The Water Footprint of Morocco

and its added value for national water policy

by

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Preface

This thesis is written in partial fulfilment of the requirements for completion of the Master Civil Engineering & Management (track: Water Engineering & Management) at the University of Twente, The Netherlands. The study is commissioned by and carried out during an internship at applied research institute Deltares, The Netherlands.

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Summary

Morocco is a semi-arid country in the Mediterranean that faces water scarcity and deteriorating water quality. The limited water resources constrain the activities in different sectors of the Moroccan economy. The national water strategy of Morocco includes options to reduce water demand and increase supply. However, it does not include the global dimension of water by considering international virtual water trade, nor does it consider whether water resources are efficiently allocated based on physical and economic water productivities of crops (the main water consumers).

The overall objective of this study is to find out the added value of knowledge on the water footprint (WF) of activities in Morocco and the virtual water flows from and to Morocco in formulating national water policy. The study includes analysis of the WF of activities in Morocco (on the river basin level on a monthly scale), the virtual water balance of the country and the WF in the context of water availability and waste assimilation capacity. Based on this, response options are formulated to reduce the WF within Morocco, alleviate water scarcity and allocate water resources more efficiently. Results and conclusions from the WF assessment are compared with the scope of analysis of, and action plans included in, Morocco's national water strategy and river basin plans in order to address the added value of WF assessment relative to these existing plans.

Main results of the WF assessment are:

- The total WF of Moroccan production in the period 1996-2005 was 38.8 Gm³/yr (77% green, 18% blue, 5% grey). Crop production is the largest contributor to this WF, mainly related to the production of wheat and barley, followed by olives and maize. Evaporation from storage reservoirs accounts for the second largest form of blue water consumption nationally, after irrigated crop production. Largest WFs are found in the basins Oum Er Rbia and Sebou, the main agricultural areas. The green WF is largest in the rainy period December-May, whereas the blue WF is largest in the period April-September when irrigation demands increase.
- In the period 1996-2005, Morocco's water resources were mainly used to produce relatively low-value water-intensive (in US$/m³) crops such as cereals, olives and almonds. These crops also took the largest share in the country's harvested area in the same period, although they had the lowest value per hectare cultivated (in US$/ha). More economic return per drop and per hectare of land cultivated was generated by production of grapes, sugar beets, citrus fruits (oranges and mandarins etc.) and tomatoes.
- Morocco was a net virtual water importer in the period 1996-2005. Virtual water import was 12,643 Mm³/yr with an average cost of 0.98 US$/m³ and virtual water export was 4,307 Mm³/yr with an average earning of 1.66 US$/m³. Only 31% of the virtual water export originated from Moroccan water resources (remainder was re-export). Virtual water import and export were for 95% and 91% related to trade in crop products, respectively. By import of products instead of producing them domestically, Morocco saved 27.8 Gm³/yr (75% green, 21% blue and 4% grey) of domestic water, equivalent to 72% of the WF within Morocco.
- Blue water scarcity on a monthly scale is severe in all river basins. Seasonal shortages result in high alteration of natural runoff. Also groundwater scarcity and pollution are significant in most basins, especially in the basins of Bouregreg, Oum Er Rbia and Tensift. In order to move towards sustainable use of Morocco's blue water resources, discussing and agreeing on blue WF caps, per river basin, per month and for surface and groundwater separately, would be useful.
- Potential green plus blue water savings by reallocation of crop production across basins are in the order of 1.9 and 1.2 billion m³ per year when all main crops or only annual crops are reallocated, respectively. Lowering the WFs of the main crops in each river basin down to benchmarks (which are defined as the lowest water consumption of a crop in a comparable basin) can lead to estimated green plus blue water savings of 2,768 Mm³/yr. When the water

productivities of the twelve main water-consuming crops were to be improved by 10% throughout Morocco, it could potentially save 2,462 Mm^3/yr of water (green plus blue).

- Morocco obtained fairly large savings by food (virtual water) imports in the period 1996-2005 (27.8 Gm^3/yr, see above). Increasing food imports to relieve pressure on domestic water resources increases food dependency and has negative effects on the domestic agricultural sector, which plays a critical role in the economic and social stability of Morocco.
- About 4% of the water used in the Moroccan agricultural and industrial sector is used for making export products (period 1996-2005). The remainder is applied for producing products that are consumed by the Moroccan population. However, most of the virtual water export from Moroccan resources relates to the export of products with a relatively low economic value per m^3 water exported (in US$/$m^3$).

Several insights and response options emerged from the WF assessment, which are currently not considered in the national water strategy of Morocco and the country's river basin plans. They include:

I. New insights in the water balance of Morocco and the country's main river basins:

- The evaporative losses from storage reservoirs are not explicitly considered for newly planned dams in Morocco, but these losses should be taken into account in the cost-benefit analysis of the new dams, since they account for a significant part of the blue WF within Morocco.
- Blue water scarcity on a monthly scale is severe and hidden by annual analysis of demand versus supply, which is the common scale of analysis in the Moroccan river basin plans. The effects of heavily modified river flows and stream desiccation on aquatic and riparian ecosystems, and the livelihoods that depend on these systems, require attention and local case studies should be carried out to map these effects.

II. New insights in how economically efficient water and land resources are used:

- Analysis of the economic value of crop products per unit of water and land used in the period 1996-2005 indicate that agricultural policy may be better brought in line with water policy by reconsidering which crops to grow.
- It is shown that the export policy in this period was not optimal from a water-economics point of view, which raises the question whether the foreign income generated by export covers the direct and indirect costs of mobilization and (over)exploitation of Moroccan water resources.

III. New response options to reduce the WF of crop production:

- Analysis of the WF of the main crops in Morocco and its variation across the river basins offers new ways of looking at reducing water consumption in the agricultural sector. The estimated potential water savings by reallocation of crops to basins where they consume less water and by lowering WFs of crops down to benchmarks are significant compared to demand reducing and supply increasing measures considered in the national water strategy.

Given these new insights and response options, it can be said that knowledge on the WF of activities in Morocco and the virtual water flows from and to Morocco has an added value for formulating national water policy. WF assessment forces to look at end-users and -purposes of freshwater, which is key in determining efficient and equitable water allocation within the boundaries of what is environmentally sustainable, both on the river basin and on the national level. This is especially relevant for water-scarce countries such as Morocco. Furthermore, considering the green and grey components of a WF provides new perspectives on blue water scarcity, because pressure on blue water resources might be reduced by more efficient use of green water and by less pollution.

1 Introduction

Morocco is a semi-arid country in the Mediterranean that faces water scarcity and deteriorating water quality. The limited water resources constrain the activities in different sectors of the economy of the country. Agriculture is the largest water consumer in the country and withdrawals for irrigation peak in the dry period of the year, which contributes to low surface runoff and desiccation of streams. Currently, 130 reservoirs are in operation to deal with this mismatch in water demand and natural water supply and to serve for hydro-power production and flood control (Ministry of Energy, Mining, Water and Environment of Morocco, Department of Water, 2011). Groundwater resources also play an important role in the socio-economic development of the country, in particular by ensuring the water supply for rural communities (Ministry of Energy, Mining, Water and Environment of Morocco, Department of Water, 2012a). However, a large part of the aquifers is being overexploited and suffer from deteriorating water quality by intrusion of salt water, caused by the overexploitation, and nitrates and pesticides that leach from croplands, caused by excessive use of fertilizers. Surface water downstream of some urban centres is also polluted, due to untreated waste water discharges.

In 1995, the Moroccan Water Law (no. 10-95) came into force and introduced decentralized integrated water management and rationalisation of water use, including the principles of the polluter-pays and the user-pays. It also dictates the development of national and river basin master plans (Official State Gazette, 1995). Although not formally established, these plans should be elaborated in accordance with the national water strategy (S. Laraichi, personal communication, May 24, 2013). To cope with water scarcity and pollution, the national water strategy includes action plans to reduce demand, increase supply and preserve and protect water resources (Ministry of Energy, Mining, Water and Environment of Morocco, Department of Water, 2011). It also proposes legal and institutional reforms for proper implementation and enforcement of these actions. Demand management focuses on improving the efficiency of irrigation and urban supply networks and valorisation of water to rationalise its use. Plans to increase supply include the construction of more dams and a large North-South inter-basin water transfer, protection of existing hydraulic infrastructure, desalinization of sea water and reuse of treated wastewater.

Although the national water strategy considers options to reduce water demand in addition to options to increase supply, it does not include the global dimension of water by considering international virtual water trade, nor does it consider whether water resources are efficiently allocated based on physical and economic water productivities of crops (the main water consumers). Analysis of the water footprint (WF) of activities in Morocco and the virtual water trade balance of the country therefore might reveal new insights to alleviate water scarcity.

The concept of WF was introduced by Hoekstra in 2002 (Hoekstra, 2003) and subsequently elaborated by Hoekstra and Chapagain (2008) and Hoekstra *et al*. (2011). The WF is an indicator of freshwater use that looks not only at direct water use of a consumer or producer, but also at the indirect water use. As such, it provides a link between human consumption and human impacts on freshwater systems. The WF of a product is the volume of freshwater used to produce the product, measured over the full supply chain (Hoekstra *et al*., 2011). The total freshwater volume consumed or polluted within the territory of a nation as a result of activities within the different sectors of the economy is called the WF of national production. The water use behind the products a nation trades, are referred to as virtual water flows or trade.

The WF is specified spatially and temporarily, i.e. it shows not only the volume of water consumed, but also where and when it is consumed. Three different components of a WF are distinguished: green, blue and grey. The green WF is the volume of rainwater evaporated or incorporated into the product. Blue water refers to the volume of surface or groundwater evaporated, incorporated into the product or returned to another catchment or the sea. It thus differs from the traditional measure of water withdrawal, as it does not include water returned to where it came from. The grey WF relates to pollution and is defined as the volume of freshwater that is required to assimilate the load of pollutants given natural background concentrations and existing ambient water quality standards (Hoekstra *et al*., 2011).

Mekonnen and Hoekstra (2011) quantified and mapped the WFs of nations (incl. Morocco) from a production and consumption perspective and estimated international virtual water flows and national and global water savings as a result of trade. They state that understanding the WF of a nation is highly relevant for developing well-informed national policy. On the regional level, Aldaya *et al*. (2010b) conclude that WF analyses can provide a transparent framework to identify potentially optimal alternatives for efficient water use at the catchment level and that this can be very useful to achieve an efficient allocation of water and economic resources in the region. In a case study for an agricultural region in Spain, they found that significant changes in water demand can occur not only by changing the amount of irrigated area but also by modifying the cropping patterns. Aldaya *et al*. (2010b) were the first to introduce the concepts of economic water and land productivity in relation to WF accounting. By expressing the economic value of farm output per unit of water consumed, they showed Spain uses its scarce water resources mainly to produce low-income water-intensive crops. According to Aldaya *et al*. (2010a), one of the most relevant consequences of the WF and virtual water trade knowledge in arid and semiarid countries is the change in the water security and food security concepts. They state water crisis is a problem of water management in relation to various aspects and that WF analysis provides new data and perspectives that make a more optimistic outlook possible of the frequently spread looming 'water scarcity crisis'. Chahed *et al*. (2011) link this to food security by stating that integration of all water resources at the national scale, including the green water used in rain-fed agriculture and as part of the foodstuffs trade balance, is essential in facing the great challenges of food security in arid countries.

The overall objective of this study is to find out the added value of knowledge on the WF of activities in Morocco and the virtual water flows from and to Morocco in formulating national water policy. The question assessed is whether assessment of the WF of Morocco can provide new insights and response options that are currently not considered in the country's national water strategy and river basin plans. The study includes an assessment of the WF of activities in Morocco and the virtual water balance of the country and, based on this, response options are formulated to reduce the WF within Morocco, alleviate water scarcity and allocate water resources more efficiently. Results and conclusions from the WF assessment are compared with the scope of analysis of, and action plans included in, Morocco's national water strategy and river basin plans in order to address the added value of WF assessment relative to these existing plans.

Specifically, the WF assessment in this study aims to:

1. Analyse the WF of activities in Morocco (i.e. WF of Moroccan production). The assessment follows the terminology and methodology as set out in the Water Footprint Assessment Manual (Hoekstra *et al*., 2011). The WF of production includes estimates on the green, blue and grey WF and is analysed on the river basin level on a monthly scale. It is largely based on data from Mekonnen and Hoekstra (2011), who estimated the WF of nations (incl. Morocco) over the period 1996-2005 related to: crop production, grazing, industrial production, domestic water supply and animal water supply. Their estimates are supplemented with estimates on the evaporation from the Moroccan irrigation supply network and storage reservoirs.
2. Place the blue WF within Morocco in the context of natural runoff and groundwater availability and compare the volume of polluted groundwater by nitrates with actual groundwater availability. The monthly blue WF is compared with monthly natural runoff, since water scarcity usually manifests itself on a monthly scale (Hoekstra *et al.*, 2012). Since nitrate pollution in

Morocco mainly occurs in aquifers, nitrate pollution of groundwater is compared with the assimilation capacity of groundwater.

3. Assess the water consumption (in m^3/ton), economic water productivity (in US$/$m^3$) and economic land productivity (in US$/ha) of the main crops in Morocco and the variation of these parameters across river basins within the country.
4. Analyse the virtual water flows from and to Morocco related to international trade in commodities and the water savings by this trade, based on estimates by Mekonnen and Hoekstra (2011). It includes analysis of which part of its resources Morocco uses for producing export products and the economic value of imports and exports per unit of water imported and exported, respectively.
5. Discuss the WF of consumption by the Moroccan population as estimated by Mekonnen and Hoekstra (2011).
6. Formulate response options to reduce the WF within Morocco and allocate water resources more efficiently, including:
    a. Reducing the WF of crop production by:
        i. reallocation of crop production across river basins (which is possible due to spatial differences in crop water use);
        ii. improving water productivities: overall and by benchmarking.
    b. Maximum sustainable WFs (i.e. WF caps) per river basin.
    c. Resource allocation to different crops (based on economic water and land productivities).
    d. Wise virtual water import and export.

The WF of Morocco has not been assessed previously on the river basin level on a monthly scale. Furthermore, this study is the first to include in a national WF assessment:

- Specific estimates of the evaporative losses from the irrigation supply network and from storage reservoirs;
- Quantitative estimates of the potential water savings by:
    - reallocation of crop production to regions with lower water consumption per ton of crop by means of an optimization;
    - lowering WFs of crops down to benchmarks (which are defined as the lowest water consumption of a crop achieved in a basin with comparable reference evapotranspiration).

The applied methodology and data are described in chapter 2. Chapter 3 includes analysis of the WF of activities within Morocco, the virtual water balance of the country and the WF in the context of water availability and waste assimilation capacity. Based on this, response options are formulated in chapter 4. The added value of WF assessment for national water policy is discussed in chapter 5. A discussion of the WF assessment in this study is included in chapter 6. The final chapter contains conclusions.

2 Method and data

The applied methods, assumptions and data for the estimates and analyses in this study are described in this chapter. This study follows the terminology and methodology as set out in the Water Footprint Assessment manual (Hoekstra *et al*., 2011), the global standard for water footprint (WF) assessment developed by the Water Footprint Network.

2.1 Scope and study area of water footprint of Moroccan production

In this study, the WF of Moroccan production, i.e. the total freshwater consumption and pollution related to the activities within Morocco, is analysed. It is estimated for the activities included in Table 2-1 and includes the green, blue and grey components. The analysis is done per river basin on a monthly scale. With the exceptions that the grey WF is analysed on an annual scale and that the WFs of grazing and animal water supply are only available as national and yearly aggregates.

