not work – and under which circumstances – need to be shared widely in order to inspire and encourage stakeholders and decision-makers.
- *Do more to assess and communicate virtual water contents, water footprints and related impacts* so that we know better how international trade patterns could be used to support decoupling where it is most needed.

6 Glossary

Absolute decoupling implies that resource use declines, irrespective of the growth rate of the economic driver (UNEP, 2011a). Absolute reductions in resource use are rare (De Bruyn, 2002; Steger and Bleischwitz, 2009); they can occur only when the growth rate of resource productivity exceeds the growth rate of the economy (UNEP, 2011a).

Allocative efficiency refers to the allocation of the resources needed for the “production” of water products and services (including services to the environment) and the allocation of the available water resources among competing “uses”, such as agriculture, domestic and industrial water supply and ecosystem use, so as to maximise the net benefits from their use. In the latter case, it means the efficiency with which a country allocates water and related resources to achieve sustainable development (GWP, 2006).

Blue water is referred to as the sum of surface and groundwater (UNEP 2012).

Decoupling refers to reducing the amount of resources such as water or fossil fuels used to produce economic growth and delinking economic development from environmental deterioration (UNEP, 2011a).

Green water is referred to as rainwater insofar as it does not become run-off (UNEP, 2012).

Impact decoupling involves increasing economic output while reducing negative environmental impacts (UNEP, 2011a).

Non-revenue water- Those components of system input that are not billed and do not produce revenue. This is equal to unbilled authorized consumption plus physical and commercial losses (ADB, 2010).

Resource decoupling means reducing the rate of use of (primary) resources (e.g. water) per unit of economic activity (e.g. Gross Domestic Product) (UNEP, 2011a).

Relative decoupling of resources or impacts means that the growth rate of the environmentally relevant parameter (resources used or some measure of environmental impact) is lower than the growth rate of a relevant economic indicator (for example GDP) (UNEP, 2011a).

Technical efficiency is the production of as much physical output as possible given a particular level of physical inputs (GWP, 2006).

Water consumption, or water abstraction, is usually described in terms of annual water withdrawal as the gross amount of water extracted from all sources, either permanently or temporarily, for a given use. Some may be returned to the original source, the rest may be consumed in the use. Consumptive use refers to water that is made unavailable for reuse in the same basin or irrecoverable, for example through seepage to a saline sink, evapotranspiration or contamination. Most agricultural water use is consumptive, being bound up in plants or consumed by evapotranspiration, whereas water abstracted for electricity

generation is nearly all returned to a water body (UNEP, 2012).

Water productivity (product units/m³ water) measures how a system converts water into goods and services. It captures the ratio of net benefits derived, for example, from crops, forestry, fisheries, livestock and industrial systems, to the amount of water used in the production process. In general terms, increased water productivity means increasing the amount of benefit - i.e. output, service or satisfaction - from a unit of water input. When the output per unit of water is monetary rather than physical, it is referred to as economic water productivity (UNEP, 2012).

Water-use efficiency (WUE) (m³/product units) is defined as the ratio of the water input to the useful economic/product output of a system or activity. It is thus the inverse of water productivity. Greater water-use efficiency would imply using less water to achieve the same or more goods and services. In statistical publications the ratio (m³/product units) is also neutrally referred to as water intensity (UNEP, 2012).

Water scarcity can be described as a physical or a social measure; it is a measure of the relationship between the use of water and its availability. For clarity, the physical term will be used in this report to denote a lack of enough water (i.e. quantity) and/or access to safe water (i.e. quality) (UNEP, 2012).

Water shortage is an absolute lack of water, where the available amount does not meet defined minimum per capita requirements for water use (UNEP, 2012). In some cases it is measured as the number of people that have to share each unit of water resource (Falkenmark *et al.*, 2007).

Water stress describes the consequences of water scarcity on ecosystems and human populations. It can be related to a decline in quality or to the level of conflicts (UNEP, 2012).

Water withdrawal usually describes the amount of water used per person. This varies considerably around the world, from 20 m³ per year in Uganda to 5 000 m³ in Turkmenistan; the average is 630 m³ per person per year from surface and groundwater sources (UNEP, 2012).

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About the International Resource Panel

The International Resource Panel (IRP) was established to provide decision makers and other interested parties with independent and authoritative policy-relevant scientific assessments on the sustainable use of natural resources and, in particular, on their environmental impacts over their full life cycles. It aims to contribute to a better understanding of how to decouple economic growth from environmental degradation. This report is the second in a series of reports of the IRP on Sustainable Water Management, providing a conceptual and analytical basis for decoupling and focusing on how decoupling can enable maximize water efficiency and productivity, reduce water pollution and at the same time support sustained growth and human wellbeing.

Working Group on Sustainable Water Management

The objectives of the International Resource Panel are to:

- a. provide independent, coherent and authoritative scientific assessments of policy relevance on the sustainable use of natural resources and in particular their environmental impacts over the full life cycle; and
- b. contribute to a better understanding of how to decouple economic growth from environmental degradation.

The rationale and overall objective of the Working Group (WG) relate to both bullet points and the core strategic basis for the work of the International Resource Panel.

The first report in the series, entitled “Measuring Water Use in a Green Economy” (UNEP, 2012), analyses the different ways for quantifying and accounting for water flows and productivity within the economy (including environmental needs). Based on data from the literature, the report provides the current state of knowledge of the different indicators and tools for quantifying water productivity and highlights why this is important for developing robust allocation and management systems that preserve the natural capital.

This second report draws on existing literature and conceptual frameworks developed by the IRP in other research, to provide a conceptual and analytical basis for decoupling policy and decision-making in water resource management. In particular, it clarifies the conditions and the context for potential actions and solutions moving towards decoupling. And provides a collection of technical and policy tools to achieve decoupling. It is therefore an important piece of work to inform the discussions on decoupling economic growth from water use and impacts and the debate on the sustainable development goals.

Access to water is becoming a limiting factor to development in many regions, due to water scarcity, a changing climate, unsustainable use and projected changes in demand. In a growing number of regions, the water that is available is increasingly threatened by pollution. Building a greater knowledge about water availability and quality in relation to water use decisions, water law and governance, under changing climate and other stresses is crucial.

This second report of the UNEP-hosted International Resource Panel (IRP) provides a conceptual and analytical basis and compelling case for decoupling policy and decision-making in water resource management. Drawing on the conceptual frameworks developed by the IRP research and the existing literature, the report provides an independent assessment of technological and policy-relevant tools and approaches for implementing the sustainable use of natural resources considering environmental impacts over the full life cycle. It explores innovative instruments and opportunities to strengthen decoupling and achieve the environmental and economic benefits of increased water-use efficiency and productivity for both developing and developed countries.

The report focuses on decoupling water resource use and impacts from economic growth in the agricultural, municipal and industrial sectors followed by larger scale system-level such as the river basin. In this globally interconnected world, it makes the case for water decoupling from a life-cycle perspective in order to avoid burden shifting between the geographic regions, such as shifting water-intensive production activities onto other countries.

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