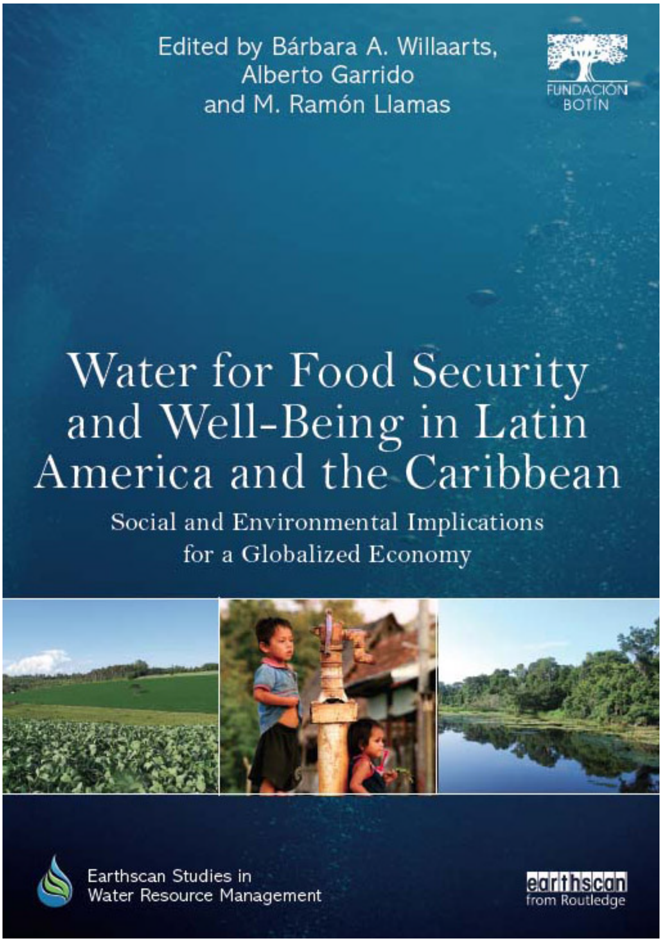

Chapter 10

Water efficiency: status and trends

To be cited as:

Donoso, G., Aldaya, M., Cabral de Sousa, Wilson Jr., Cai, X., Chico, D., de Miguel, A., Dumont, A., Gurovich, L., Lautze, J., López-Gunn, E., Pahlow, M., Pascale-Palhares, J.C., Zarate, E.(2014), Water efficiency: status and trends, In: Willaarts, B.A., Garrido, A., Llamas, M.R. (Eds.), In: *Water for Food and Wellbeing in Latin America and the Caribbean. Social and Environmental Implications for a Globalized Economy*. Routledge, Oxon and New York, pp. 261-283.

Book title

Water for Food and Wellbeing in Latin America and the Caribbean. Social and Environmental Implications for a Globalized Economy, Routledge, Oxon and New York, 432 pp.

Edited by: Bárbara A. Willaarts, Alberto Garrido and M.R. Llamas

Year: 2014

10

WATER EFFICIENCY: STATUS AND TRENDS

Coordinator:
Maite M. Aldaya, Water Observatory – Botín Foundation, and Complutense University of Madrid, Spain

Authors:
Guillermo Donoso, Pontificia Universidad Católica de Chile, Chile
Maite M. Aldaya, Water Observatory – Botín Foundation, and Complutense University of Madrid, Spain
Wilson Cabral de Sousa Junior, Aeronautics Technology Institute, São José dos Campos, Brazil
Xueliang Cai, International Water Management Institute (IWMI), Pretoria, South Africa
Daniel Chico, Water Observatory – Botín Foundation, and CEIGRAM, Technical University of Madrid, Spain
Angel de Miguel, IMDEA Agua – Madrid Institute for Advanced Studies, Spain
Aurélien Dumont, Complutense University of Madrid ,and Water Observatory – Botín Foundation, Spain
Luis Gurovich, Pontificia Universidad Católica de Chile, Chile
Jonathan Lautze, International Water Management Institute (IWMI), South Africa
Elena Lopez-Gunn, I-Catalist, Complutense University of Madrid, and Water Observatory – Botín Foundation, Spain
Markus Pahlow, Department of Water Engineering & Management, University of Twente, The Netherlands
Julio Cesar Pascale Palhares, Embrapa Cattle Southeast, Brazil
Erika Zarate, Good Stuff International, Switzerland

Contributors:
Barbara Soriano, CEIGRAM, Technical University of Madrid, Spain
Laurens Thuy, Utrecht University, The Netherlands

Highlights

- Latin America may well be water rich, but economic and urban growth from the last two decades has polluted freshwater resources of many countries.
- Several factors such as population growth, rapid urbanization, water contamination and pollution, and increased water demands due to increased economic growth are putting considerable pressure on available water resources. Decoupling economic growth from water use is at the core of innovation strategies for sustainable consumption and production and ultimately for resource efficiency.
- In LAC, as in other regions of the world, agriculture is the main user of freshwater. Within this sector about 90% of the water consumption is based on green water – rainwater stored in the soil as soil moisture.
- The greatest opportunity for improvement in water productivity and efficiency is in rain-fed agriculture through enhanced and known management practices.
- In general, irrigation efficiency of the existing systems in LAC countries is medium to low; the average irrigation efficiency for the region is reported at 39%, varying between 30 and 40%, whereas the world average is 56%.
- Urban water use in LAC also shows low technical water efficiency relative to developed countries; on average, water conveyance efficiency is reported to be 59%.
- Water efficiency in the electricity sector also shows significant room for improvement.
- Thus LAC countries must improve water use efficiencies in order to increase water and food security as well as protect aquatic ecosystems. LAC countries must consider water policy changes that provide adequate incentives to use water resources efficiently and ultimately achieve a more sustainable use of water in all sectors.

10.1 Introduction

10.1.1 Rationale for water efficiency in Latin America and the Caribbean

Latin America and the Caribbean (LAC) is graced with an abundance of fresh water, holding 31% of the world's freshwater resources (UNEP, 2010). However, several factors such as population growth, rapid urbanization, water contamination and pollution, and increased water demands due to increased economic growth are putting considerable pressure on available water resources.

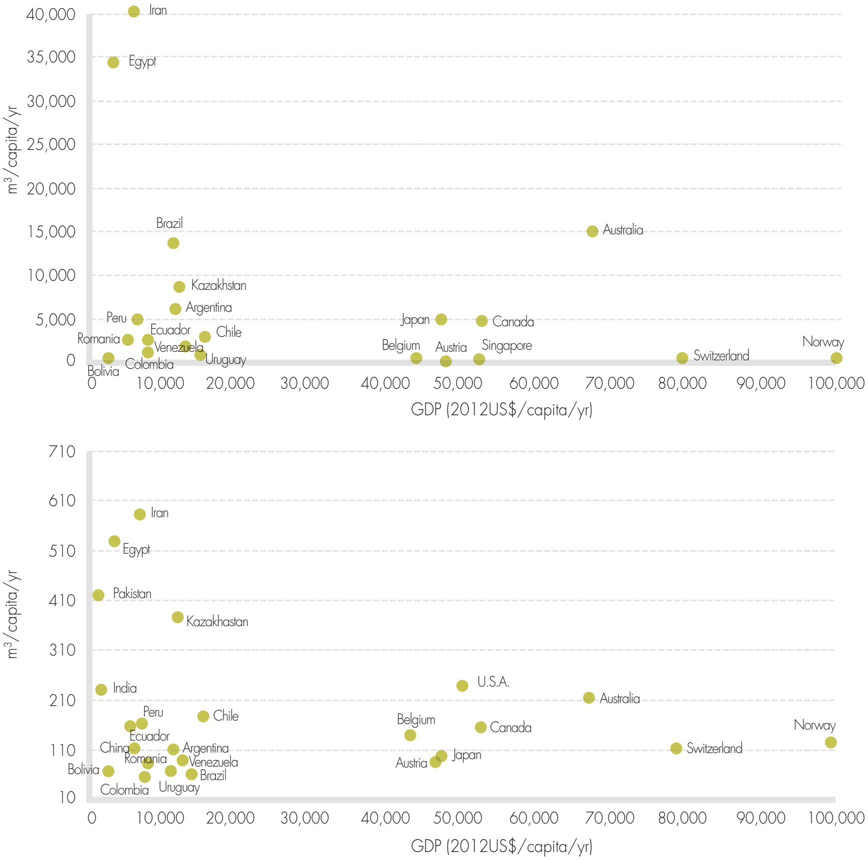

Figure 10.1 The relation between the blue water footprint of production (upper) and consumption (lower) and the level of economic development. *Source: own elaboration based on data from Mekonnen and Hoekstra (2011) and World Bank (2013).*

Available empirical evidence suggests a dubious relationship between the rates of water consumption and GDP growth in many countries (Figure 10.1).