The watershed delineation is determined from a digital elevation model with a spatial resolution of 30 arc seconds obtained from NIMA (2013), after which catchments and sub-catchments are merged to equal the action zones of Morocco's river basin agencies, see Figure 2-1. Unless stated otherwise, when in this study is spoken about catchments, watersheds or river basins, this division is meant. The basin of Sud Atlas corresponds with more than one river basin agency action zone, namely the ones of (Souss-Massa-)Draa and Guir-Ziz-Rhéris-Maîder. The southern basins of Sakia El Hamra and Oued Eddahab are excluded from the analysis, because water consuming activities in these river basins are very limited compared to the northern river basins of Morocco. Moreover, the runoff in the basins of Sakia El Hamra and Oued Eddahab is practically negligible (Shahin, 2007).

Table 2-1: Water footprint estimates included in this study.

Water footprint of	Components	Period	Source
Crop production	Green, blue, grey	1996-2005	Mekonnen and Hoekstra (2010b)
Grazing	Green	1996-2005	Mekonnen and Hoekstra (2011)
Animal water supply	Blue	1996-2005	Mekonnen and Hoekstra (2011)
Industrial production	Blue, grey	1996-2005	Mekonnen and Hoekstra (2011)
Domestic water supply	Blue, grey	1996-2005	Mekonnen and Hoekstra (2011)
Storage reservoirs	Blue	-	Own elaboration
Irrigation water supply network	Blue	1996-2005	Own elaboration

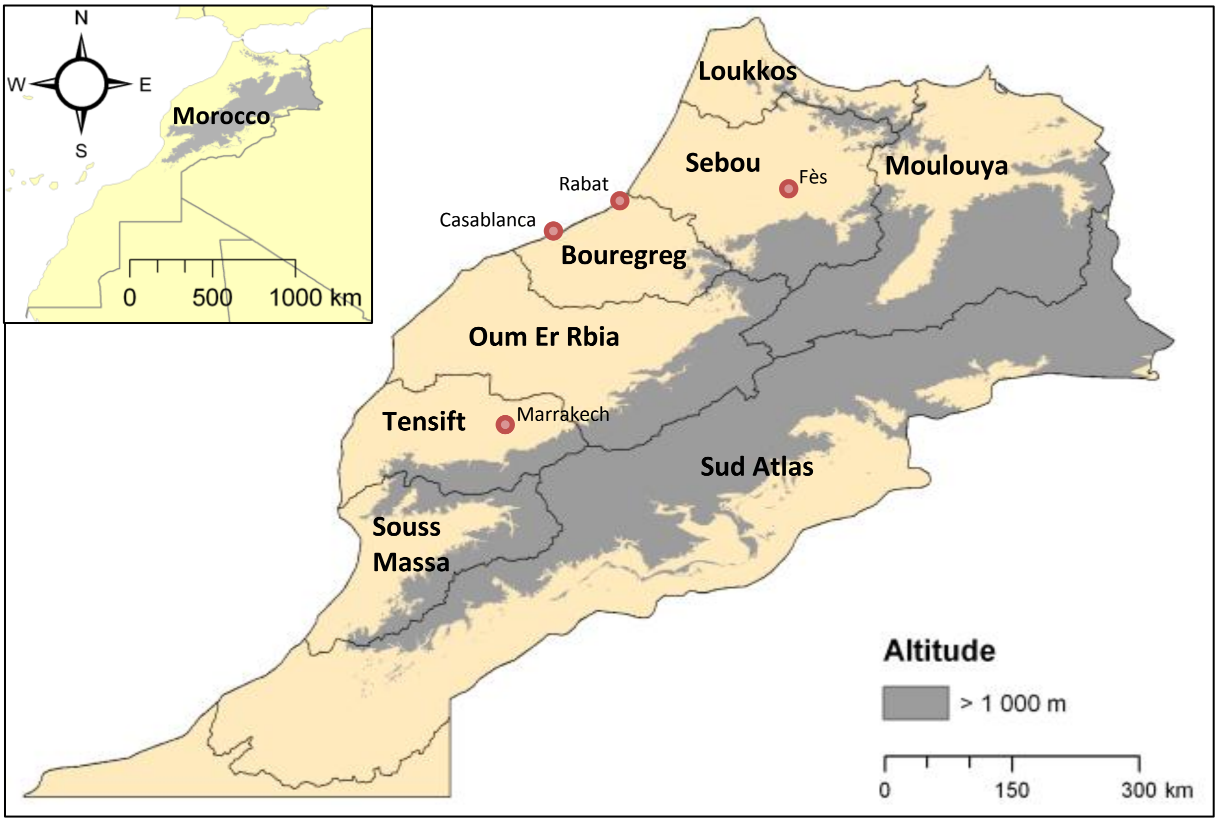


Figure 2-1: Study area with river basin delineation and Morocco's four most populated cities.

2.2 Water footprint estimates based on Mekonnen and Hoekstra (2010b; 2011)

The WF related to crop production is estimated by Mekonnen and Hoekstra (2010b) on a global scale with a spatial resolution of 5 by 5 arc minute, which is approximately 10 by 10 kilometres in Morocco. They used a grid-based dynamic water balance model which computes a daily soil water balance and calculates crop water requirements, actual crop water use (both green and blue) and actual yields under non-optimal crop growth conditions. 'Non-optimal conditions' means that actual crop evapotranspiration is lower when the actual available soil moisture in the root zone is below its maximum. The model was applied to calculate the crop water use of 126 primary crops at high spatial resolution (5x5 arc minute) and for 20 minor crops they used the CROPWAT 8.0 model. Estimates of the grey WF of crops relate to nitrogen use only. It is assumed that crops receive the same amount of nitrogen fertilizer per hectare throughout the country and that 10% of the applied fertilizers leach to surface or groundwater. The application rates in Morocco used by Mekonnen and Hoekstra (2010b) vary from crop to crop: 5.0 kg/ha for olives; 13.5 kg/ha for wheat; 58.6 kg/ha for oranges; 102.3 kg/ha for sugar beets. A maximum value of 10 mg/l nitrate-nitrogen (NO_3-N) is used, which corresponds with 44 mg/l of nitrate (NO_3) (Self and Waskom, 2013), and natural nitrogen concentrations are assumed to be zero.

The WF of grazing is calculated by Mekonnen and Hoekstra (2010c) at national level based on livestock feed consumption. Chapagain and Hoekstra (2003) estimated the water consumption for drinking and servicing of livestock over the lifetime of animals (i.e. the WF of animal water supply). Both these WFs are excluded from the monthly analysis at river basin level, because they are not available at these scales.

The blue WF estimates by Mekonnen and Hoekstra (2011) of industrial production and domestic water supply are based on withdrawal data from the AQUASTAT database of the Food and

Agriculture Organization of the Unites Nations (FAO). For industries it is assumed that 5% is actual consumption and that the remainder is return flow. For households a consumptive portion of 10% is assumed. The part of the return flow which is disposed into the environment without prior treatment is taken as a measure of the grey WF, thus conservatively assuming a dilution factor of 1. For rural areas zero treatment is assumed. The WF of industrial production and domestic water supply are both mapped with a global population density map. The annual blue WF estimates for industries and households by Mekonnen and Hoekstra (2011) are distributed throughout the year according to the monthly distribution of public water supply obtained from Ministry of Energy, Mining, Water and Environment of Morocco, Department of Water (2013a). These distributions are available for the basins Loukkos, Sebou, Bouregreg and Oum Er Rbia. For the other basins an average of these distributions is taken.

High resolution raster data (5x5 arc minute) are obtained from Mekonnen and Hoekstra (2010a, 2011), including:

- The green and blue WF of crops produced in the Morocco (in m^3/month) as well as the grey WF of crops (in m^3/yr)
- Crop yield (in ton/ha)
- Harvested area per crop (in ha/yr)
- Production per crop (in ton/yr)
- The blue and grey WF of industrial production (in m^3/yr)
- The blue and grey WF of domestic water supply (in m^3/yr)

All data are averages over the period 1996-2005. The raster data are aggregated per river basin and for the complete study area according to the delineation in Figure 2-1 (section 2.1). Two minority crops are not included in the obtained grids, their WFs are only available as annual national aggregate, namely carobs (WF_{green} = 79.0 Mm^3/yr; WF_{blue} = 5.6 Mm^3/yr) and peppermint (WF_{green} = 14.2 Mm^3/yr; WF_{blue} = 4.3 Mm^3/yr). Therefore, the WFs of carobs and peppermint are excluded from the analysis. Reported WF estimates in this study slightly differ (in the order of 1%) from the reported values by Mekonnen and Hoekstra (2010b; 2011), due to different methods applied in retrieving the data from the database.

2.3 Water footprint of storage reservoirs

The monthly WF of storage reservoirs per catchment, i.e. evaporation from reservoirs (in m^3/month), is calculated as the surface area of storage reservoirs (in m^2) times the open water evaporation (in m/month).

Data per reservoir on long-term monthly average open water evaporation (1939-2011) and surface area at different reservoir levels for the basins Loukkos, Sebou, Bouregreg and Oum Er Rbia are obtained from Ministry of Energy, Mining, Water and Environment of Morocco, Department of Water (2013c). The surface areas of reservoirs at upper storage level in the other basins are derived from AQUASTAT's geo-referenced database of African dams (FAO, 2013b), which includes 105 dams in Morocco. Reservoir area is reported in 1,000 square metres, but comparison with data from the Ministry of Energy, Mining, Water and Environment of Morocco, Department of Water (2013c), shows the correct unit is more likely to be hectares (10,000 square metres) and is therefore treated as such in this study. It should be noted, that in an update of the database most reported reservoir areas in Morocco are indeed marked as 'probably incorrect'. For the basins for which no reservoir specific evaporation data are available, monthly average daily Penman-Monteith potential evaporation is obtained from a model simulation with the global hydrological model PCR-GLOBWB carried out by Sperna Weiland *et al*. (2010). These values are derived at points corresponding with the locations of reservoirs in these catchments (more than one location/reservoir for large catchments). At these locations, the Penman-Monteith potential evaporation equals the evaporation from open water. Simulation was carried out for the period 1961-1990 with a time step of one day. Appendix IV contains a comparison of open water evaporation estimates per river basin (in mm/yr) according to the different data sources used.

Although for the basins Loukkos, Sebou, Bouregreg and Oum Er Rbia reservoir area is known at different water levels, for reasons of consistency, for all basins the surface area of reservoirs at upper storage level is taken. Since storage levels vary throughout the year (and over the years), and reservoir area accordingly, this is most certainly an overestimation of the evaporation from reservoirs. To counteract this overestimation, but due to lack of data on monthly storage level and reservoir area, for all months a fraction of 43% of the evaporation at upper storage level is taken as estimate of the WF of storage reservoirs. This 43% represents the average reservoir area as fraction of its area at upper storage level. This fraction is calculated per reservoir for which data are available on its surface area at different reservoir levels and subsequently an average is taken over all reservoirs for which the fraction is calculated. The estimation of the WF of storage reservoirs is a conservative estimate, because reservoirs are probably filled for more than 43% most of the time.

2.4 Water footprint of irrigation supply network

The WF of the irrigation supply network represents the evaporative losses in the network and is estimated as a constant fraction *K* of the estimated surface-WF of crop production at field level, i.e. the part of the irrigation water that originates from surface water and is lost at the crop field through evapotranspiration (see Appendix I for a clarifying figure). The surface-WF of crop production at field level is estimated by means of a best estimate of the fraction of irrigation water withdrawn from surface water (as opposed to groundwater) per river basin. These estimates are included in Appendix II. The fraction *K* is estimated at 15% according to the following calculation (see Appendix I for the derivation of the formula):

$$K = \left[\frac{1}{e_a \times e_c} - \frac{1}{e_a}\right] \times f_E$$

In which f_E represents the fraction of the water volume lost in the network that evaporates (the rest percolates). The constants e_c and e_a are the weighted conveyance and field application efficiency, respectively (see Table 2-2). The first term accounts for the losses between water diversion and application to the field and the second for the losses after application to the field (Hoekstra, 2013). The fraction f_E is estimated at 50% in this study. Irrigation efficiencies for different irrigation types from the national irrigation water saving programme (PNEEI) are obtained from ABH Sebou (2011). Since the efficiencies used are targets to be achieved with the PNEEI, the estimate can be regarded as conservative for the current situation. Figure 2-2 shows how the irrigation water conveyance network looks like in the Tadla region in the Oum Er Rbia basin.

Table 2-2: Field and conveyance efficiencies used for estimation of the water footprint of the irrigation supply network.

	Type of irrigation				Weighted
	Surface	Sprinkler	Localized	Spate	efficiency*
Field application efficiency	70%	85%	90%	70%	73%
Conveyance efficiency	80%	90%	90%	100%	82%
Scheme irrigation efficiency	56%	77%	81%	70%	60%
% in total area equipped for irrigation	81%	10%	7%	2%	

* Weighted average of the irrigation efficiencies according to the area equipped with a specific irrigation type in the total area equipped for irrigation in Morocco.
Source: Irrigation efficiencies from ABH Sebou (2011)
Area equipped for irrigation from FAO (2013a)

(a) **(b)**

Figure 2-2: Primary (a) and secondary (b) irrigation channels in the Oum Er Rbia basin on the plains of Tadla.

2.5 Economic water and land productivity

The WF of crops per unit of production is calculated by dividing its WF (in m³/yr) by its production (in ton/yr), for which data are obtained from Mekonnen and Hoekstra (2011). Physical water productivity (in ton/m³) is the inverse of the WF per unit of production. Following Aldaya *et al*. (2010b), the economic water productivity (EWP) and economic land productivity (ELP) of crops are analysed in this study. EWP (in US$/m³) represents the economic value of farm output per unit of water consumed and is calculated as the average producer price for the period 1996-2005 (in US$/ton) obtained from FAO (2013d) divided by the green plus blue WF (in m³/ton). Similarly, ELP (US$/ha) represents the economic value of farm output per hectare of harvested land and is calculated as the same producer price multiplied by crop yield (in ton/ha), which is also obtained from Mekonnen and Hoekstra (2011).
Producer prices reported by FAO (2013d), are the prices received by farmers for primary crops as collected at the farm-gate or at the first point of sale. No producer price for dates is available for Morocco. Therefore an average producer price for dates is taken based on data for two other African Mediterranean countries: Algeria (1,019 US$/ton) and Tunisia (1,009 US$/ton).

2.6 Virtual water flows and associated economic value

Virtual water flows (green, blue and grey) related to Moroccan import and export of agricultural and industrial commodities for the period 1996-2005 are obtained from Mekonnen and Hoekstra (2011), who estimated these flows at a global scale.

Part of the total virtual water export is from domestic resources, another part is re-export from foreign resources. The virtual water export that originates from domestic resources is estimated based on the relative share of the virtual water import to the total water budget:

$$V_{e,dom.res.} = \frac{WF_{national}}{V_i + WF_{national}} \times V_e$$

In which $WF_{national}$ is the WF within the nation, V_i the virtual water import and V_e the virtual water export.

This formula is applied separately for agricultural products and industrial products. Within the first category the formula is applied separately for the main (virtual water) export commodities and the crop groupings: perennials; annuals; citrus fruits; pulses. For the crop groupings the total virtual water export (green, blue, grey) is splitted to the parts from domestic and foreign resources based on values for green and blue water only, because the grey WF of these groupings within Morocco is not available.

The average earning per unit of water exported (in US$/m³) is calculated by dividing the value of export (in US$/yr) by virtual water export (in m³/yr). Analogue, the cost per unit of virtual water import is calculated by dividing the import value (in US$/yr) by virtual water import (in m³/yr). Both are calculated separately for crop, animal and industrial products and for specific crop products associated with large virtual water.