Some developed countries (e.g. USA) and developing countries (e.g. India and China) have high water consumption rates per unit of GDP, i.e. a high water intensity ratio. Other developed countries (e.g. Singapore, Switzerland, Norway) and many developing countries have a low water consumption rate per unit of GDP (e.g. Uruguay) (Figure 10.1).

These examples suggest that relative decoupling of economic growth from water use is already happening in some countries. However, these assessments do not take into account the increases in burden shifting through virtual water flows (Gilmont, 2013). For example, OECD countries may have achieved the 'decoupling' by shifting water intensive production activities towards non-OECD countries (Figure 10.1). Decoupling should be assessed for Latin America and the Caribbean in light of the evidence that it is a net virtual water exporting region.

Empirical case studies of selected countries confirm that decoupling of economic growth from water uses and water pollution is not an automatic by-product of growth in national incomes but requires dedicated policies on improving water efficiency and water productivity at the required temporal and spatial scales.

Decoupling of economic growth from water use is critical for food security in LAC as water resource restrictions is one of the most important barriers to food production. The increase in irrigation activities has contributed to the substantial growth in agricultural production, enabling humanity to feed its growing population. However, more efficient use of green water (rainwater stored in the soil as soil moisture) and blue water (surface water and groundwater) has been stressed as one of the most important factors to achieve greater agricultural productivity (Pasha, 2002; Molden et al., 2003; Rosegrant et al., 2003).

Although improved methods and technologies have produced efficiency gains in all economic sectors, in some regions the need and potential exists for further improvements to ensure food security for a growing world population while minimizing the impacts on ecosystems and their goods and services.

Yet, the region is moving towards meeting the Millennium Development Goals (MDGs),but poor farming practices, unregulated human activity (or poorly implemented or -monitored existing regulations), including industrial development and urban poverty, have negatively affected LAC's water resources (UNEP, 2013). Additionally, given the region's rate of population growth, rapid urbanization and current patterns of water use, sustaining an adequate water supply for future generations is an increasingly important issue. There are many opportunities to enhance water efficiency and management in the region.

This chapter reviews the efficiency of water resources use in LAC. For this purpose, first of all, it provides the concepts and definitions together with the drivers for water efficiency. Second, it analyses the efficiency of water resources use in Latin America, looking at the water users in different sectors: urban and industry, agriculture, energy and the environment. Finally, it provides a summary of challenges and opportunities for enhanced water efficiency and management across the region.

10.1.2 Definitions and approaches

Achieving an efficient use of natural resources and other factors of production is a common goal of many current policies towards sustainability. Efficiency can be defined in general terms as the ratio between a desired output and an input, that is, the quantity of resource consumed in the process. Improving efficiency means creating more value with less resource consumption. However, depending on the scale and the disciplinary approach, the formulation of this indicator and the possibility of increasing it, imply different approaches (Jollands, 2006). Particularly in the case of water, three main interpretations for efficiency are usually recognized: technical efficiency, water productivity and economic or allocation efficiency (GWP, 2006).

- Technical efficiency considers the rate of physical application of water to its desired purpose. This factor can be defined for all the water uses in every sector. In agriculture, the value depends mainly on the technique (e.g. surface, drip irrigation) but also on the management system such as the mode of application of water linked to this technique (turns, on demand) and other factors (maintainability) allowing for the correct use of technology. Thus, factors other than the change of technique can lead to efficiency improvement.
- Water productivity is defined as the ratio between an output linked to a use and a water volume input. It provides a description of how well water resources are made productive (i.e. generating value) in their different uses.
- Economic or allocation efficiency deals with the objective of allocating the resource in order to maximize the net social benefits for society. It represents a general criterion characterizing the distribution of water between users (not a technical ratio attached to a specific use) (Wichelns, 2002). Possibilities to improve efficiency are linked to the economic instruments and governance arrangements, such as water markets, water rights reallocation, or the virtual water trade, leading to a higher benefit from the use of the available resources.

A comprehensive assessment of the relationship between green water (rainwater stored in the soil as soil moisture), blue water (surface water and groundwater) and grey water (volume of freshwater polluted) and economic efficiency should also consider the efficiency of the use of other resources, such as financial capital, labour or energy, in obtaining water services. Indeed, not only obtaining more benefit per unit of water is important but also more water per unit of other resources (GWP, 2006). For instance, this is also relevant in the debate on the efficiency between private and public sectors (Pierce, 2012).

It is also important to remember that these definitions are only valid within the broader economic context and other social objectives in order for efficiency not to be considered the final objective (Adger et al., 2003). For the most part, a higher efficiency does not mean that total consumption will be reduced as other incentives may govern resource use. Moreover, efficiency can make a resource cheaper, or increase its availability, incentivizing new uses (Pfeiffer and Lin, 2010; Dumont et al., 2013).

10.1.3 Determinants of the adoption of water conservation technologies

Theoretically speaking, the scarcer a resource becomes, the more likely it is that technologies will be adopted to save this resource. Empirical studies demonstrate that the scarcity of water resources is an important driver of water-saving technology adoption (see e.g. Schuck et al., 2005). However, water-saving technology adoption will increase in response to augmented water shortage only if users perceive that adoption will lead to water savings or generate other benefits.

In agriculture, the most important determinant of technology adoption is ultimately the farmer’s perception of the incremental benefits and costs to his own farm income (Sharma and Sharma, 2004; Blanke et al., 2007). Hence farm-level perceptions of the water-saving properties and the impacts on income of each water-saving technology are critical determinants of the successful adoption of water conservation technologies.

Perry et al. (2009) state that farmers invest in improved irrigation technology for a variety of reasons, including increased income, risk aversion/food security, convenience and reduced costs. Varying prices for market goods, land, labour, water, electricity, energy, inputs, technology and soil management change farmers' perceptions on the value of water relative to these inputs. The farmers respond to market rules searching for the highest return per unit of land or water, depending on the relative scarcity of both resources (Ali and Talukder, 2008).

Studies demonstrate that public, government-supported extension of water-saving technologies has a positive effect on adoption of water conservation technologies (Schuck et al., 2005). Generally speaking, government policies promote the adoption of water-saving to incentivize water users to increase their technical and economic efficiency (Sharma and Sharma, 2004; Blanke et al., 2007).

Dagnino and Ward (2012) found that water conservation subsidies that promote a change from surface to drip irrigation can increase the demand for water despite the absence of new depletable supplies. Findings show that where water rights exist, water rights administrators will need to safeguard against increased depletion of the water source with increased subsidies that reward reduced water applications. There is a need for good water accounting as discussed by Molden et al. (2010), to take into account these environmental impacts of the adoption of water conservation technologies.

10.2 Methodology and data for evaluating water use efficiency and its socio-economic implications

The methodology follows the different approaches to efficiency as presented in the introduction: technical efficiency, water productivity, economic efficiency and efficiency in the provision of water.

10.2.1 Methodology and data to evaluate technical efficiency

10.2.1.1 Specific uses/local scale

Technical efficiency considers the rate of physical application of water to its desired purpose (eq. 1). Therefore, it is a percentage indicating how well a technique or mode of distribution delivers water.