The average economic value of import and export for the period 1996-2005 are derived from the SITA database (Statistics for International Trade Analysis) available from the International Trade Centre (ITC, 2007). This database covers trade data over ten years (1996-2005) from 230 reporting countries disaggregated by product and partner countries. Mekonnen and Hoekstra (2011) used trade data from this database in their estimates of international virtual water flows. The selected products and partner countries for derivation of the value of import and export correspond with the products and partner countries Mekonnen and Hoekstra (2011) estimated virtual water flows for.

2.7 Water footprint in context of water availability and pollutant assimilation capacity

To assess the environmental sustainability of the WF within Morocco, the total blue WF of production is placed in the context of monthly natural runoff and the ground-WF in the context of annual groundwater availability. The water needed to assimilate the nitrogen fertilizers that reach the water systems due to leaching is compared with the waste assimilation capacity of aquifers.

The ground-WF is calculated by splitting the blue WF of crop production, industrial production and domestic water supply according to the fraction withdrawn from groundwater per river basin. These fractions are estimated separately for agricultural withdrawals and withdrawals for industrial and/or domestic purposes based on data from the river basin plans. The estimates are included in Appendix II. Subsequently, it is assumed that 100% of the groundwater withdrawn for industrial and domestic purposes is consumed, i.e. none of the water abstracted from groundwater for these purposes returns (clean) to the groundwater in the same period of time. The ground-WFs of industrial production and domestic water supply are therefore increased to equal water withdrawal by dividing them by the consumptive fractions assumed by Mekonnen and Hoekstra (2011): 5% for industries and 10% for households.

Monthly historical runoff series (1939-2011) (later referred to as 'series') for the basins Oum Er Rbia, Bouregreg, Sebou and Loukkos are obtained from Ministry of Energy, Mining, Water and Environment of Morocco, Department of Water (2013b). The series represent actual inflow per sub-catchment as received from the river basin agencies. Only small-scale withdrawals upstream of these points are subtracted from natural inflow. Large-scale withdrawals for irrigation are not subtracted from the inflow figures, since these are withdrawn from the reservoirs at the downstream end of the sub-catchments. Natural runoff is therefore considered equal to the actual inflow series, which are also taken as estimate of surface water availability in the river basin plans. Generally, environmental flow requirements are not considered in Morocco's river basin plans and local studies on the minimal flows Moroccan rivers require to sustain aquatic and riparian ecosystems, and the livelihoods that depend on them, are lacking. Therefore environmental flow requirements are not subtracted from natural runoff in this study. Monthly natural runoff for the four river basins is calculated by summation of the monthly inflows of the sub-catchments. Subsequently, a long-term average of these monthly inflows is taken for the period 1980-2011. In Morocco, a significant decrease in water availability is observed since the eighties. However, the chosen period is considered to represent the current climate and as an appropriate context for the WF estimates over the period 1996-2005.

The long-term average annual runoff in the basins Bouregreg, Oum Er Rbia and Sebou, derived from the monthly historical runoff series, does not differ significantly from the figures mentioned in the corresponding river basin plans (ABH Bouregreg et de la Chaouia, 2012; ABH Oum Er Rbia, 2011; ABH Sebou, 2011). For the Loukkos basin there is, however, a large discrepancy in this. ABH Loukkos (2011) estimates the average annual runoff at 3,600 Mm³/yr for the period 1945-2010, while the series used in this study give an average annual runoff of 2,113 Mm³/yr for the same period. The series used exclude some small Mediterranean basins in the east of the action zone of the river basin agency of Loukkos (see Appendix V), but their runoff is relatively small (<230 Mm³/yr) according to ABH Loukkos (2011). The reason of the discrepancy remains unclear. Therefore the blue water resources in the Loukkos basin might be underestimated. The historical runoff series for the basin of Oum Er Rbia excludes the runoff in the Atlantic coast basins south of the watershed from the Oum Er Rbia river, but within the action zone of the river basin agency of Oum Er Rbia, the unit of analysis in this study (see Appendix V). In the river basin plan of this agency, the water availability in these coastal basins is estimated to be 40 Mm³/yr (ABH Oum Er Rbia, 2011). This volume is added to the long-term average runoff in the Oum Er Rbia basin and distributed over the months according to the variation of the originally obtained series. Although the long-term average annual runoff for the basins Sebou and Bouregreg from the series used in this study does not significantly differ from the figures mentioned in the corresponding river basin plans, their natural runoff might be slightly underestimated. The series for Sebou exclude a part of the coastal area (also excluded in surface water availability assessment in the river basin plan of Sebou (ABH Sebou, 2011)) and the plains of Berrechid and Chaouia south of Casablanca in the Bouregreg basin are excluded in the series for Bouregreg (see Appendix V). Net precipitation in these areas is thus not accounted for.

Monthly historical runoff series are not available for the river basins Moulouya, Souss Massa, Sud Atlas and Tensift. Alternatively, annual natural runoff in the basins is obtained from the corresponding river basin plans (ABH Moulouya, 2011; ABH Souss Massa Draa, n.d.a; ABH Souss Massa Draa, n.d.b; ABH Tensift, 2011; Direction de la Region Hydraulique du Guir Rheris Ziz, 2012) and subsequently distributed over the months according to different sources:

- For Moulouya, annual natural runoff relates to the period 1981-2003 and is distributed according to mean monthly precipitation over the period 1971-2005 obtained from Tekken and Kropp (2012).
- For Sud Atlas, annual natural runoff is calculated as the sum of the annual natural runoff in the basins of Draa, Guir-Ziz-Rhéris-Maîder and the North-Eastern region Zousfana and relates to different periods, but all within the timespan of 1970-2010. Distribution over the months

is done according to mean monthly precipitation over the period 1973/75-1994 in the basins of Ziz-Rhéris obtained from Riad (2003).

- For Tensift, annual natural runoff relates to the period 1980-2010 and is distributed according to the average monthly natural discharge of the river Tensift and its tributaries within the period 1970-2006 obtained from JICA, MATEE and ABHT (2007).
- For Souss Massa, annual natural runoff relates to the period 1971-2007 and is distributed according to the same temporal variation as for the Tensift basin, due to lack of data. The basin of Tensift is considered the most comparable with the basin of Souss Massa, since both are located in the Middle/South of Morocco and their streams spring from the High (and Anti) Atlas and discharge into the Atlantic Ocean.

Groundwater availability is defined by Hoekstra *et al*. (2011) as the rate of groundwater recharge minus the fraction of natural groundwater outflow required to sustain environmental flow requirements in the river. As discussed previously, environmental flow requirements are not considered in this study. In this study, groundwater availability is assessed on river basin scale and defined as the recharge by infiltration of rainwater and from rivers, minus the direct evaporation from aquifers. Underground connections between aquifers are not included to avoid double-counting. In most of the river basin plans the mentioned fluxes are given per aquifer and groundwater availability is calculated as defined. For the basins of Draa, Guir-Ziz-Rhéris-Maîder (both part of Sud Atlas basin in this study) and Souss Massa these fluxes are not available. Instead, for the basin of Souss Massa, data on aquifer recharge by infiltration of rainwater and streams are obtained from Laouina (2001). For the Sud Atlas basin, groundwater availability is taken as the sum of available groundwater in the basins Draa and Guir-Ziz-Rhéris-Maîder and the North-Eastern region Zousfana. For the latter region, above mentioned fluxes are available and groundwater availability is calculated according to the above definition. The terms used to indicate the groundwater resources in the river basin plans of Draa and Guir-Ziz-Rhéris-Maîder are taken as estimate of the groundwater availability in these basins. However, different terms are used and no clear definition is given. In the river basin plan of Draa is spoken of exploitable resources (ABH Souss Massa Draa, n.d.a), whereas in the plan for the rivers Guir-Ziz-Rhéris-Maîder one speaks of renewable resources (Direction de la Region Hydraulique du Guir Rheris Ziz, 2012). The latter probably comes close to the definition of groundwater availability in this study. The exploitable resources can be smaller than the natural water availability due to political, social, economic or environmental constraints (FAO, 2003). Some aquifers cross the border between action zones of river basin agencies and are included in both river basin plans. These are the aquifers of Bahira and Haouz between Tensift and Oum Er Rbia and the aquifer of Chaouia côtière between Bouregreg and Oum Er Rbia (see Appendix III). The percentages according which the groundwater availability is accounted to the defined river basin action zones in this study are included in Table 2-3. The estimate of the groundwater availability for these aquifers is based on data in the river basin plan of the agency that contains the major part of the aquifer.

Table 2-3: Aquifers crossing border between river basin agency action zones. Percentages are estimated based on map in Appendix III.

Aquifers crossing hydrological border, double-counted in river basin plans	Major part of aquifer in basin of:	Minor part of aquifer in basin of:
Chaouia côtière	Bouregreg (~90%)	Oum Er Rbia (~10%)
Bahira	Tensift (~75%)	Oum Er Rbia (~25%)
Haouz	Tensift (~80%)	Oum Er Rbia (~20%)

Blue water scarcity is defined as the ratio of the total blue WF in a catchment over the blue water availability in that catchment (Hoekstra *et al*., 2011). In this study, this ratio is calculated as the total blue WF to monthly natural runoff and as the ground-WF to annual groundwater availability. Blue water scarcity manifests itself on a monthly scale, but varying groundwater stocks throughout the year do not have to be problematic as long as annual withdrawals remain far below annual recharge. Following Hoekstra and Mekonnen (2011) and Hoekstra *et al*. (2012), blue water scarcity values have been classified into four levels of water scarcity. Hoekstra *et al*. (2012) argue their classification is comparable with the commonly used classification for the annual withdrawal-to-availability indicator, because the criterion they use is less strict, but they apply a monthly evaluation which is stricter. The classification in this study corresponds with their classification, with the note that the levels in this study are five times lower, because Hoekstra *et al*. (2012) take into account environmental flow requirements that take up 80% of natural runoff. The used classification is as follows:

- low blue water scarcity (<0.20): the blue WF is lower than 20% of natural runoff and does not exceed blue water availability; river runoff is unmodified or slightly modified.
- moderate blue water scarcity (0.20-0.30): the blue WF is between 20 and 30% of natural runoff; runoff is moderately modified.
- significant blue water scarcity (0.30-0.40): the blue WF is between 30 and 40% of natural runoff; runoff is significantly modified.
- severe water scarcity (>0.40): the monthly blue WF exceeds 40% of natural runoff, so runoff is seriously modified.

As mentioned before, environmental flow requirements are not taken into account in this study, since they are generally not considered in Moroccan river basin plans and local studies on the level of these requirements are lacking. Therefore, the maximum blue WF is assumed equal to natural runoff. One could argue whether this maximum blue WF is sustainable, because it would be wise to account for minimum flows in Moroccan rivers.

The water pollution level is defined as the total grey WF in a catchment divided by the actual catchment runoff (Hoekstra *et al*., 2011). Whereby a ratio of 1 means that the complete catchment runoff is needed to assimilate the load of pollutants. Similarly, in this study the grey WF of crop production (related to nitrate-nitrogen pollution) is compared with the waste assimilation capacity of groundwater, which is defined as actual groundwater availability, calculated as groundwater availability minus the ground-WF. The grey WF of crop production is put in the context of waste assimilation capacity of groundwater instead of actual catchment runoff, because from most river basin plans emerges that nitrate pollution mainly occurs in aquifers. The maximum sustainable grey WF is thus assumed equal to the actual groundwater availability.

2.8 Reallocation of crop production and benchmarking water productivities

The potential water savings by changing the allocation of crop production across river basins are quantified by means of an optimization model. The country total green plus blue WF of 12 main crops (in Mm^3/yr) is minimized by changing the allocation of production (in hectare) over the rivers basins under constraints for production demand (in ton/yr) and land availability (in hectare/yr). Results are compared with a base case. The base case corresponds with the average WF of the analysed crops over the period 1996-2005. The input data and base case are recorded in Appendix IX.

Two optimization cases are distinguished, with different constraints on land availability (see Table 2-4). For both cases, the restriction is imposed that the country total production per crop (in ton/yr) should be equal to (or greater than) the country total production of the crop in the base case.

Table 2-4: Land availability constraints for the two different optimization cases.

Case	Constraint on land availability	Implications
A	'Total allocated land for production of crops per basin' ≤ 'Total harvested area (period 1996-2005) per basin'	Basin- and crop- specific WF (m^3/ton) and yield (ton/ha) play a role in the allocation. Production of a crop is not necessarily allocated to the basin with the smallest WF (m^3/ton).
B	'Total allocated land for production of annual crops per basin' ≤ 'Total harvested area (period 1996-2005) of annual crops per basin' & 'Allocated land for production per perennial crop and per basin' ≤ 'Harvested area (period 1996-2005) per perennial crop and per basin'	Same as for optimization A. Effect of additional constraint is that perennial crops cannot be relocated.

In addition to the above assessment, an assessment is made of the potential water savings by benchmarking the water productivities of 12 main crops (i.e. lowering the WFs of the main crops down to benchmarks). For each basin and crop a benchmark is set in the form of the lowest water consumption of that crop which is achieved in a comparable river basin in Morocco. In this case, basins are considered comparable when the reference evapotranspiration (ET_0 in mm/yr) is in the same order of magnitude (see Table 2-5). Reference evapotranspiration expresses the evaporating power of the atmosphere at a specific location (and time of the year) and does not consider the crop characteristics and soil factors (Hoekstra *et al*., 2011). Differences in soil and development conditions are thus not accounted for.

Table 2-5: Comparison of river basins based on reference evapotranspiration (ET_0 in mm/yr). Period: 1961-1990.

No.	River basin	ET_0 (mm/yr)	Considered comparable with no.
1	Sud Atlas	1,652	-
2	Souss Massa	1,450	3
3	Moulouya	1,409	2
4	Tensift	1,389	5
5	Oum Er Rbia	1,387	4
6	Sebou	1,266	7,8
7	Bouregreg	1,239	6,8
8	Loukkos	1,212	6,7

Source: ET_0 from FAO (2013e)

2.9 Addressing the added value of water footprint and virtual water information

In order to address whether WF assessment provides new insights and response options in addition to the existing water management plans in Morocco, results and conclusions from the WF assessment are compared with the scope of analysis of and action plans included in Morocco's national water strategy (Ministry of Energy, Mining, Water and Environment of Morocco, Department of Water, 2011) and river basin plans (ABH Bouregreg et de la Chaouia, 2012; ABH Loukkos, 2011; ABH Moulouya, 2011; ABH Oum Er Rbia, 2011; ABH Sebou, 2011; ABH Souss Massa Draa, n.d.a; ABH Souss Massa Draa, n.d.b; ABH Tensift, 2011; Direction de la Region Hydraulique du Guir Rheris Ziz, 2012). A summary of the action plans in the national water strategy is provided in Appendix X. The action plans in the river basin plans conform to the national water strategy.

3 Water footprint and virtual water balance of Morocco

In this chapter the water footprint (WF) of activities in Morocco and the virtual water balance of the country are analysed. Firstly, the green, blue and grey WFs within Morocco are assessed (section 3.1). The WF of the main Moroccan crops, their economic water and land productivity and the variation of these parameters across the river basins are analysed in sections 3.2 and 3.3. What follows is an analysis of Morocco's virtual water balance and the costs and earnings per m³ water imported and exported, respectively (section 3.4), and a brief discussion of the WF of Moroccan consumption and external water dependency (section 3.5). Lastly, the blue WF is placed in the context of blue water availability (section 3.6) and the grey WF of crop production is compared with the waste assimilation capacity of groundwater (section 3.7).

3.1 Water footprint of Moroccan production

The total WF of Moroccan production in the period 1996-2005 was 38.8 Gm³/yr (77% green, 18% blue, 5% grey), see Table 3-1. Crop production is the largest contributor to this WF. The sector accounts for 78% of all green water consumed, 83% of all blue water consumed (evaporative losses in irrigation water supply network included) and 66% of the total volume of polluted water.

Evaporative losses from storage reservoirs are estimated at 884 Mm³/yr, which is 13% of the total blue WF within Morocco. Evaporation from these reservoirs actually needs to be attributed to the blue WF of the end-users and -purposes of the reservoirs. Most reservoirs in Morocco serve multiple purposes, such as irrigation, potable water supply (for humans and livestock), hydropower production and flood control. However, for most reservoirs, the blue WF of the reservoir is ultimately linked with irrigated agriculture and in some cases potable water supply.

The green, blue and grey WF of Moroccan production per river basin and the variation in the green and blue WF throughout the year are shown in Figures 3-1 and 3-2, respectively. These figures exclude the WF of grazing and animal water supply, since these values are only available as annual national aggregates. For more spatial detail, see Appendix VI, where the green, blue, grey and total WF of production are shown on a 5 by 5 arc minute grid scale.

Largest WFs (green, blue and grey) are found in the basins Oum Er Rbia and Sebou, the basins containing the main agricultural areas of Morocco. Together, these two basins account for 63% of the total WF of national production. In general, the green WF is largest in the rainy period December-May, while the blue WF is largest in the period April-September when irrigation demands increase. The relevance of the green WF should not be underestimated. Although rain is free and evaporation happens anyway, green water that is used for one purpose cannot be used for another purpose (Hoekstra, 2013), e.g. green water consumed for the production of maize for livestock fodder is no longer available for the growing of olives for consumption within Morocco or for export.

In the basins Bouregreg and Loukkos, evaporation from storage reservoirs accounts for 45% and 55% of the total blue WF, respectively (see Table 3-2). Irrigated agriculture is the largest blue water consumer in the other basins, but evaporation from storage reservoirs is also significant in these basins. Main irrigated crops in the Oum Er Rbia basin are maize, wheat, olives and sugar beets, together they account for 60% of the total irrigation water consumed in the period 1996-2005. In the basin of Sebou, 56% of the blue WF of crop production relates to the irrigation of wheat, olives, sugar beets, sugar cane and sunflower seed.

Inter-basin water transfers from the Oum Er Rbia basin to the basins of Bouregreg (91 Mm³/yr) and Tensift (212 Mm³/yr) add up to a volume of 302 Mm³/yr (ABH Oum Er Rbia, 2011). Since this volume of water is transferred out of the Oum Er Rbia basin, it is a blue WF within this basin, although not included in the presented WF figures. The transferred volume compares to 12% of the total blue WF of activities within the Oum Er Rbia basin (2,531 Mm³/yr).

Table 3-1: Water footprint of activities within Morocco (i.e. water footprint of Moroccan production) (in Mm³/yr).

Water footprint of	Period	Green	Blue	Grey	Total	% of total
Crop production [a]	1996-2005	23,245	5,097	1,378	29,719	77%
Grazing [a]	1996-2005	6,663	-	-	6,663	17%
Animal water supply [a]	1996-2005	-	151	-	151	0%
Industrial production [a]	1996-2005	-	18	69	88	0%
Domestic water supply [b]	1996-2005	-	125	640	765	2%
Storage reservoirs [b]	-	-	884	-	884	2%
Irrigation water supply network [b]	1996-2005	-	549	-	549	1%
Total water footprint	1996-2005	29,908	6,824	2,087	38,819	100%
% of total		77%	18%	5%	100%	

Source: [a] Mekonnen and Hoekstra (2011)
[b] Own elaboration

Table 3-2: Blue water footprint within each river basin per purpose (in Mm³/yr). Period: 1996-2005.

River basin	Industrial production [a]	Domestic water supply [a]	Irrigation supply network [b]	Storage reservoirs [b]	Crop production [a]	Total	% of total
Bouregreg	4	25	2	113	105	249	4%
Loukkos	2	12	17	253	174	458	7%
Moulouya	2	12	40	42	334	430	6%
Oum Er Rbia	3	21	244	182	2,027	2,478	37%
Sebou	4	25	182	196	1,612	2,020	30%
Souss Massa	1	9	12	41	217	280	4%
Sud Atlas	1	9	17	52	194	273	4%
Tensift	2	11	36	5	433	486	7%
Total	18	125	549	884	5,097	6,673	100%
% of total	0.3%	1.9%	8.2%	13.3%	76.4%	100%	

Source: [a] Mekonnen and Hoekstra (2011)
[b] Own elaboration

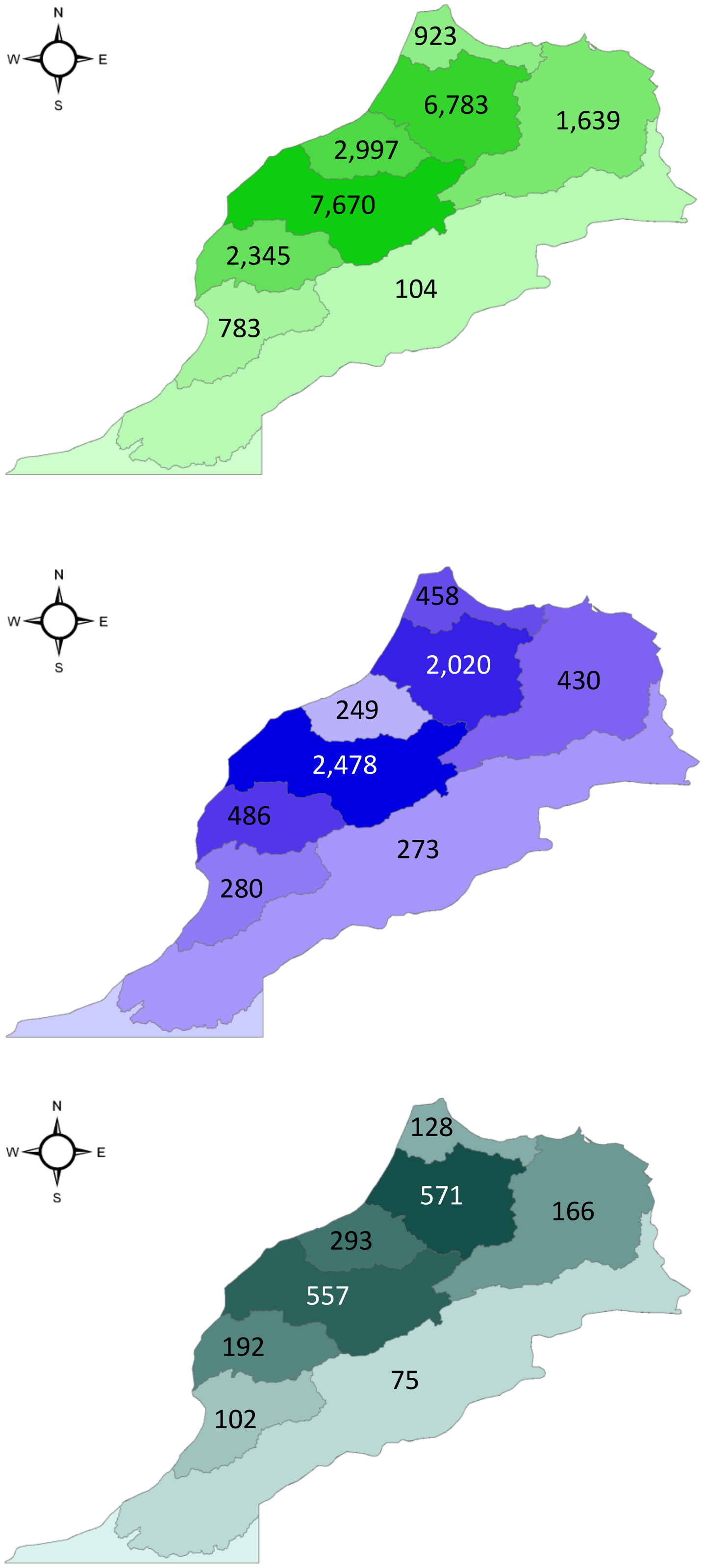


Figure 3-1: Water footprint of national production per river basin (in Mm³/yr). Top-down: total green, total blue and total grey water footprint of national production. Period: 1996-2005. River basin names shown in Figure 2-1, section 2.1.

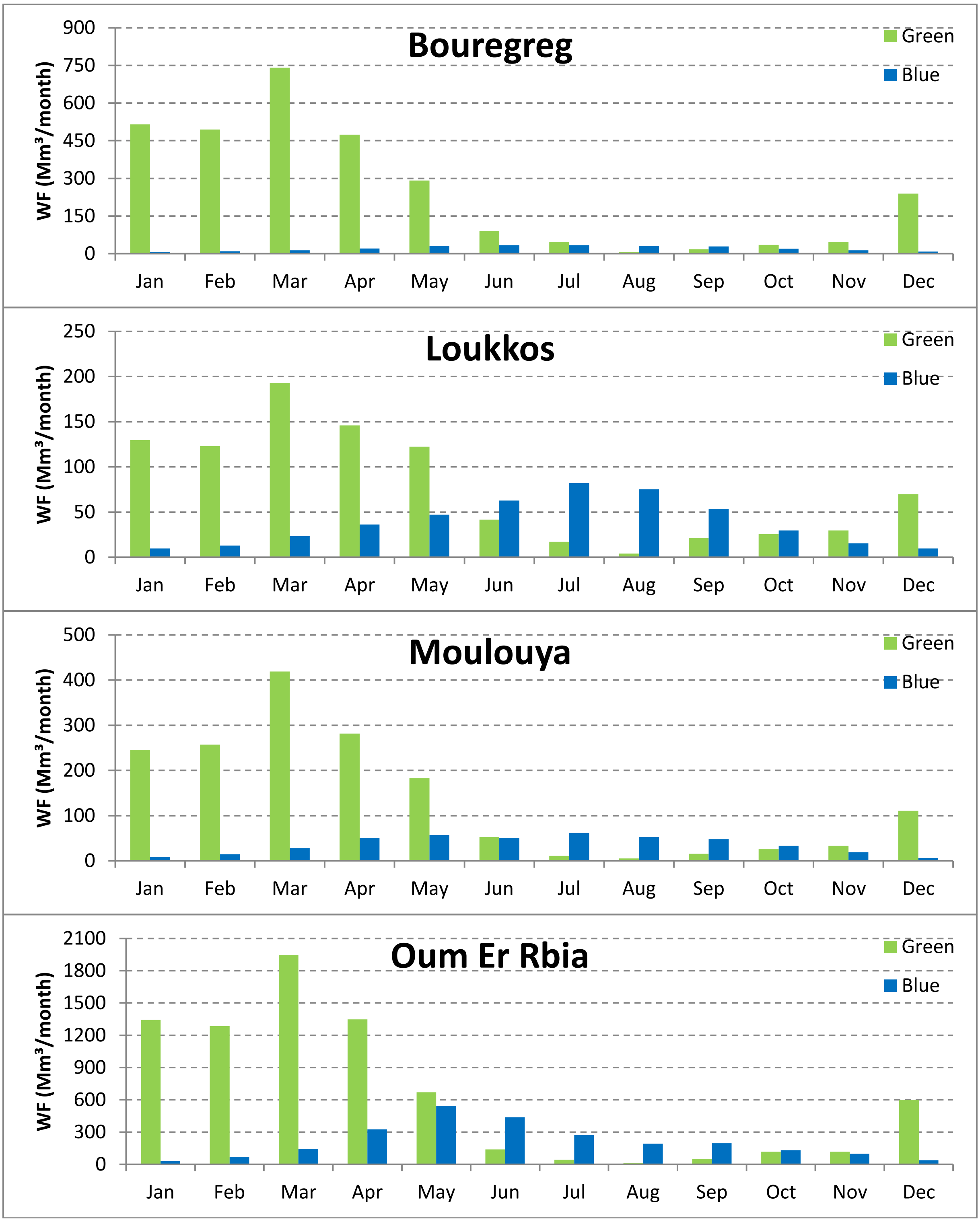


Figure 3-2: Monthly distribution of the water footprint of national production per river basin (in Mm³/month). Period: 1996-2005. Note the different scales on the y-axis.

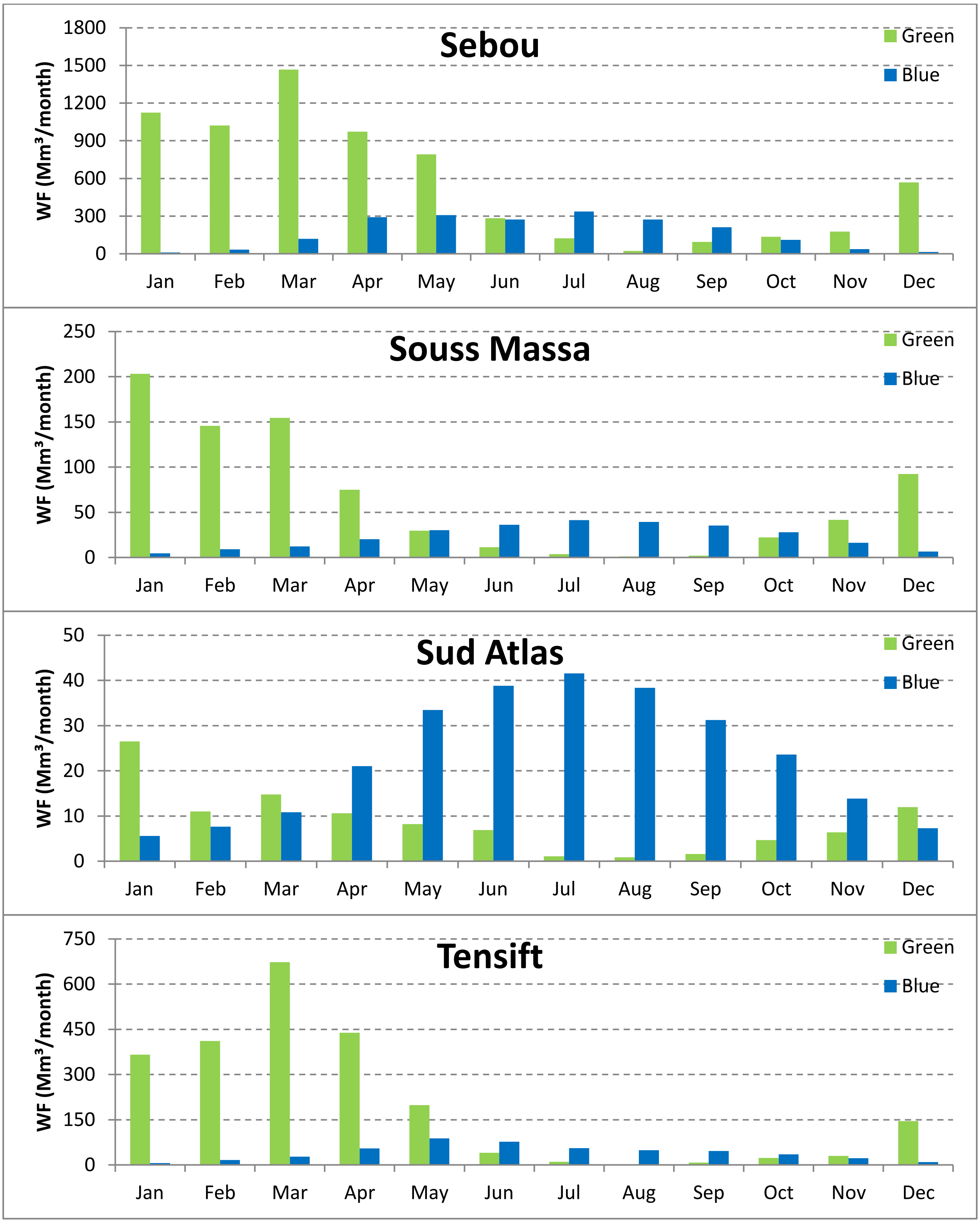


Figure 3-2 (continued): Monthly distribution of the water footprint of national production per river basin (in Mm³/month). Period: 1996-2005. Note the different scales on the y-axis.