Thus, the technical efficiency (eff) can be defined as:

$$\text{eff}= \frac{\text{water delivered for the intented use}}{\text{water withdrawals}} \tag{1}$$

This expression is valid for all water uses. For instance, in the urban sector, efficiency of water delivery characterizes how much water is lost during its distribution to the final user. However, a priori this ratio must be considered as a partial indicator only. Particularly low efficiencies calculated according to this indicator do not mean that excess water is wasted or lost as return flows can generate value once they go back to the river basin.

A more detailed characterization of water use and reuse potentialities can be obtained based on the quantification of fractions (Perry, 2007). Water use is divided into:

- Consumed fraction (evaporation and transpiration) comprising beneficial consumption (water evaporated or transpired for the intended purpose) and non-beneficial consumption (water evaporated or transpired for purposes other than the intended use);
- Non-consumed fraction, comprising the recoverable fraction (water that can be captured and reused) and non-recoverable fraction (water that is lost to further use).

This allows for the differentiation between uses that remove the water from further use (evaporation, transpiration, flows to sinks) and those uses that have little quantitative impact on water availability (e.g. navigation, most domestic uses).

An alternative expression of efficiency could be the ratio between water delivered for the intended use and total water evaporated (eq. 2). It is particularly meaningful in the case of irrigation, as it would indicate the distribution between evaporation and plant transpiration.

$$\text{eff}= \frac{\text{water delivered for the intended use}}{\text{total evaporated water}} \tag{2}$$

10.2.1.2 At the basin scale

The principal consequence of not identifying the potential reusability of return flows is that an increase in efficiency (first definition) may lead to downstream users being deprived from resources they were receiving. Other unintended effects should also be taken into account. For instance, switching from surface irrigation to sprinkler or drip irrigation implies that farmers will potentially have greater flexibility in their water use (on demand instead of turns), allowing the improvement of yields or growing crops that are more sensitive to water shortage (Dumont et al., 2013). This will increase water productivity but also water consumption.

The traditional approach of technical efficiency applied at the catchment or river basin level implies the consideration of the ratio between water consumption (total evapotranspiration, ET) and the basin's total resources. For a closed basin (i.e. where all the resources are allocated) this ratio is close to 100%. This result has sometimes been interpreted as efficiency and cannot be improved in this situation. However, this refers to technical efficiency and not economic efficiency (see section 10.2.3). In a closed basin, therefore, there exists the possibility of improving the total value of water use, even though 100% technical efficiency is achieved.

10.2.2 Methodology and data to evaluate water productivity of specific uses

Water productivity (WP), defined as WP = product/water consumed [mass/volume] (i.e. the inverse of the sum of the green and blue water footprint), is used at plant, field and farm scale. Many times total withdrawal is considered in the expression of WP. It should be observed, however, that this would lead to technical efficiency ratios (as described in the previous section).

Looking at the biophysical level first, WP is an efficiency parameter of the crop production process, where water (as well as other inputs) is subject to a transformation process of crop or biomass production, owned and managed by the farmer. We define green water productivity $WP_{green}=yield/ET_{green}$ as the water productivity in rain-fed agriculture. For irrigated agriculture, blue water productivity is the difference between total water productivity and green water productivity ($WP_{blue}=WP_{total}-WP_{green}$).

In the industrial sector, water use efficiency is commonly determined as the ratio of production and water withdrawal. Here we use consumption in the denominator, not withdrawal.

The notion of WP can also be applied in a wider sense, by attributing different values to the numerator. This is commonly done in water valuation approaches, where economic attributes can be given in monetary terms (e.g. US$), social attributes (e.g. jobs, food security), or environmental attributes (e.g. carbon sequestration, biodiversity).

Pollution is not formally included in water efficiency or productivity measures, yet polluted water may reduce yield and hence enters the equation for crop WP indirectly. However, it ought not to be neglected, especially when considering urban environments, industry and other sectors. In the end, water pollution is also a form of water use that subtracts from other uses (e.g. due to pollution of return flows or salinization). It is therefore worth pursuing efficiency increases in those areas, which means: lowering the pollution per unit of production.

10.2.3 Economic efficiency: characterizing the allocation of water resources at the basin scale or amongst other geographical areas

Indeed, at this scale allocative efficiency considers re-allocating and co-managing water among uses by re-allocating water from lower value to higher value uses within and between sectors, thereby mitigating adverse impacts (Wichelns, 2002; Molden et al., 2003). At the same time environmental flow requirements need to be identified and managed (Richter et al., 2011). The total amount of water allocated in a river basin needs to be based on the maximum sustainable water footprint level of that basin (Hoekstra, 2013).

Value can be expressed in monetary terms (e.g. $/litre), food calorie terms (e.g. kcal/litre), energy terms (e.g. MJ/litre). Evaluation of water productivity should be carried out both in a physical sense (more crop per drop), and in an economic sense (more value per drop), in order to obtain the greatest benefit.

Economic water productivity (as defined in the previous section) provides a tool to attribute value and productivity to all water uses and users within a hydrological domain, and not only those pertaining to irrigated agriculture. When based on hydrological accounting of actual water consumption, a value (whether economic, social, ecological or agronomic) can be attributed to all water uses and reuses, including those that tend to be left unaccounted for in irrigation efficiency approaches as 'wasted fractions' non-utilized by irrigation (van Halsema and Vincent, 2012).

The water available within a catchment or river basin for allocation purposes is determined by the water balance equation:

$$P=ET+R+D\pm\Delta S \tag{3}$$

where P is precipitation, ET is evapotranspiration, (evaporation, E and transpiration T), D is drainage and ΔS is the change in soil moisture. In order to assess whether or not a new technology that is available to farmers is beneficial to society, one needs to calculate net social returns instead of net private returns. The two concepts are identical, except that net social returns value all inputs and outputs at social prices, not market prices. Social prices are identical to market prices when well-functioning markets exist. When well-functioning markets do not exist, as is almost always the case with water, then one must attach a social value to water, which is defined as the value of the water in the best alternative use (at the margin) (Barker et al., 2003).

10.3 Technical efficiency in the use of water resources in Latin America from the production perspective

10.3.1 Urban and industrial uses

According to UN data for the year 2011, 78% of the population in the LAC region is concentrated in cities and this figure is increasing. Indeed it is expected to reach 86% by 2050. This trend carries with it the difficult task of satisfying the needs of existing megacities and balancing the environmental impacts that derive from them such as increased direct and indirect water consumption. Efficiency increases in the use of water in this context represents a way of limiting water stress and thus reducing the impacts of population growth and urbanization.

In LAC, technical efficiency in urban water supply is rather low. In Brazil, 37.57% of the water is lost (ANA, 2013). In Nicaragua, this figure reaches 25% in urban areas (GWP, 2011), and in the case of Colombia it was 20.5% in 2004 (ICC, 2007). The Inter-American Development Bank reported that 56% and 60% of the water was either lost or irregularly consumed in the water sector in Ecuador and Venezuela respectively (CAF, 2013). Approximately 36% of the water is lost in Mexico (Aguilar and Castro, 2010).

The Americas Association of water regulators surveyed water utilities in 2011. They obtained responses from twenty-three utilities in seven countries. On average, water conveyance efficiency is reported to be 58.81%, but ranges from 30.88% in Paraíba to 92.5% in Ceará, both states of Brazil. However, only ten out of twenty-three companies reported any data.

Nonetheless these figures do not reflect the complete picture. The quality of the services needs to be improved (CEPAL, 2010), not only the quality of the service as such (pressure, hours of service, reliance) but also the quality of the water for consumption (GWP, 2011).

Many problems for urban water management are rooted outside the urban scope. A recent report (GWP, 2011) mentions that unsustainable land management (soil and forest management), as well as industrial and agricultural pollution affect urban water availability and quality. Solutions for water provision and degradation are more feasible if a more systemic view of water resources, considering ecosystem services, is taken, which would require the adoption of integrated water management (GWP, 2012). Under this framework, water planners link basin level water management to the cities' water management and also consider the combined management of surface and groundwater resources (GWP, 2012).