3.2 Water footprint of main crops in Morocco

Crop production contributes the most to the WF of national production. In the period 1996-2005 its WF was 29,719 Mm^3/yr, of which 28,342 Mm^3/yr was consumed by crops (green and blue water) and 1,378 Mm^3/yr was needed to assimilate the nitrogen fertilizers that reach the water systems due to leaching or runoff (grey water). The water consumption (i.e. green plus blue WF) of the main (water consuming) crops in the period 1996-2005 is shown in Table 3-3, and per crop grouping in Table 3-4. Cereals, mainly in the form of wheat, barley and maize are ranked high in Table 3-3. Olives take up the third position after wheat and barley. For the top 10 water consuming crops in the period 1996-2005, their water consumption per ton of production and its variation over the river basins is analysed. In addition, this analysis is done for crops that play an important role in the Moroccan agricultural sector, but are not included in the top 10 water consuming crops. These are clementine ('Tang.Mand.Clement.Satsma' in Table 3-3), sugar cane and tomatoes. Clementine and tomatoes are important crops produced in Morocco and principal export products and the Moroccan sugar cane sector is well organised (Ministry of Agriculture and Fisheries of Morocco, 2010).

For the 13 analysed crops, their average green and blue WFs in the period 1996-2005 are shown in Figure 3-3. Most green water was consumed by the production of wheat, barley and olives. The largest blue WFs relate to the production of wheat, olives and maize. For wheat, the number one blue water consuming crop, the blue WF was largest in the period March-May and peaked in April.

The country-average green plus blue WF of crops per ton produced is shown in Figure 3-4. Almonds, dates and maize consume the most water per ton of production, followed by olives, barley and wheat. Blue water consumption is largest for dates, maize, olives, almonds and grapes. It should be noted that barley and fodder crops are completely rain-fed throughout the study area. Sugar beets are only grown in the basins Oum Er Rbia, Bouregreg, Moulouya, Sebou and Loukkos. Sugar cane is only grown in the basins Bouregreg, Moulouya, Sebou and Loukkos.

Table 3-3: Green plus blue water footprint of main (water consuming) crops in Morocco. Period: 1996-2005.

FAO crop code	Crop	Green plus blue water footprint (Mm³/yr)
15	Wheat	10,981
44	Barley	6,787
260	Olives	2,951
56	Maize	1,148
221	Almonds	641
577	Dates	449
490	Oranges	440
560	Grapes	367
900a	Fodder crops	361
157	Sugar Beets	353
515	Apples	300
267	Sunflower Seed	266
116	Potatoes	211
495	Tang.Mand.Clement.Satsma	209
156	Sugar Cane	200
388	Tomatoes	99
242	Groundnuts in Shell	77
83	Sorghum	73
27	Rice, Paddy	50
79	Millet	16
328	Seed Cotton	3
236	Soybeans	2
270	Rapeseed	2

Source: Mekonnen and Hoekstra (2010b)

Table 3-4: Green plus blue water footprint of perennials, annuals, citrus fruits and pulses in Morocco. Period: 1996-2005.

Crop grouping	Green plus blue water footprint (Mm³/yr)
Perennials	4,786
Annuals	853
Citrus fruits	668
Pulses	687

Source: Mekonnen and Hoekstra (2010b)

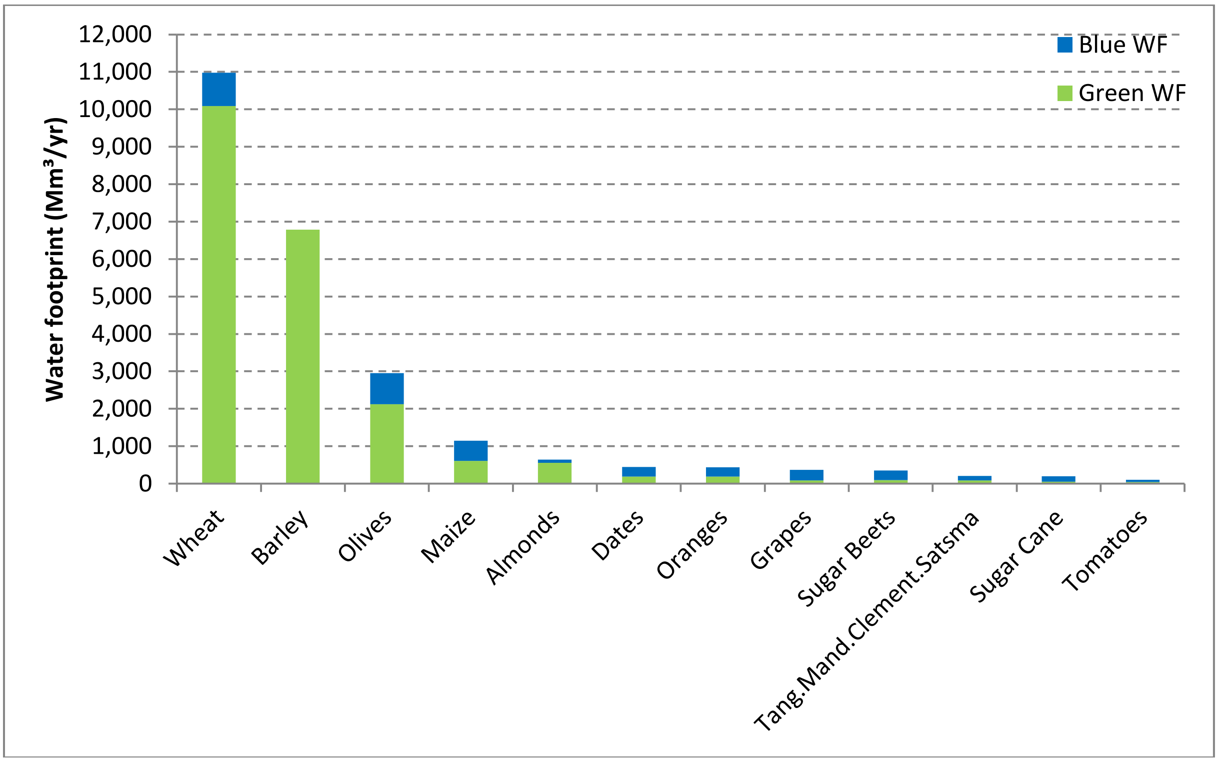


Figure 3-3: Water footprint of main crops in Morocco (in Mm³/yr). Period: 1996-2005.

Source: Mekonnen and Hoekstra (2010b)

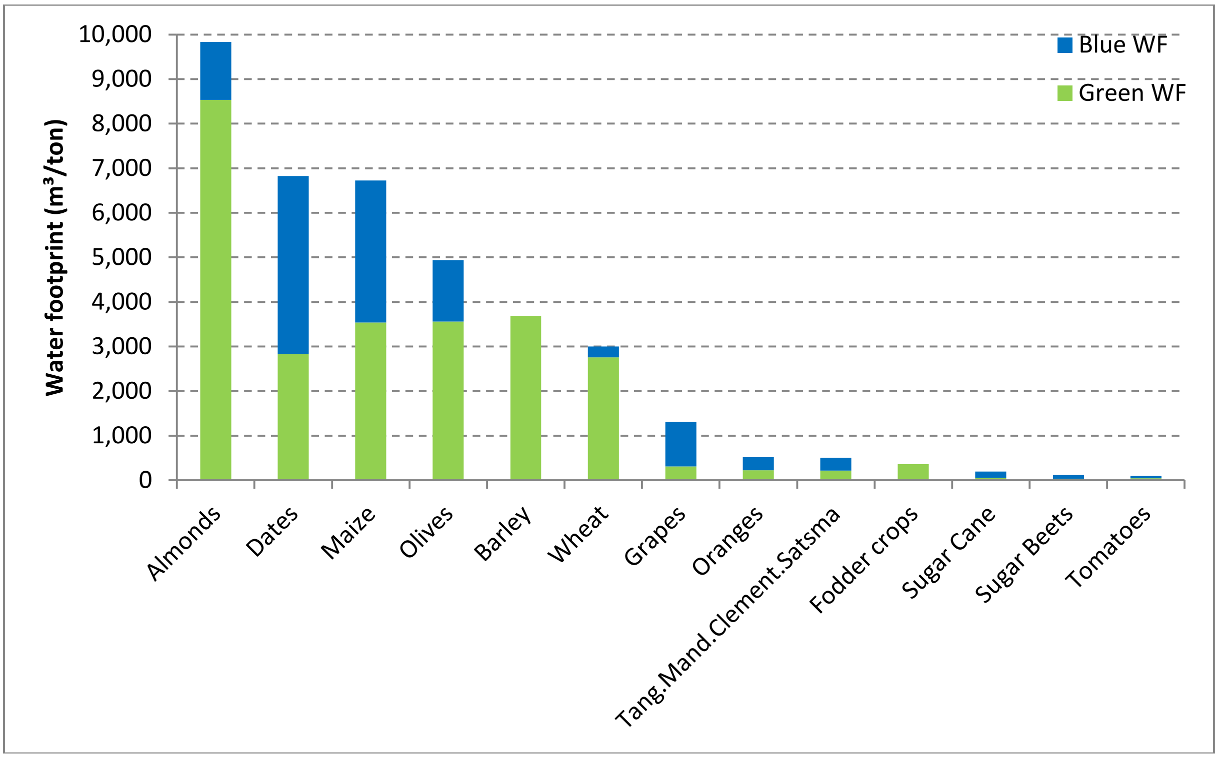


Figure 3-4: Country-average water consumption of main crops (in m³/ton). Period: 1996-2005.

Source: Mekonnen and Hoekstra (2010b)

Due to differences in climatic conditions, water consumption of crops (in m³/ton) varies significantly per river basin, see Figures 3-5 and 3-6. In general, water consumption of crops is above country-average in the basins Oum Er Rbia and Tensift and below country-average in the northern basins Bouregreg, Sebou, Loukkos and Moulouya. In the basins Sud Atlas and Souss Massa the picture is not so clear. Barley, dates, fodder crops, maize and wheat consume significantly less water in the Sud Atlas basin compared to country-average (up to 64% less for wheat), while the other crops consume more than average water in this basin. In the Souss Massa basin these crops (except for maize) also consume less water than average, while the other crops consume above average water. For all analysed crops, the blue/green water use ratio is above country-average in the Sud Atlas basin, even up to 7 times more for the production of wheat. In other words, crops in the Sud Atlas basin receive relatively much irrigation water. Appendix VII includes data per river basin on the WF of crops in Mm³/yr and m³/ton.

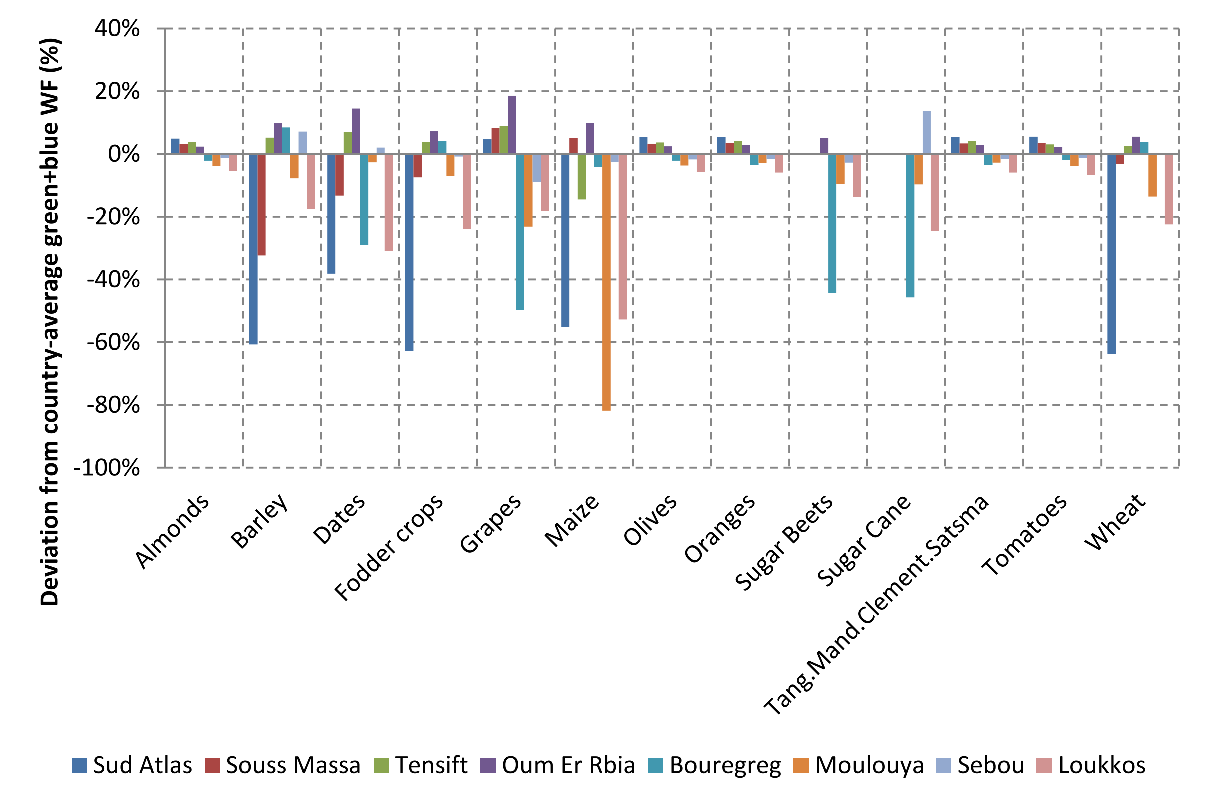


Figure 3-5: Variation in green plus blue water footprint (in m³/ton) across river basins. Period: 1996-2005.

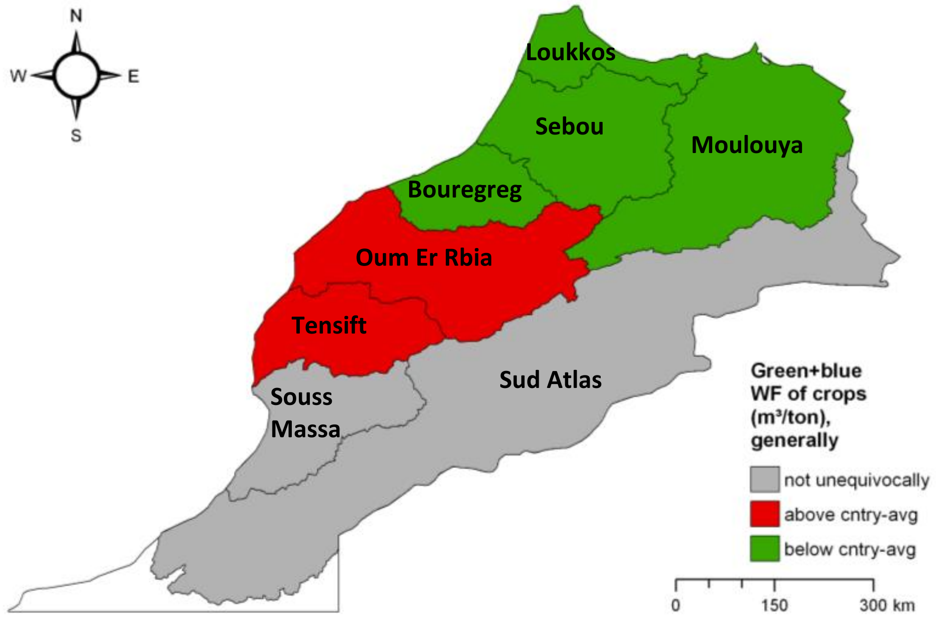


Figure 3-6: Green plus blue water footprint of main crops (in m³/ton) compared to the country-average. Period: 1996-2005.

3.3 Economic water and land productivity of main crops in Morocco

Here, the value of the main crops analysed in the previous section is assessed per unit of water used for their production (economic water productivity – EWP) and per hectare of land harvested (economic land productivity – ELP). Only fodder crops are excluded in this analysis, because no data are available on their producer price.

The five crops that consumed the most green plus blue water in the period 1996-2005 are the crops with the lowest EWP, ranging from 0.08 US$/m³ for wheat to only 0.02 US$/m³ for almonds, see Figure 3-7. Grapes, sugar beets and citrus fruits (oranges and mandarins etc.) have higher economic value per drop, ranging from 0.26 US$/m³ for grapes to 0.54 US$/m³ for mandarins and others. Tomatoes consumed the least water in the period 1996-2005 of the analysed crops, while they have the highest EWP of 1.82 US$/m³. Production of tomatoes thus yielded 22 times more value per drop than production of wheat in the same period.

ELP is lowest for the five crops that take up the largest share in the harvested area in the period 1996-2005, ranging from 375 US$/ha for olives to 112 US$/ha for almonds (see Figure 3-8). Sugar crops, dates, grapes and citrus fruits had higher ELP, but the highest value per hectare cultivated was obtained by production of tomatoes, namely 8,291 US$/ha, which is equivalent to 26 times the ELP of wheat in the same period. Moroccan tomatoes are largely grown in greenhouses (mainly in the Souss Massa basin) where yields are generally higher than when produced on open fields.

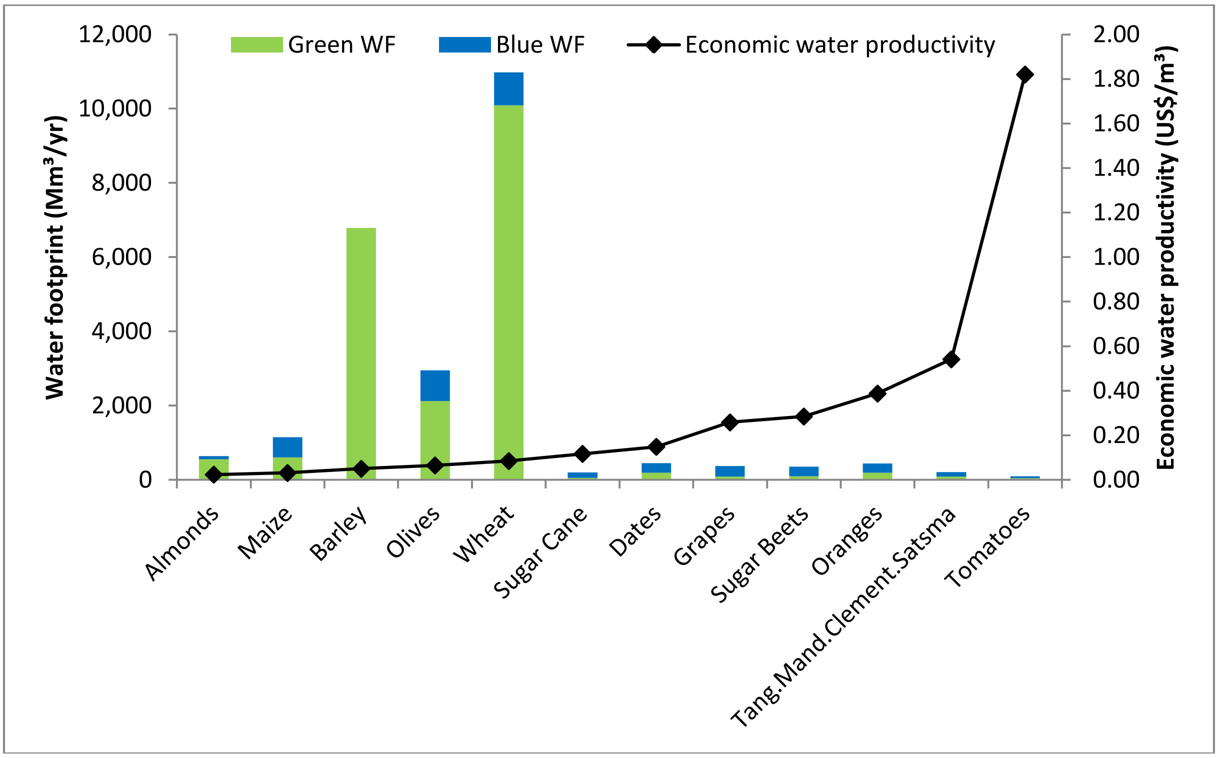


Figure 3-7: Economic water productivity (in US$/m³) and green and blue crop water use (in Mm³/yr) of main crops in Morocco. Period: 1996-2005.

Source: Water footprint from Mekonnen and Hoekstra (2010b)
Producer prices from FAO (2013d)

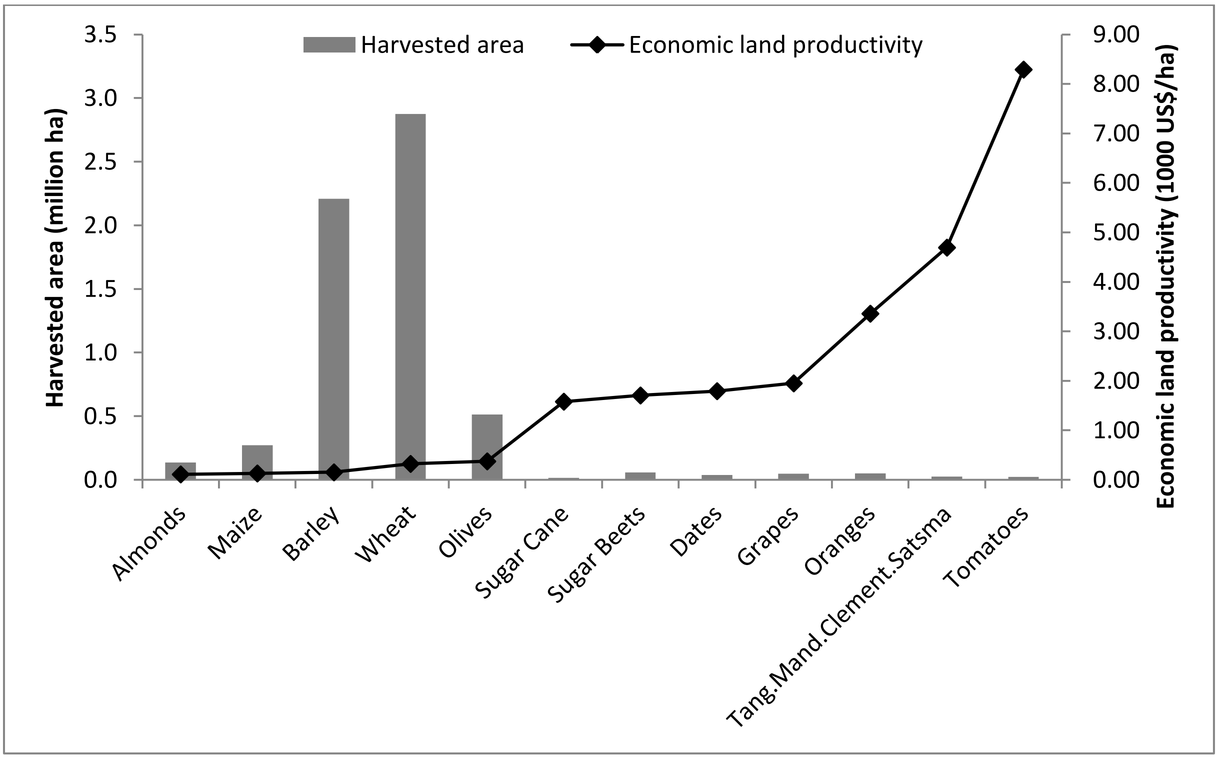


Figure 3-8: Economic land productivity (in US$/ha) and harvested area (in ha/yr) of main crops in Morocco. Period: 1996-2005.

Source: Harvested area and yield from Mekonnen and Hoekstra (2010b)
Producer prices from FAO (2013d)

EWP of crops varies across the basins according to their water consumption (m³/ton) as discussed in section 3.2, being large in basins where water consumption is small and vice versa. Economic land productivity of crops varies across the basins analogue to differences in yield. Significant variation across the basins from country-average yield is observed for almonds, barley, maize, olives and wheat, see Figure 3-9. In general, yields (and thus ELPs) of these crops are above country average in the basins Moulouya, Sebou and Loukkos and below country-average in the southern basins. However, this general picture is not unequivocally, in particular for the basins Sud Atlas and Souss Massa.

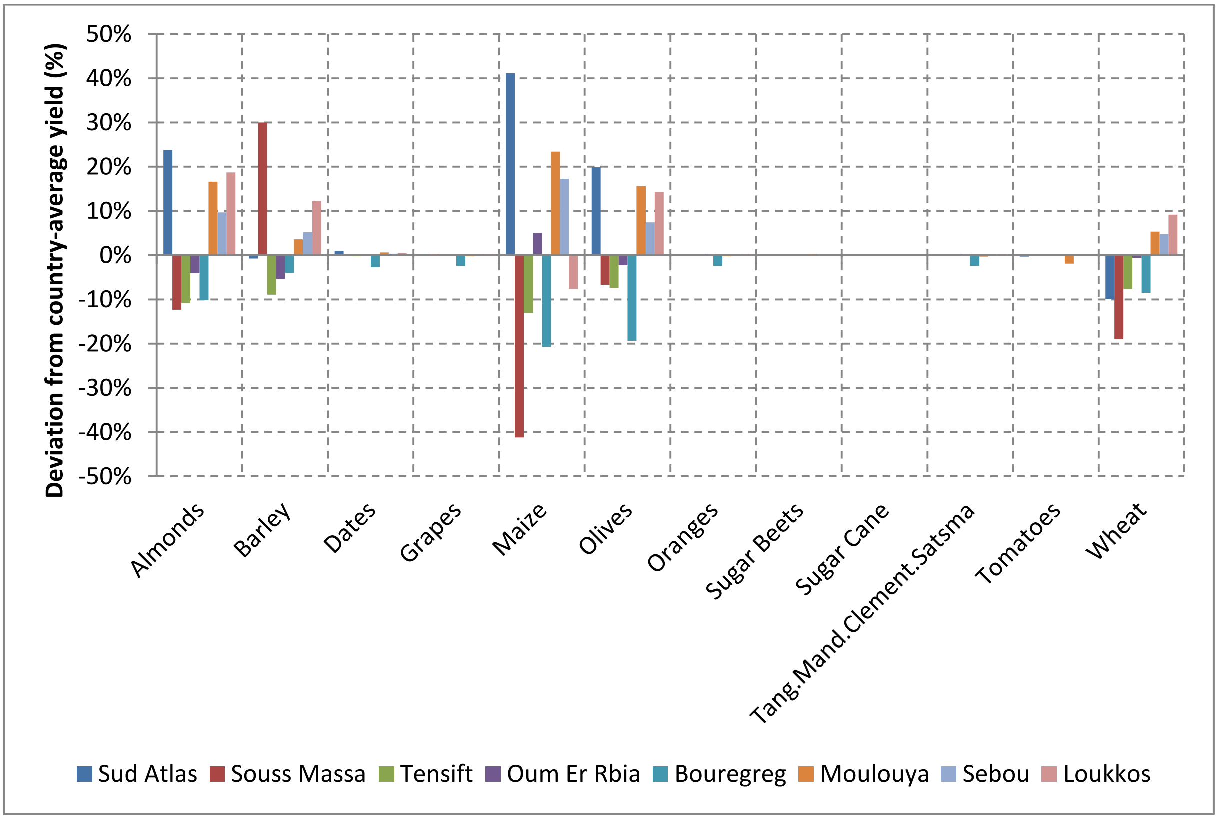


Figure 3-9: Variation in crop yield across river basins. Period: 1996-2005.

3.4 Virtual water balance and national water saving of Morocco

Morocco's virtual water balance for the period 1996-2005 is shown in Figure 3-10. Virtual water import exceeds virtual water export, which makes Morocco a net virtual water importer. Only 31% of the virtual water export originates from Moroccan water resources, the other 69% is related to re-export of imported virtual water. The following sections contain more details on the virtual water import and export and the associated costs and earnings per m³ water, respectively.

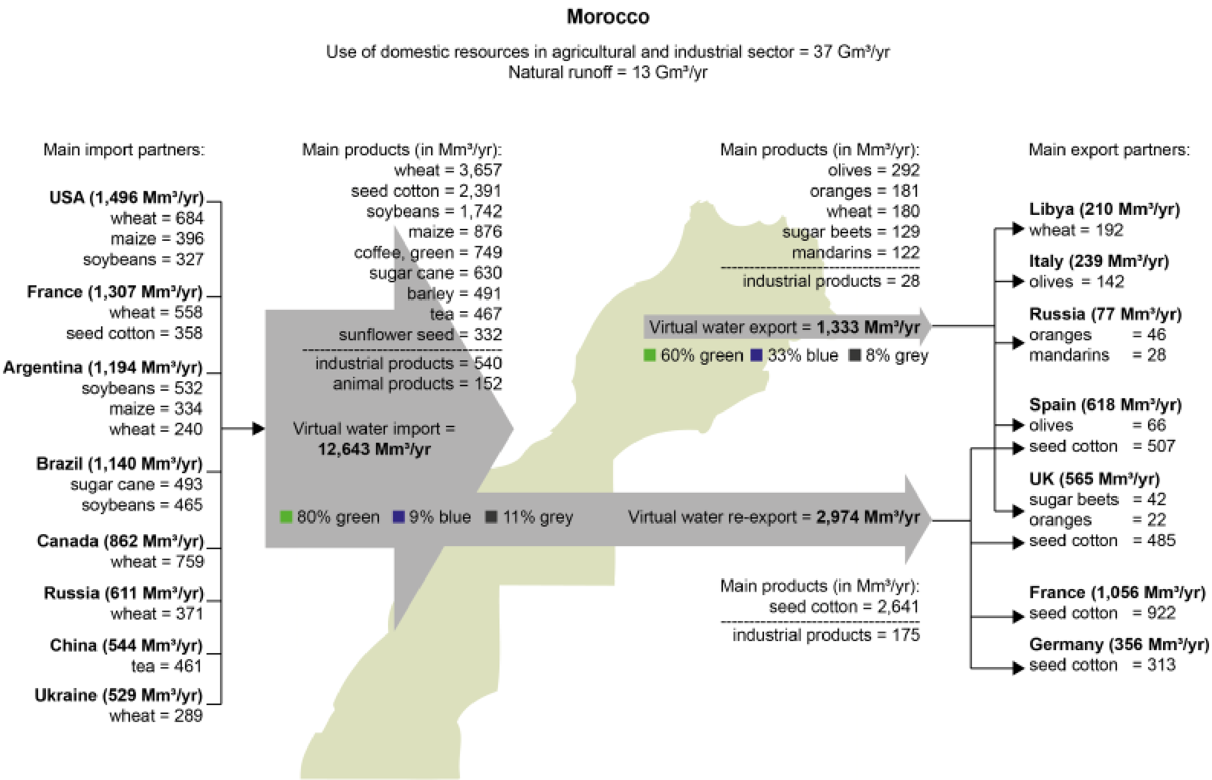


Figure 3-10: Morocco's virtual water balance related to trade in agricultural and industrial commodities. Period: 1996-2005.