10.3.2 Agricultural use

In LAC, as in many other regions of the world, agriculture is the main user of freshwater. However, the large and growing proportion of the population living in urban areas as well as the increased water demand from a growing industry and mining sector in LAC, in addition to reduced water supplies due to increased water pollution and climate change will put considerable pressure for continued transfers of water away from agriculture.

Trends in individual country's economies in LAC, the contribution and importance of agriculture to each of these national economies, trends in agricultural exports and the share of people employed in agriculture are all important factors underlying the development of irrigation and other water uses in the region. Since LAC's GDP growth for 2012 is projected to be 3.2% and 4.0% in 2013, compared to 1.6% and 2.2% in the OECD countries (see Chapter 4) and given that the decoupling of economic growth from water uses and water pollution is not yet generalized in the LAC region, increasing water efficiency in agriculture is a major challenge. However, there has been a decrease in the investment in irrigation in LAC in the last years (Molden, 1997; CAWMA, 2007; Ringler et al., 2010).

Focusing on South America and the Caribbean, the total irrigated area is around 18.6 millions of hectares; corresponding to only 7% of the world's total estimated irrigated area (CAWMA, 2007). Brazil has 3.5 million irrigated hectares, followed by Chile, Argentina and Bolivia. In general, irrigation in South American countries has been inefficient; a major weakness is the failure to provide adequately for the operation and maintenance of irrigation systems once construction or installation is completed (Garces-Restrepo et al., 2007).

Thus, in general irrigation efficiency of the existing systems in LAC countries falls below expectations. However, some efficient irrigation systems exist in the region, such as the case of banana production in Ecuador and fruit and vineyards in Chile (Ringler et al., 2010). With few exceptions, agricultural water use in general has been inefficient in LAC due to the predominance of traditional surface irrigation technologies; FAO (2003) reports that 95.6% of irrigated lands in LAC are surface irrigated; 2.7% use sprinklers and just 1.7% use localized irrigation (drip and micro-sprinkler). These percentages indicate that there is considerable potential to increase water productivity in the region by switching to more efficient water application methods (de Oliveira et al., 2009).

In the LAC region, the levels of technical irrigation efficiency are medium to low, in the range between 30% and 40% (Figure 10.2). In its country database, FAO (2013) includes average irrigation efficiencies for LAC countries (referred to as water requirement ratios) ranging from 18% (Costa Rica) up to 48%, 51% and 65% (Brazil, Paraguay and Puerto Rico respectively). The average for the region is reported at 39%, whereas the world average is 56%. Field estimates in various irrigation projects in Brazil, for example, resulted in average actual and potential water application efficiencies of 40 % and 60%, respectively, for conventional and improved irrigation systems (Ringler et al., 2010). The introduction of efficient irrigation systems in Chile during the past fifteen years has led to a significant increase in the proportion of irrigated land with efficient irrigation technology; at present, 30% of Chile's total irrigated surface is equipped with efficient irrigation technologies such as drip and sprinkler systems. This trend has led to an overall irrigation efficiency of 58% in the last ten years. Brazil shows progress towards a better application of water with 59% of irrigated lands being under surface irrigation, 35% with sprinkler irrigation, and 6% with localized irrigation; here water scarcity and farm characteristics have encouraged the use of more efficient irrigation methods. Thus, in order to ensure water and food security in LAC, there is a need to improve water efficiency, both in humid and arid regions.

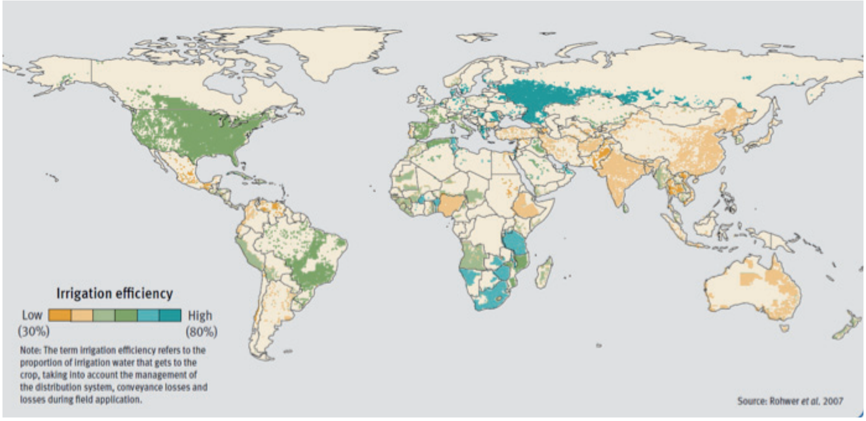

Figure 10.2 Global irrigation efficiencies, year 2000. *Source: UNEP (2012).*

In a comprehensive evaluation of 144 projects that adopted sustainable agricultural technologies and practices, including several studies in LAC, Pretty et al. (2006) demonstrate that the greatest opportunity for improvement in water productivity, i.e. marketable yield divided by crop water consumption, is in rain-fed agriculture. Water-related risks due to high rainfall variability can successfully be reduced by improved farm management, thereby avoiding low productivity or crop failure. Adequate measures include (supple-mental) irrigation, soil, and nutrient and crop management.

However, inadequate agricultural water use in LAC is salinizing, waterlogging, and eroding agricultural lands and polluting water for agricultural use. Most salinization problems originate from the inefficient use of water. Argentina and Chile have about 35% of their irrigated lands affected by salinity whereas 30%, equivalent to 250,000ha, of the coastal region of Peru under irrigation is also impacted by this problem. In Brazil 40% of the irrigated land in the northeast is affected by salinity as a result of improper irrigation (Ringler et al., 2010).

10.4 Water productivity in the use of water resources in Latin America from the production perspective

In the LAC region as a whole, the largest water user is the agricultural sector, amounting to 99% of the green and blue water consumption and 46% of the nitrogen-related pollution (Figure 10.3). Urban water supply represents as much as 0.5% of the total water consumed and 37% of the total nitrogen pollution. Meanwhile the industrial sector represents just 0.1% of the total water consumed and 17% of the total nitrogen pollution.

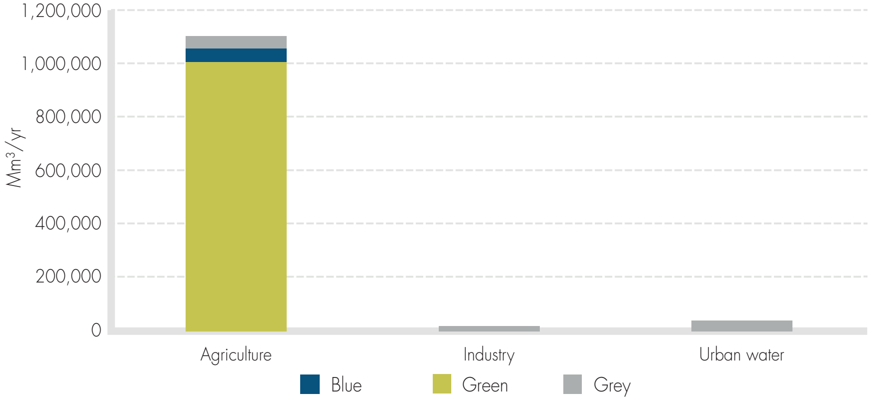

Figure 10.3 The annual water footprint of national production in LAC (in million cubic metres, Mm³), average for the period 1996–2005. *Source: Mekonnen and Hoekstra (2011)*

10.4.1 Urban and industrial uses

Figures 10.4 and 10.5 show the water footprint for domestic water supply and for industrial production for several countries of the LAC region. These values are inversely related to water productivity as was defined in section 10.2.2.

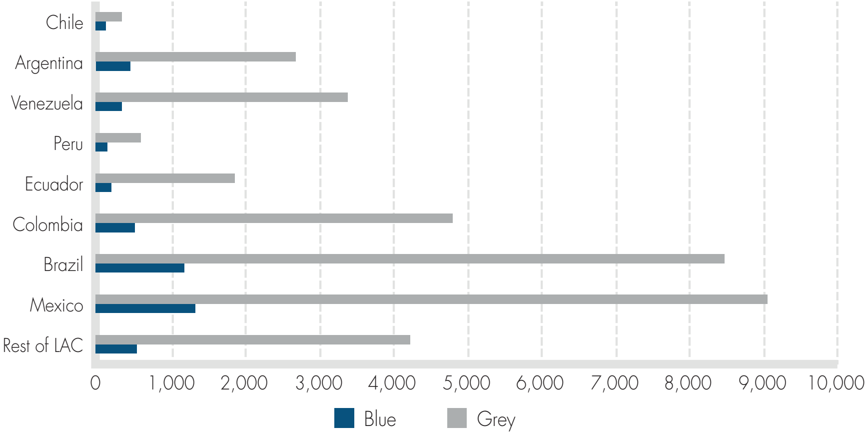

Figure 10.4 Annual water footprint of domestic water supply (in million cubic metres, Mm³), average for the period 1996–2005. *Source: Mekonnen and Hoekstra (2011)*

The water footprint of domestic water supply is determined by the grey water footprint; the grey footprint represents close to 88% of LAC's total water footprint for domestic water supply. Mexico has the highest value for its grey water footprint of domestic water supply and sanitation, followed by Brazil, Colombia, Venezuela and Argentina, in decreasing order. These five countries represent approximately 80% of LAC's domestic water supply grey water footprint. On the other hand, Chile has one of the lowest grey water footprints for domestic water supply for the southern sub-region. This is a reflection of the significant increase in the coverage of water treatment in the past decade, which has changed from 10% in 1990 to 80% in 2010.

Chile and Peru have the lowest blue water footprints for domestic water supply, accounting for 6% of LAC's total domestic supply blue water footprint. In contrast, Brazil and Mexico have the highest blue water footprints; theirs being eight times that of Chile and Peru.

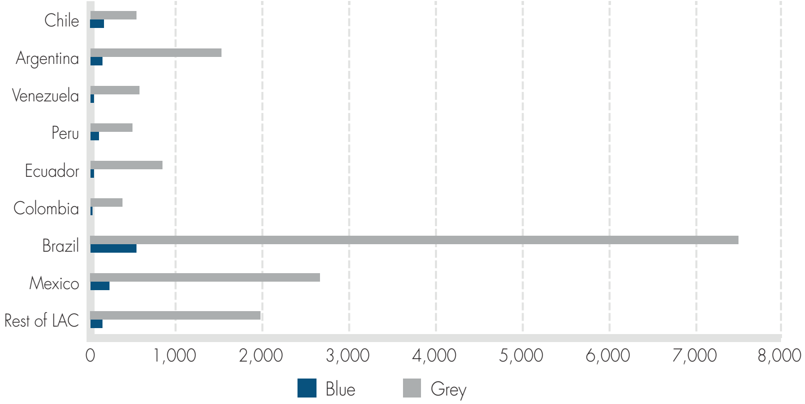

Figure 10.5 Annual water footprint of industrial production (in million cubic metres, Mm³), average for the period 1996–2005. *Source: Mekonnen and Hoekstra (2011)*

As was the case with the domestic water supply water footprint, the industrial production water footprint is mainly composed of the grey water footprint. The industrial production grey water footprint accounts for over 90% of its total water footprint. However, it is important to note that the industrial grey water footprint is less than half the value of the domestic water supply grey footprint. Brazil is by far the country with the highest industrial production grey water footprint. Mexico, the country with the second highest grey water footprint related to industrial production has a grey water footprint 65% lower than that of Brazil. Chile and Peru have the lowest figures, while Argentina has a medium-level industrial production grey footprint.

Mexico and Brazil also have the highest industrial production blue water footprint, thus these countries have the lowest industrial water productivities. The highest blue water productivities for industrial production are found in Colombia, Ecuador, and Venezuela; their industrial blue water footprints range from 20 to 45Mm^3/yr. Medium industrial blue water productivity countries are Argentina, Chile, and Peru, with industrial blue water footprints from 102 to 158Mm^3/yr.

10.4.2 Agricultural use

It is evident from Figure 10.6 that the LAC region relies extensively on rain-fed production systems, as the green water footprint is the most important component of the total crop production water footprint in LAC. Crop production in Argentina and Brazil has the highest crop production water footprint (Figure 10.6) whilst Mexico has a crop water footprint close to the average for the rest of LAC.

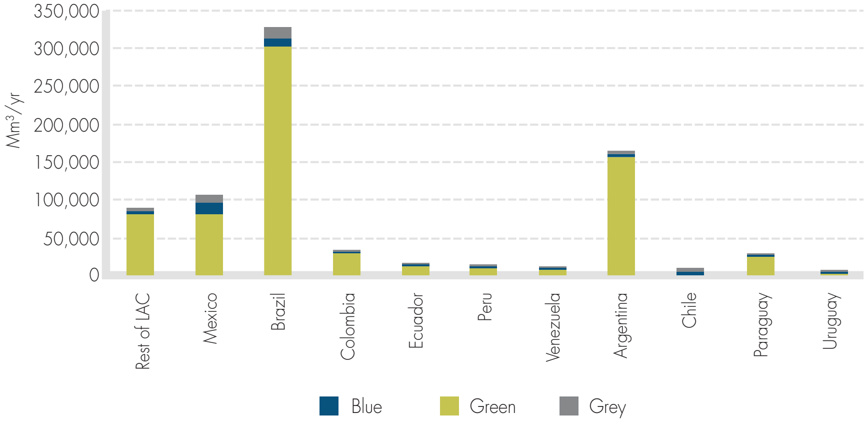

Figure 10.6 Total water footprint of agricultural crop production for the LAC region (average 1996–2005). *Source: Mekonnen and Hoekstra (2011).*

Mexico and Brazil have the highest blue water footprint for crop production, ranging from 9,000 to 14,000Mm^3/yr. Medium-range crop production blue water productivities can be found in Peru, Argentina, Chile and Colombia; the average blue water footprint of these countries ranges between 2,500 and 4,000Mm^3/yr.

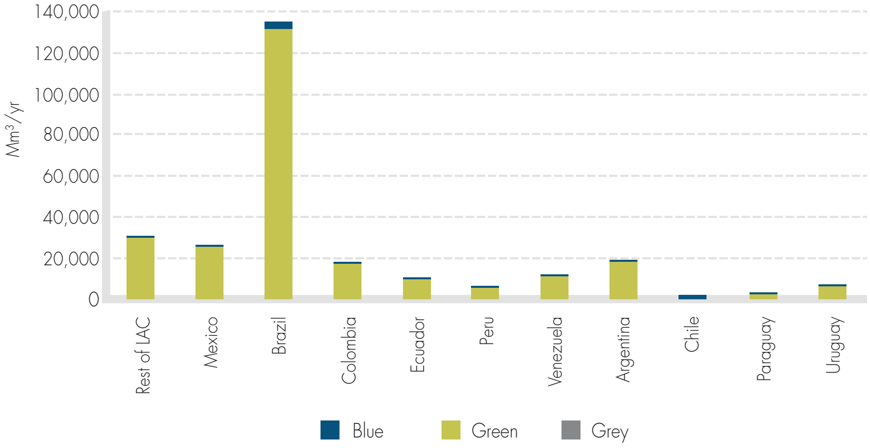

Figure 10.7 Water footprint of livestock production (Mm³/yr), period 1996–2005. *Source: Mekonnen and Hoekstra (2011).*

As in the case of crop production, the most significant component of livestock's water footprint in LAC is the green water footprint (Figure 10.7). Brazil stands out as the country with the highest water footprint of LAC countries although livestock's blue water footprint only represents 4% of the total water footprint in this country.

10.4.3 Energy production

The relationship between water and energy is mainly characterized by hydropower generation. The main hydropower producing countries in the world belong to the OECD and are responsible for 42% of the entire hydroelectric output. Asian countries are responsible for 26%, where China is the main contributor. LAC has a hydropower production share of 20%, mostly contributed by Brazil, which produces almost 12% of the world's total. In Brazil, 75% of the electric power is provided by hydropower.