Source: Virtual water import and (total) virtual water export from Mekonnen and Hoekstra (2011)

3.4.1 Morocco's virtual water import

The total virtual water import for the period 1996-2005 was 12,643 Mm³/yr (80% green, 9% blue, 11% grey), see Table 3-5. Import of crop products contributes for 95% to this total. Import of animal and industrial products contribute for 1% and 4%, respectively. The main countries from which Morocco imports virtual water are shown in Table 3-6. Imports from these countries together account for 61% of the total virtual water imported.

The value of the total virtual water imported in the period 1996-2005 was 12.4 billion US$/yr. Import of industrial products accounted for 83%, import of crop products for 16% and import of animal products for 1%. The average cost of imported commodities per unit of virtual water imported was 0.98 US$/m³.

Table 3-5: Virtual water import and import expenditure. Period: 1996-2005.

	Related to crop products	Related to animal products	Related to industrial products	Total
Green (Mm³/yr)	9,964	119	-	10,083
Blue (Mm³/yr)	1,100	24	42	1,166
Grey (Mm³/yr)	888	9	498	1,394
Total (Mm³/yr)	11,951	152	540	12,643
Economic value of imports (million US$/yr)	1,975	125	10,329	12,429
Value per m³ imported (US$/m³)	0.17	0.82	19.14	0.98

Source: Virtual water import from Mekonnen and Hoekstra (2011)
Economic value of imports from ITC (2007)

Table 3-6: Virtual water import from main import partners (in Mm³/yr). Period: 1996-2005.

Country where Morocco imports from	Crop products	Animal products	Industrial products	Total	% of total
United States of America	1,481	1.7	13.4	1,496	12%
France	1,201	38.8	67.0	1,307	10%
Argentina	1,192	1.9	0.2	1,194	9%
Brazil	1,136	0.5	3.0	1,140	9%
Canada	858	2.1	2.0	862	7%
Russian Federation	486	0.3	124.7	611	5%
China	508	0.6	35.4	544	4%
Ukraine	497	0.6	31.2	529	4%
World Total	11,951	152	540	12,643	100%

Source: Mekonnen and Hoekstra (2011)

Import of crop products had the largest contribution to the total virtual water import. Imported crops associated with large virtual water import are shown in Table 3-7. Import of wheat products (mainly from Canada, US, France, Russian Federation, Ukraine and Argentina), seed cotton products (mainly from France, India, Spain, UK) and soybean products (mainly from Argentina, Brazil and the USA) together account for 65% of the total virtual water import related to crop products.

The total economic value of crop products imported by Morocco was 1,975 million US$/yr. About 34% of the total cost of imported crop products is related to import of seed cotton products and 23% is related to the import of wheat products. Costs of seed cotton products imported are for 99.9% related to fabrics and textiles. The average cost of imported crop products per unit of virtual water imported was 0.17 US$/m³.

Table 3-7: Imported crops associated with large virtual water import. Period: 1996-2005.

Products	Virtual water import related to crop products Green (Mm³/yr)	Blue (Mm³/yr)	Grey (Mm³/yr)	Total (Mm³/yr)	% of total	Economic value (million US$/yr)	Value per m³ imported (US$/m³)
Wheat	3,279	69	309	3,657	31%	463	0.13
Seed Cotton	1,500	722	168	2,391	20%	673	0.28
Soybeans	1,631	88	23	1,742	15%	218	0.13
Maize	708	39	129	876	7%	132	0.15
Coffee, Green	741	0	8	749	6%	36	0.05
Sugar Cane	545	42	43	630	5%	141	0.22
Barley	422	8	61	491	4%	64	0.13
Tea	374	32	61	467	4%	69	0.15
Sunflower Seed	304	7	21	332	3%	36	0.11
Other	462	91	64	617	5%	144	0.23
Total	9,964	1,100	888	11,951	100%	1,975	0.17

Source: Virtual water import from Mekonnen and Hoekstra (2011)
Economic value of imports from ITC (2007)

3.4.2 Morocco's virtual water export

Total virtual water export for the period 1996-2005 was 4,307 Mm³/yr (36% green, 57% blue, 6% grey), see Table 3-8. Export of crop products contributes for 91% to this total. Export of animal and industrial products contribute for 5% each. Exports to the countries included in Table 3-9 together account for 81% of the total virtual water export of Morocco.

The value of the total virtual water exported in the period 1996-2005 was 7.1 billion US$/yr. Export of industrial products accounted for 51%, export of crop products for 48% and export of animal products for 1%. The average earning of exported commodities per unit of virtual water exported was 1.66 US$/m³.

Table 3-8: Virtual water export and export earning. Period: 1996-2005.

	Related to crop products	Related to animal products	Related to industrial products	Total
Green (Mm³/yr)	1,399	171	-	1,570
Blue (Mm³/yr)	2,429	21	17	2,467
Grey (Mm³/yr)	78	5	186	270
Total (Mm³/yr)	3,906	197	203	4,307
Economic value of exports (million US$/yr)	3,418	47	3,674	7,138
Value per m³ exported (US$/m³)	0.87	0.24	18.07	1.66

Source: Virtual water export from Mekonnen and Hoekstra (2011)
Economic value of exports from ITC (2007)

Table 3-9: Virtual water export to main export partners (in Mm³/yr). Period: 1996-2005.

Country where Morocco exports to	Crop products	Animal products	Industrial products	Total	% of total
France	1,056	2.2	61.8	1,120	26%
Spain	618	7.6	26.4	651	15%
United Kingdom	565	0.0	17.3	582	14%
Germany	356	0.1	12.0	368	9%
Italy	239	8.8	9.9	258	6%
Libyan Arab Jamahiriya	210	25.8	1.5	237	6%
United States of America	144	0.0	9.6	153	4%
Belgium	127	0.1	7.3	134	3%
World Total	3,906	197	203	4,307	100%

Source: Mekonnen and Hoekstra (2011)

Export of crop products takes up the largest share in the total virtual water exported for the period 1996-2005. Table 3-10 shows the crop products associated with large virtual water export. Export of seed cotton products (mainly to France, Spain, UK and Germany) accounts for 81% of the total virtual water export related to crop products.

The total economic value of crop products exported by Morocco was 3,418 million US$/yr. About 75% of the total earning of exported crop products is related to export of seed cotton products (almost completely in the form of fabrics and textiles). The average cost of exported crops per unit of virtual water exported was 0.87 US$/m³. Export of tomatoes, mandarins and seed cotton products returned an above average value per m³ exported. For tomatoes this was even 8 times the average for crop products.

Table 3-10: Exported crops associated with large virtual water export. Period: 1996-2005.

	Virtual water export related to crop products					Economic	Value per
Products	Green (Mm³/yr)	Blue (Mm³/yr)	Grey (Mm³/yr)	Total (Mm³/yr)	% of total	value (million US$/yr)	m³ exported (US$/m³)
Seed Cotton	652	1,992	0	2,645	68%	2,559	0.97
Olives	214	83	3	299	8%	31	0.10
Wheat	211	19	8	238	6%	4	0.02
Oranges	73	97	11	181	5%	152	0.84
Sugar Beets	31	79	19	129	3%	5	0.04
Tang.Mand.etc	49	65	8	122	3%	168	1.37
Maize	12	11	1	12	1%	0	0.02
Tomatoes	10	11	3	10	1%	169	7.13
Other	147	71	26	244	6%	330	1.35
Total	1,399	2,429	78	3,906	100%	3,418	0.87

Source: Virtual water export from Mekonnen and Hoekstra (2011)
Economic value of exports from ITC (2007)

Part of the total virtual water export is from Moroccan water resources, another part is re-exported from foreign resources (see Table 3-11). The total volume of Moroccan water virtually exported out of the country in the period 1996-2005 is estimated at 1,333 Mm³/yr. This means that about 4% of the water used in the Moroccan agricultural and industrial sector is used for making export products. The remainder is used to produce products that are consumed by the inhabitants of Morocco. Virtual export of blue water from Moroccan resources was 435 Mm³/yr, which is to equivalent 1.5% of Morocco's renewable blue water resources.

Export of crop products had the largest share in the virtual water export from Moroccan water resources, returning 0.87 US$/m³ on average (see Table 3-10). Specific crop products associated with large virtual water export from Moroccan origin are olives, oranges, wheat, sugar beets and mandarins. In the period 1996-2005, only export of the latter returned a value larger than the average for crop products.

Table 3-11: Virtual water export from Moroccan resources and re-export from foreign resources (in Mm³/yr). Period: 1996-2005.

		Export from Moroccan resources					
	Products	Green	Blue	Grey	Total	Total re-export from foreign resources	Total
Agricultural products	Seed Cotton	1	3	0	4	2,641	2,645
	Olives	209	81	2	292	7	299
	Wheat	160	14	6	180	58	238
	Oranges	73	97	11	181	0	181
	Sugar Beets	31	79	19	129	0	129
	Tang.Mand.Clement.Satsma	49	65	8	122	0	122
	Maize	7	6	0	14	10	24
	Tomatoes	10	11	3	24	0	24
	Perennials (excl. Olives)	29	15	5	49	12	61
	Annuals (excl. Tomatoes)	28	15	7	51	6	57
	Citrus fruits (excl. Oranges and Tang.Mand.etc)	1	1	0	2	0	3
	Pulses	22	2	6	31	3	34
	Other	177	41	8	226	61	287
	Total agricultural products	796	432	76	1,305	2,799	4,103
Industrial products		-	2	26	28	175	203
Total		796	435	102	1,333	2,974	4,307

Source: Total virtual water export from Mekonnen and Hoekstra (2011)

3.4.3 Morocco's water savings related to trade

The national water saving of Morocco related to trade is the volume of water saved by import of products instead of producing them domestically. In total, Morocco saved 27.8 Gm³/yr (75% green, 21% blue and 4% grey) by trade in agricultural and industrial products in the period 1996-2005, see Table 3-12. The total water saving is 72% of the WF within Morocco. The blue water saving is even 87% of the blue WF within Morocco. The majority of the green (99%), blue (100%) and grey (91%) water savings is related to trade in crop products. Wheat import from France resulted in a national water saving for Morocco of 3.77 Gm³/yr (Mekonnen and Hoekstra, 2010a).

Table 3-12: National water saving related to trade in agricultural and industrial products (in Mm³/yr). Period: 1996-2005.

	Green	Blue	Grey	Total
Related to trade in crop products	20,542	5,920	971	27,434
Related to trade in animal products	256	15	5	277
Related to trade in industrial products	-	8	90	98
Total	20,798	5,944	1,066	27,808

Source: Mekonnen and Hoekstra (2011)

3.5 Water footprint of Moroccan consumption and external water dependency

In total terms, the WF of Moroccan consumption was 50.0 Gm^3/yr (81% green, 12% blue and 6% grey) for the period 1996-2005 (Mekonnen and Hoekstra, 2011). Only 2% of this WF is at home, corresponding with 26 $m^3/yr/cap$ (16% blue, 84% grey). The other 98% of the WF is 'invisible', it is related to the products consumers buy at the market, namely 1,684 $m^3/yr/cap$ for agricultural products and 15 $m^3/yr/cap$ for industrial products. Twenty-nine per cent of the WF of Moroccan consumption lies outside Moroccan territory. This external component is 14.6 Gm^3/yr (84% green, 7% blue and 8% grey) in total terms. The internal component is 35.4 Gm^3/yr (80% green, 14% blue and 6%).

The WF of the average consumer in Morocco for the period 1996-2005 is shown in Figure 3-11. Consumption of cereals and meat are associated with the largest WFs. The large consumption of cereals makes that they account for the majority of crops produced in Morocco and are principal import products. As such, they are the main water consuming crops in Morocco and account for the largest virtual water import flows. The consumption of meat and dairy products contribute to the WF in Morocco by the water used for drinking and servicing livestock (i.e. the WF of animal water supply, see section 3.1), but mainly by the water use for the production of feed that the animals consume during their lifetime. A vast amount of green water consumption is associated with the production of fodder crops and the pastures for livestock grazing (see sections 3.2 and 3.1, respectively).

The largest part of imports comes from United States of America, France, Argentina, Brazil, Canada, Russian Federation, China and Ukraine (see also section 3.4.1). Morocco has a dependency against these countries in terms of virtual water trade.

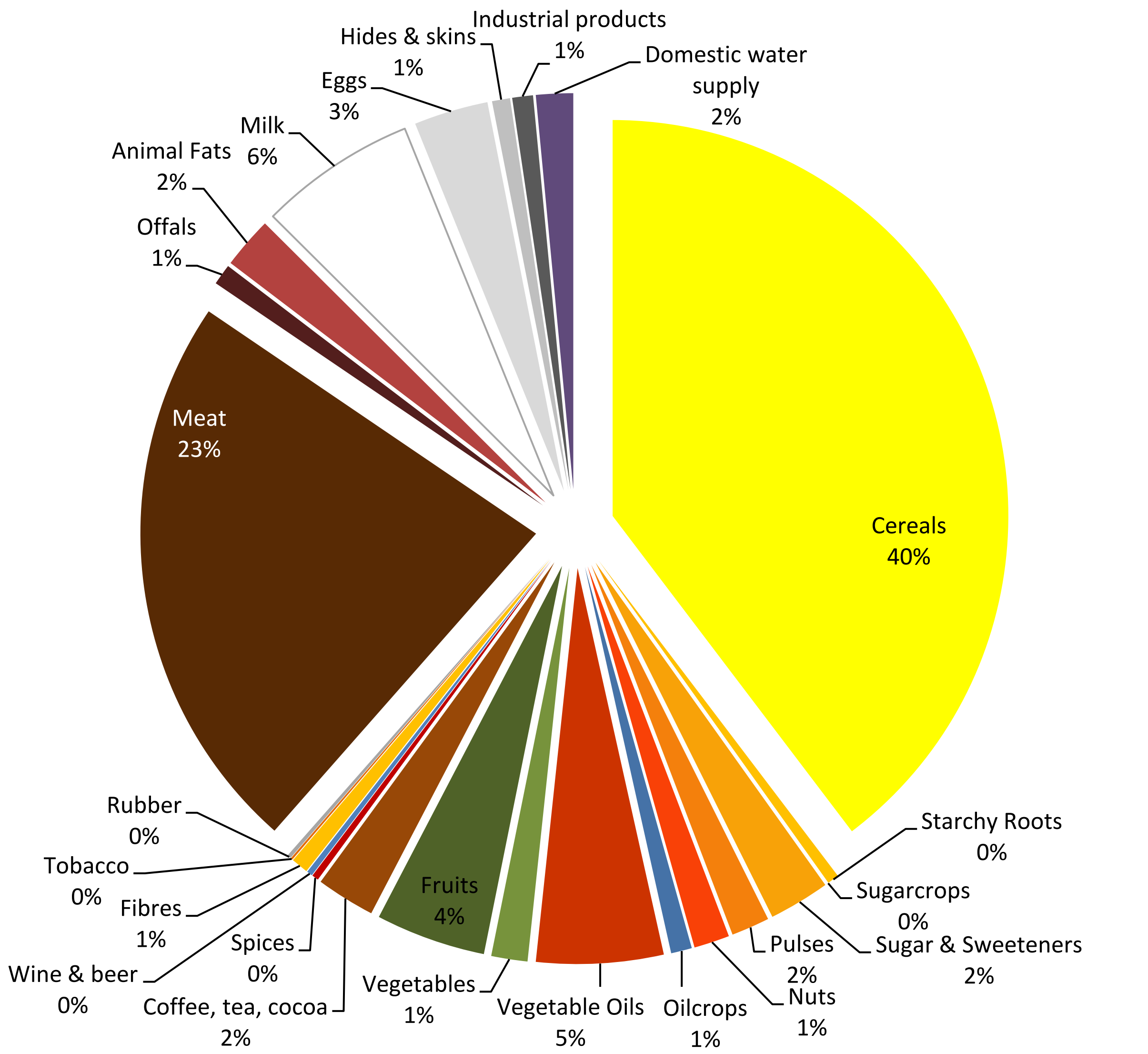


Figure 3-11: Product breakdown of the water footprint of the average consumer in Morocco. Period: 1996-2005.