Hydropower generation is generally associated with a reservoir, which accumulates water in order to maintain a regular flow regime. The evaporation rates in these reservoirs drive water losses in watersheds with hydroelectric dams or reservoirs. This factor gives hydropower dams a consumptive profile in terms of water use, an important fact which is in general overlooked in national or regional water plans.

An interesting indicator of water efficiency in the case of hydropower reservoirs is the ratio between the amount of water evaporated and the capacity for electricity generation. Mekonnen and Hoekstra (2011), exploring this indicator, have presented a preliminary study on hydroelectricity water efficiency. The authors used an evaporation database of thirty-five hydropower reservoirs throughout the world, eight of them in Brazil. The authors' results indicate that hydropower's blue water footprint averages from 140 and 244L/kWh for potential capacity and real charges, respectively.

In Brazil there are more than a hundred hydropower reservoirs with nominal capacities over 30MW. Sousa and Reid (2010) presented a blue water footprint assessment of the main Brazilian hydropower reservoirs, based on their estimated evaporation rates. They have found values ranging from 0.47 to 399.84L/kWh, for sixty-six studied reservoirs. The average blue water footprint was 35.46 L/kWh. The results are not directly comparable to Mekonnen and Hoekstra's range due to methodological differences with respect to real evaporation estimates. For the case of Chile, the average blue water footprint of hydroelectric reservoirs was 45L/kWh.

A similar study conducted by Torcellini et al. (2003) has estimated an average blue water footprint of 68L/kWh for the US's hydropower reservoirs. Blue water footprints of hydropower reservoirs are generally much higher than those of other energy sources. For example, Torcellini's values for hydropower reservoirs are thirty times higher than those found for thermoelectric plants.

10.5 Economic efficiency in the use of water resources in Latin America from the production perspective

As mentioned in section 10.4, in the LAC region as a whole, the largest water user is the agricultural sector, accounting for 99% of the green and blue water consumption and 46% of the nitrogen-related pollution (Figure 10.3), while it accounts for between 1 and 23% of the total Gross Domestic Product (GDP) and employs from 1 to 36% of the economically active population. Urban water supply represents as much as 0.5% of the total water consumed and 37% of the total nitrogen pollution. Meanwhile the industrial sector represents just 0.1% of the total water consumed and 17% of the total nitrogen pollution, while it contributes from 15 to 68% to the GDP that it generates and employs from 13 to 32% of the economically active population.

Economic efficiency of water use for the industrial sector in LAC is on average US\$ 155/m^3 (see Figure 10.8). Agriculture's water efficiency in LAC is significantly lower, with an average value of US\$ 5/m^3.

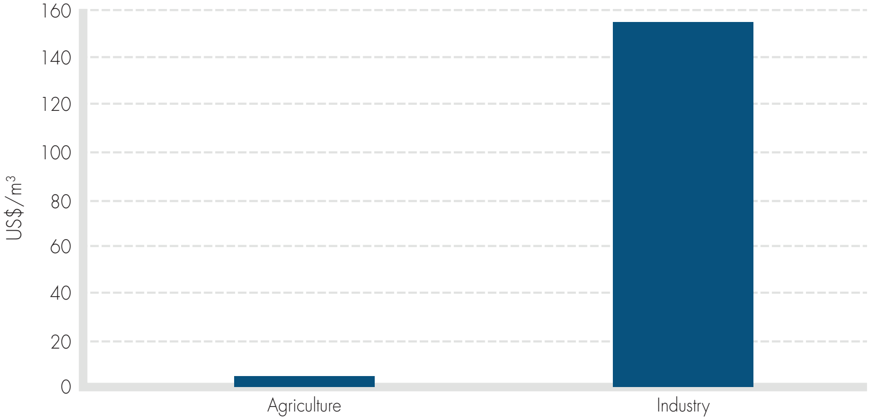

Figure 10.8 Economic water productivity (US\$/m^3) in agriculture and industry in LAC countries (2011). *Source: Mekonnen and Hoekstra (2011).*

10.5.1 Industrial use

As Figure 10.9 indicates, Colombia, Venezuela, and Uruguay are LAC countries with the highest economic water efficiencies in the industrial sector. These countries present economic water efficiencies from US$ 280/m^3 to US$ 300/m^3.

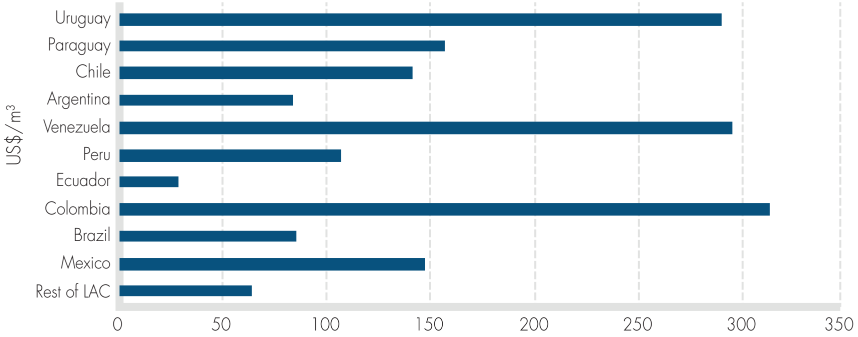

Figure 10.9 Economic water efficiency of industrial production for the LAC region (average 1996-2005) (US$/m^3). *Source: Mekonnen and Hoekstra (2011).*

Paraguay, Mexico, Chile and Peru show medium figures for the economic water efficiency indicator for their industrial sector (US$ 140/m^3 to US$ 155/m^3). The countries with the lowest economic water efficiency in their industrial sectors are Ecuador, Argentina, and Brazil, with an economic efficiency indicator which varies between US$ 27/m^{3}and US$ 80/m^3.

10.5.2 Agricultural use

As pointed out previously, agriculture is the productive sector with the lowest economic water efficiency, with values between US$ 0.15/m^3 and US$ 35/m^3 (see Figure 10.10). The highest economic water efficiencies can be found in Venezuela and Uruguay. All other LAC countries have low economic water efficiencies for their agricultural sectors which are all less than US$ 1/m^3.

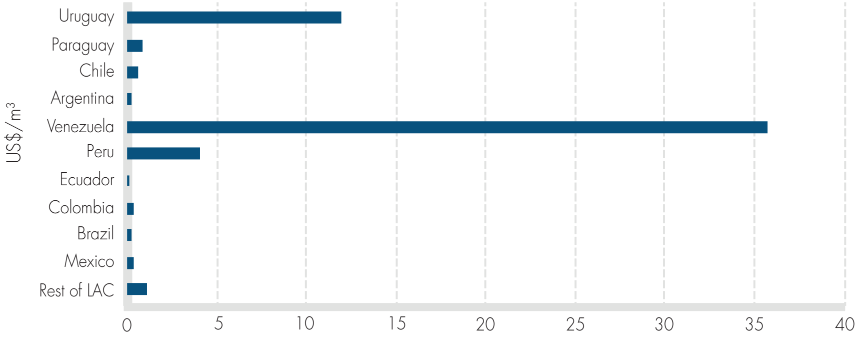

Figure 10.10 Economic water efficiency of agricultural production for the LAC region (average 1996–2005) (US$/m^3). *Source: Mekonnen and Hoekstra (2011).*

10.6 Environmental impacts of increased water efficiency

With reference to the environment, environmental efficiency is defined as the ratio of the minimum feasible use of an environmentally detrimental input to the observed use of said input, given the technology and the observed levels of outputs and conventional inputs (Reinhard et al., 2002). Whilst resilience is defined as the ability of a system to withstand perturbations or shocks (Gunderson and Light, 2006). In the case of water ecosystems, these perturbations could come from droughts or floods for example, or could be related to changes in water availability and water quality. Thus, improved efficiency in water use in an economic sector such as agriculture or urban water demand could increase the occurrence of environmental impacts in other ways (Box 10.1). However, it could also improve water availability in terms of both the quantity and the quality of the water. For example, the modernization of irrigation infrastructures is likely to increase energy demand, which in turn could increase water requirements to produce this energy. Thus, it is important to consider these environmental effects when projects that increase water efficiency are evaluated. The current challenge is to improve water efficiency whilst maintaining environmental sustainability (Ulanowicz et al., 2009).

Box 10.1 Environmental implications of irrigation modernization

[Adapted from Eugenio Gómez Reyes 'Inventario de recursos hídricos e implicaciones de la modernización del riego' in LA-Mexico (2012)]

Modernization of irrigation is widely viewed as a water-conservation strategy by policy makers who wish to increase water availability for human consumption and the environment. However, the adoption of more efficient irrigation technologies has not always achieved this desired result. There may be a rebound effect; water efficiency means the same production can be delivered with less water, but in fact more can be produced with the same amount of water. Furthermore, irrigation modernization reduces return flows, decreasing available water resources downstream. Additionally, reducing return flows leads to less leaching of pollutants; however, water available to absorb the contamination is also reduced. Ward and Pulido-Velázquez (2008) developed an integrated basin-scale analysis in the Upper Río Grande basin of North America (New Mexico) in order to study the effects of several water conservation policies on irrigation use and on water saved. They observed that incentive-based water conservation tools promote a change in the crop mix with more productive and water-intensive crops thus increasing the net farm income but also increasing the total water depleted. Subsequently, the adoption of water conservation technologies leads, in several cases, to an expansion of irrigated acreage (Pfeiffer and Lin, 2010).

During the last few decades, several irrigation programmes have been developed by Mexico's government in an attempt to improve water efficiency in irrigated agriculture. These water conservation programmes have often been developed without considering important factors in decision-making such as an integrated basin-scale analysis. Despite the large financial resources allocated in these projects, the main objective of water saving has not been achieved. Similarly, an analysis of Chile's agricultural census data of 1997 and 2007 indicates that irrigation efficiencies have increased significantly reaching 58% in 2007. However, during the same period, agriculture's water footprint increased. Thus it can be seen that policies focused on reducing water application do not necessarily always lead to water conservation.

As such Li and Yang (2011), conclude that a system's network must maintain a balance be-tween two essential but complementary attributes: efficiency and resilience. This is demonstrated in the current renewed interest of environmental water flows. In general it is an 'abstract water use' representing water quantities that ought to be maintained in streams and underground in order to sustain the system's functionality. According to Holling and Meffe (1997) the pathology of natural resource management arises when the range of natural variation in a system is reduced thereby producing resilience losses. In short, the balance to be struck be-tween the efficiency in the system (performance) and its resilience (reserve capacity) means en-suring more resource efficient systems: which use less land, water and inputs in order to pro-duce more food sustainably, while at the same time maintaining resilience to changes and shocks. Thus, this section introduces a certain note of caution in the pursuit of efficiency.

10.7 Conclusions and recommendations

The LAC region is fortunate enough to be endowed with an abundance of freshwater, possessing 31% of the world's freshwater resources (UNEP, 2010). This has contributed to the general perception that water is an abundant resource that is always available. This culture of abundance combined with a low educational level of farmers has resulted in the inefficient use of water. Moreover, several factors such as population growth, rapid urbanization, and increased water demands due to increased economic growth are putting considerable pressure on available water resources. Decoupling economic growth from water use is at the core of innovation strategies for sustainable consumption, production and ultimately resource efficiency.

In LAC, as in other regions of the world, agriculture is the main user of freshwater and more than 90% of the water consumed by this sector is green water. The greatest opportunity for an improvement in water productivity and efficiency is in rain-fed agriculture through enhanced and known water management practices. In general, irrigation efficiency of the existing systems in LAC countries also falls below expectations, due to the predominance of traditional surface irrigation technologies. In this region, irrigation effi-ciency ranges between 30 and 40% with the average reported at 39%; whereas the world average is 56%. These percentages indicate that there is a great potential of increasing water productivity in the region by switching to more efficient water application methods. However, future increases in irrigation efficiency in LAC countries must minimize unwanted consequences such as salinization, waterlogging, and increases in total water consumption (rebound effect).

Urban water use in LAC also has low technical water efficiency figures relative to developed countries; on average, water conveyance efficiency is reported to be 58.81%. Therefore increasing water demands due to a growing population and rapid urbanization requires increased technical efficiencies in the urban sector. There is also room for improvement with regard to the water efficiency in the electric sector.

Thus LAC countries must improve their water use efficiencies by addressing the following three major challenges (UNEP, 2011; 2013). First, the development of a water accounting system that considers the environment. This is essential in order to achieve the goals of increased water efficiency in a sustainable manner. That is, minimizing undesired environmental impacts such as salinization, decreased water availability for downstream users and increased total water consumption. Second, the implementation of transparent and comprehensive accounting systems will serve as an incentive to adopt best water management practices in agriculture so as to reduce environmental impacts. Third, the development of effective coordination mechanisms between authorities from different sectors and policies, at both national and river basin level, could ensure that their policies and objectives are mutually consistent and do not undermine each other.

In addition, appropriate policy instruments must be considered that provide adequate incentives to use water resources efficiently and ultimately achieve a more sustainable use of water in all sectors. This means that water users must consider water as a valuable resource; that is, water should be considered an economic good, as was originally recognized at the Dublin conference on Water and the Environment (ICWE, 1996). There are several policy instruments available that internalize the value of water resources when making water-use decisions; examples of these are water tariffs, water pricing, and water rights markets, among others. Chapter 13 gives an in-depth analysis of the use of these policy instruments in LAC countries.

References

Adger, W.N., Brown, K., Fairbrass, J., Jordan, A., Paavola, J., Rosendo, S. & Seyfang, G. (2003). Governance for sustainability: towards a 'thick' analysis of environmental decision making. *Environment and Planning A,* 35(6): 1095–1110.

Aguilar, B.I. & Castro, J.L. (2010). *Principios Gerenciales y Eficiencia Operativa de los Servicios del Agua: Los casos de Saltillo, Tijuana y Monterrey,* Banco de Desarrollo de América del Norte (BDAN).

Ali, M.H. & Talukder, M.S.U. (2008). Increasing water productivity in crop production — A synthesis. *Agricultural Water Management,* 95(11): 1201–1213.

ANA (2013). Agência Nacional de Águas (Brazil). [Online] Available from: www.ana.gov.br. [Accessed May, 2013].

Barker, R., Dawe, D. & Inocencio, A. (2003). Economics of water productivity in managing water for agriculture. In: Kijne, J.W., Barker, R. & Molden, D. (eds). *Water Productivity in Agriculture: Limits and Opportunities for Improvement*, Wallingford, UK, CABI Publishing, pp.19–35.

Blanke A., Rozelle S., Lohmar B., Wangc, J. & Huang, J. (2007). Water saving technology and saving water in China. *Agricultural Water Management,* 87: 139–150.

CAF (2013). Corporación Andina de Fomento. [Online] Available from: www.caf.com/es. [Accessed May, 2013].

CAWMA (2007). Comprehensive Assessment of Water Management in Agriculture. *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture,* International Water Management Institute, London, Earthscan.

CEPAL (2010). Economic Commission for Latin America. *Objetivos de Desarrollo del Milenio. Avances en la sostenibilidad ambiental del desarrollo en America Latina y el Caribe.* [Online] Available from: www.eclac.cl/cgi-bin/getprod.asp?xml=/publicaciones/xml/6/38496/P38496.xml&xsl=/dmaah/. [Accessed May, 2013]. Online report number LC/G.2428-P.

Dagnino, M. & Ward, F.A. (2012). Economics of agricultural water conservation: empirical analysis and policy implications. *International Journal of Water Resources Development*, 28 (4): 577-600.

Dumont, A., Mayor, B. & López-Gunn, E. (2013). Is the rebound effect or Jevons paradox a useful concept for better management of water resources? Insights from the irrigation modernisation process in Spain. At the water confluence. *Aquatic procedia*, 1: 64–76.

FAO (2003). Food and Agricultural Organization of the United Nations. *Unlocking the Water Potential of Agriculture*. [Online] Available from: www.fao.org/docrep/006/y4525e/y4525e00.htm#Contents. [Accessed May, 2013].

FAO (2013). Food and Agricultural Organization of the United Nations. *Irrigation water requirement and water withdrawal by country.* [Online] Available from: www.fao.org/nr/water/aquastat/water_use_agr/index7.stm. [Accessed May, 2013]. Online report.

Garces-Restrepo, C., Vermillion, D. & Muñoz, G. (2007). *Irrigation Management Transfer,* Rome, FAO. Water Reports number 32.

Gilmont, M. (2013). Decoupling dependence on natural water: reflexivity in the regulation and allocation of water in Israel, *Water Policy*. In press.

GWP (2006). Global Water Partnership. *Taking an integrated approach to improving water efficiency,* Technical Committee (TEC). Technical Brief No. 4.

GWP (2011). Global Water Partnership. *Situación de los recursos hídricos en Centroamérica: hacia una gestión integrada:* Publicaciones de la oficina regional para Centroamérica. [Online] Available from: www.gwp.org/Global/GWP-CAm_Files/SituaciondelosRecursosHidricos.pdf. [Accessed May, 2013]. Online report.

GWP (2012). Global Water Partnership. *Towards Integrated Urban Water Management.* Perspectives papers.

Gunderson, L. & Light, S.S. (2006). Adaptive management and adaptive governance in the Everglades ecosystem. *Policy Science*, 39: 323–334.

Hoekstra, A.Y. (2013). *The water footprint of modern consumer society.* Routledge, London.

Holling, C.S. & Meffe, G. (1996). Command and control and the pathology of natural resource management. *Conservation Biology,* 10: 10328-10337.

ICC (2007). International Consulting Corporation. [Online] www.icc-us.com. [Accessed May, 2013].

ICWE (1996). International Conference on Water and the Environment. *The Dublin Statement and Report of the Conference*. [Online] Available from. docs.watsan.net/Scanned_PDF_Files/Class_Code_7_Conference/71-ICWE92-9739.pdf. [Accessed May, 2013].

Jollands, N. (2006). Concepts of efficiency in ecological economics: Sisyphus and the decision maker. *Ecological Economics*, 56(3): 359–372.

LA–Mexico (2012). *Report of Mexico*. Contribution to the Water and Food Security in Latin America Project. Water Observatory Project, Madrid, Fundacion Botín.

Li, Y & Yang, Z.F. (2011). Quantifying the sustainability of water use systems: calculating the balance between network efficiency and resilience. *Ecological Modelling*, 222: 1771-1780.

Mekonnen, M.M. & Hoekstra, A.Y. (2011). *National water footprint accounts: the green, blue and grey water footprint of production and consumption*, UNESCO-IHE. Value of Water Research Report Series No. 50.

Molden, D. (1997). *Accounting for water use and productivity.* International Irrigation Management Institu-te, Colombo, Sri-Lanka. SWIM Paper No. 1.

Molden, D., Murray-Rust, H., Sakthivadivel, R., & Makin, I. (2003). A water-productivity framework for understanding and action. In: Kijne, J.W., Barker R., & Molden D. (eds). *Water Productivity in Agriculture*: *Limits and Opportunities for Improvement,* Wallingford, UK, CABI Publishing, pp. 1-18.

Molden, D., Oweis, T., Steduto, P., Bindraban, P., Hanjra, M. & Kijine, J. (2010). Improving agricultural water productivity: Between optimism and caution. *Agricultural Water Management*, 97: 528-535.

de Oliveira, A.S., Trezza, R., Holzapfel, E.A., Lorite, I. & Paz, V.P.S. (2009). Irrigation water management In Latin America. *Chilean Journal of Agricultural Research,* 69 (Suppl. 1): 7–16.

Pasha, M.R. (2002). Inefficient water management: its impact on economic growth. *The Journal*, 7(4): 87–98.

Perry, C. (2007). Efficient rrigation: inefficient communication; flawed recommendations. *Irrigation and Drainage*, 56: 367–78.

Perry, C., Steduto, P., Allen, R. & Burt, C. (2009). Increasing productivity in irrigated agriculture: Agronomic constraints and hydrological realities. *Agricultural Water Management,* 98: 1517–1524.

Pfeiffer, L. & Lin, C.Y. (2010). The effect of irrigation technology in groundwater use. *Choices* 25(3).

Pierce, G. (2012). The political economy of water service privatization in Mexico City, 1994–2011. *International Journal of Water Resources Development,* 28(4): 675–691.

Pretty, J., Noble, A., Bossio, D., Dixon, J., Hine, R.E., Penning de Vries, P. & Morison, J.I.L. (2006). Resource conserving agriculture increases yields in developing countries. *Environmental Science and Technology*, 40(4): 1114–1119.

Reinhard, S., Lovell, C.K., & Thijssen, G. (2002). Analysis of environmental efficiency variation. *American Journal of Agricultural Economics*, 84(4): 1054–1065.

Richter, B.D., Davis, M.M., Apse, C. & Konrad, C. (2011). A presumptive standard for environmental flow protection. *River Research and Applications*, 28(8): 1312–1321.

Ringler, C., Biswas, A. & Cline, S.A. (eds). (2010). *Global Change: Impact on Water and Food Security*, Berlin-Heidelberg, Springer-Verlag.

Rosegrant, M., Cai, X., & Cline, S. (2003). Will the world run dry? global water and food security. *Environment* 45(7): 24–36.

Sharma, P. & Sharma, R. (2004). Groundwater markets across climatic zones: a comparative study of arid and semiarid zones of Rajasthan. *India Journal of Agricultural Economics*, 59: 138–150.

Schuck, E., Frasier, W.M., Webb, R.S., Ellingson, L.J. & Umberger, W.J. (2005). Adoption of more technically efficient irrigation systems as a drought response. *Water Resource Development,* 21: 651–662.

Sousa Júnior, W.C. & Reid, J. (2010). Uncertainties in Amazon hydropower development: Risk scenarios and environmental issues around the Belo Monte dam. *Water Alternatives*, 3(2): 249–268.

Torcellini, P., Long, N. & Judkoff, R. (2003). *Consumptive Water Use for US Power Production*. Con-ference Paper presented at the ASHRAE Winter Meeting Anaheim, California, January 24–28, 2004. Colorado, National Renewable Energy Laboratory.

UNEP (2010). United Nations Environment Programme. International Payments for Ecosystem Services. UNEP Division of Technology, Industry and Economics. Economics and Trade Branch. [Online] Available from: www.unep.ch/etb/events/IPES%20Side%20Event%20Bonn/IPES%20SUM%20FINAL.pdf. [Accessed May, 2013].

UNEP (2011). United Nations Environment Programme. *Resource Efficiency: Economics and Outlook for Latin American Case Studies: MERCOSUR, Chile and Mexico.* [Online] Available from: www.pnuma.org/reeo. [Accessed June, 2013].

UNEP (2012). United Nations Environment Programme. *Global Environment Outlook 5* (GEO-5), Nairobi, Kenya.

UNEP (2013). United Nations Environment Programme. *The State of Natural Resource Management in Latin America and the Caribbean: Opportunities for Sustainable Practices and Prioritisation of Resources:* UNEP Division of Technology, Industry and Economics (UNEP DTIE) and UNEP Regional Office for Latin America and the Caribbean (PNUMA ROLAC).

Ulanowicz, R.E., Goerner, S.J., Lietaer, B. & Gomez, R. (2009). Quantifying sustainability: Resilience, efficiency and the return of information theory. *Ecological Complexity,* 2009: 27–36.

van Halsema, G.E. & Vincent, L. (2012). Efficiency and productivity terms for water management: A matter of contextual relativism versus general absolutism. *Agricultural Water Management,* 108: 9–15.

Ward, F.A. & Pulido-Velázquez, M. (2008). Water conservation in irrigation can increase water use. *Proceedings of the National Academy of Sciences,* 105(47): 18215–18220.

Wichelns, D. (2002). An economic perspective on the potential gains from improvements in irrigation water management. *Agricultural Water Management,* 52 (3): 233–248.

World Bank (2013). *World Development Indicators Database.* Washington DC, The World Bank.