Source: Mekonnen and Hoekstra (2011)

3.6 Blue water footprint of production in context of water availability

The annual rainfall volume in Morocco is estimated at about 150 billion m³ (Ait Kadi, 2002; EMWIS, 2012; FAO, 2013c; Riad, 2003). The rainfall pattern has high inter- and intra-annual variability and is also heterogeneous in space (INECO, 2009; Hachimi, 2009). Average annual rainfall is over 1000 mm in the northern mountainous areas and less than 300 mm in nearly 85% of the country, namely in the basins Moulouya, Tensift, Souss-Massa, areas south of the Atlas mountains and the Saharan zone (Ministry of Energy, Mining, Water and Environment of Morocco, Department of Water, 2012b). Morocco's water resources are completely produced internally and no outflow is submitted to treaties (FAO, 2013c). Surface runoff is controlled by large reservoirs to cope with its large intra- and inter-annual variability. Currently, 130 reservoirs are in operation with a total capacity of 17.5 billion m³ per year (Ministry of Energy, Mining, Water and Environment of Morocco, Department of Water, 2011). Morocco's annual groundwater resources are estimated at about 4 billion m³ and are spread over 96 aquifers of which 75 are surficial and 21 are deep aquifers (Ministry of Energy, Mining, Water and Environment of Morocco, Department of Water, 2011). So, about 21 billion m³ per year is exploitable given storage sites (17 Gm³/yr) and groundwater development (4 Gm³/yr). However, long-term average natural (undepleted) runoff over the past approximately 30 years is lower, namely

13 billion m³ per year (see Table 3-13). The inter-basin water transfers from Oum Er Rbia (302 Mm³/yr) to the basins of Bouregreg (91 Mm³/yr) and Tensift (212 Mm³/yr) can be seen as an additional water availability in the receiving basins and a reduced availability in Oum Er Rbia, because the transfers are not included in the total blue WF figures.

Blue water scarcity clearly manifests itself on a monthly scale as shown in Figure 3-12 and Table 3-14 where the total blue WF is placed in the context of long-term average monthly natural runoff per river basin. The equal weighted monthly average water scarcity indicates severe water scarcity, more severe than annual (total) water scarcity values suggest. In all basins, the total blue WF exceeds natural runoff during a significant period of the year. In the months June, July and August severe water scarcity occurs in all river basins. Crops with a large blue WF in July are: sugar beets in Oum Er Rbia and Sebou; grapes in the basins of Sud Atlas, Souss Massa and Oum Er Rbia; dates in Oum Er Rbia and Sebou; sunflower seed in the Sebou basin; maize in the basin of Oum Er Rbia. Demand for potable water peaks in the months June, July and August due to tourism and evaporation from storage reservoirs is large in these months due to the strong evaporative power of the atmosphere. Annual runoff in the Oum Er Rbia basin is almost completely consumed (inter-basin water transfers not yet considered), which raises the question whether it is wise to export water out of this basin to the basins of Bouregreg and Tensift.

The natural flow regime is a primary determinant of the structure and function of aquatic and riparian ecosystems for streams and rivers (Poff *et al*., 2010). Part of the natural runoff, with its temporal variation, needs to be maintained for the environment. Generally, environmental flow requirements are not considered in Morocco's river basin plans, nor are the effects of heavily modified natural flows. However, the Moulouya basin was subject to a project for the integration of aquatic biodiversity considerations in the planning of water management (IUCN, 2010). In the Moulouya basin the water level is low in summer, which makes it difficult to maintain aquatic biodiversity (IUCN, 2010). Irregular release of water from dams also has negative impacts on the aquatic fauna and flora in the basin (IUCN, 2010). IUCN (2010) warns for the desiccation of streams in the basin, which is partly caused by the natural cycle of drought, but aggravated by human abstractions. Minoia (2012) states ecosystems values were not considered in the construction of dams in the Sebou basin. Drainage of the wetlands has caused a loss of important habitats, which led to an impoverishment of biodiversity and ecosystem functions in the basin (Minoia, 2012). Although some wetlands are recognised as biological reserves, they are still threatened by decreasing inflows (Minoia, 2012). The effects of heavily modified river flows and stream desiccation on aquatic and riparian ecosystems, and the livelihoods that depend on these systems, require attention and local case studies should be carried out to map these effects.

Table 3-13: Long-term average monthly natural runoff* (~past 30 years) per river basin and existing inter-basin water transfers (in Mm³/yr).

River basin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Tot	Trans-fer
Bouregreg	140	148	92	43	20	12	3	4	10	19	67	123	682	+91
Loukkos	334	310	202	142	113	34	20	18	21	43	181	388	1808	
Moulouya	117	141	124	125	93	31	14	17	46	90	117	121	1036	
Oum Er Rbia	270	349	378	332	224	142	94	89	102	119	192	231	2524	- 302
Sebou	677	768	533	341	259	91	51	41	69	91	264	598	3782	
Souss Massa	61	64	109	117	85	28	7	6	8	34	41	53	613	
Sud Atlas	114	118	115	170	177	71	25	68	151	174	140	127	1450	
Tensift	96	100	172	185	134	45	10	9	13	54	65	84	967	+ 212
Total	1809	1998	1726	1456	1104	453	223	253	421	625	1068	1725	12862	

* Natural runoff is estimated as the inflow of reservoirs (see also section 2.7). It is considered undepleted runoff, since large-scale blue water withdrawals come from the reservoirs. The estimates can be considered conservative, because net precipitation in areas downstream of reservoirs is not included. Note that the estimates are significantly lower than the national renewable water resources as reported by FAO (2013c), namely 29 Gm³/yr, which can partly be explained by the previous statement.

Table 3-14: Blue water scarcity* per river basin.

River basin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Tot	Avg
Bouregreg	0.05	0.06	0.14	0.47	1.57	2.89	11.3	7.30	2.78	1.01	0.19	0.06	0.37	2.32
Loukkos	0.03	0.04	0.12	0.25	0.42	1.85	4.04	4.11	2.49	0.69	0.08	0.02	0.25	1.18
Moulouya	0.07	0.10	0.23	0.40	0.62	1.65	4.41	3.09	1.03	0.37	0.16	0.05	0.41	1.02
Oum Er Rbia	0.11	0.20	0.38	0.98	2.42	3.08	2.91	2.14	1.93	1.10	0.51	0.16	0.98	1.33
Sebou	0.02	0.04	0.22	0.86	1.19	3.01	6.66	6.72	3.05	1.21	0.14	0.02	0.53	1.93
Souss Massa	0.07	0.14	0.11	0.17	0.36	1.28	6.35	6.82	4.45	0.81	0.40	0.12	0.46	1.76
Sud Atlas	0.05	0.07	0.09	0.12	0.19	0.54	1.67	0.56	0.21	0.14	0.10	0.06	0.19	0.32
Tensift	0.06	0.16	0.16	0.29	0.66	1.72	5.39	5.40	3.66	0.64	0.34	0.11	0.50	1.55
Total	0.05	0.09	0.22	0.56	1.03	2.23	4.15	2.98	1.55	0.66	0.22	0.06	0.52	1.15

* Blue water scarcity is defined as the ratio of the total blue water footprint in a catchment over the natural runoff in that catchment. Colour marking according to scarcity classification in section 2.7: low=green, moderate=yellow, significant=orange, severe=red.

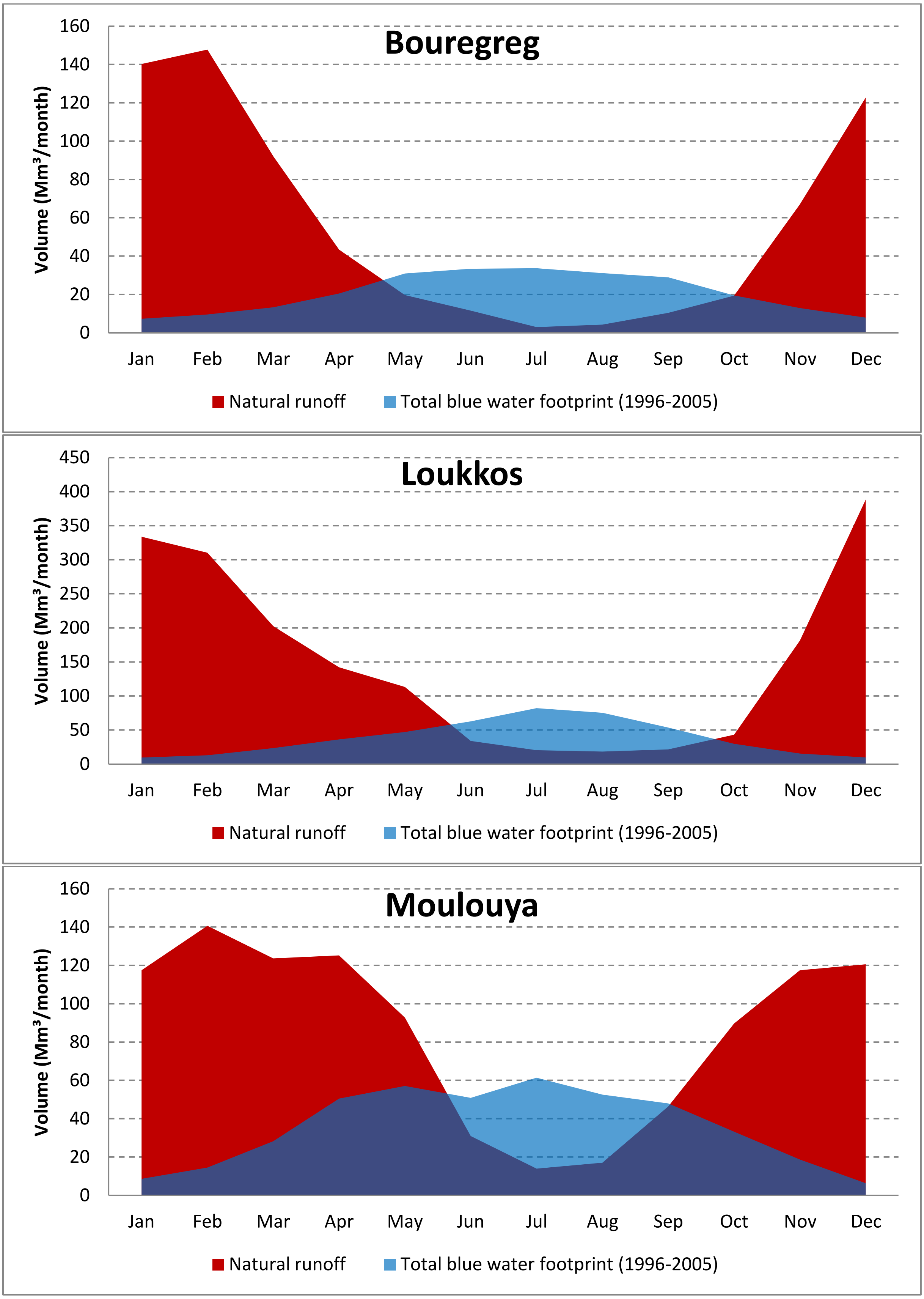


Figure 3-12: Total blue water footprint and natural runoff per river basin.

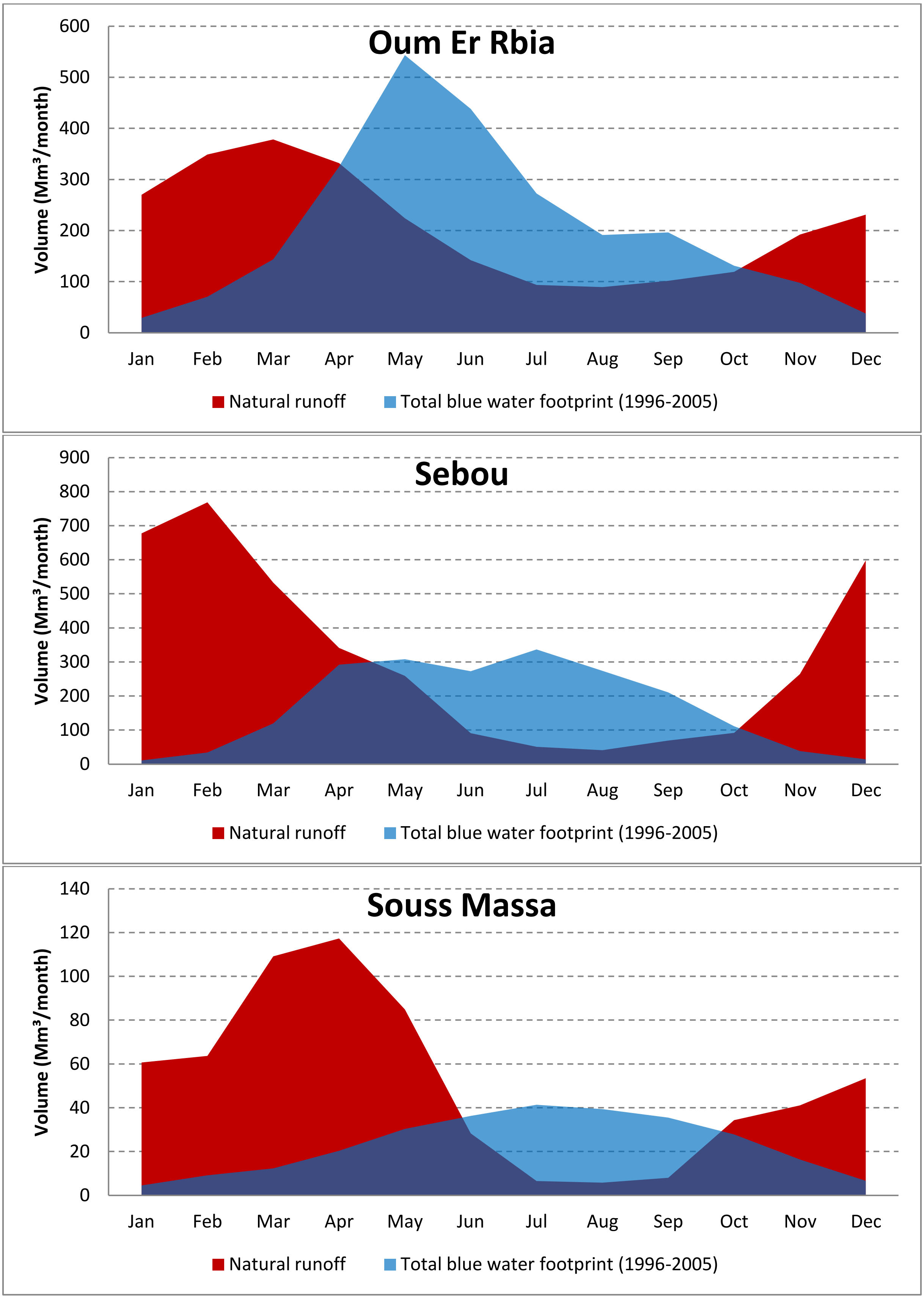


Figure 3-12 (continued): Total blue water footprint and natural runoff per river basin.

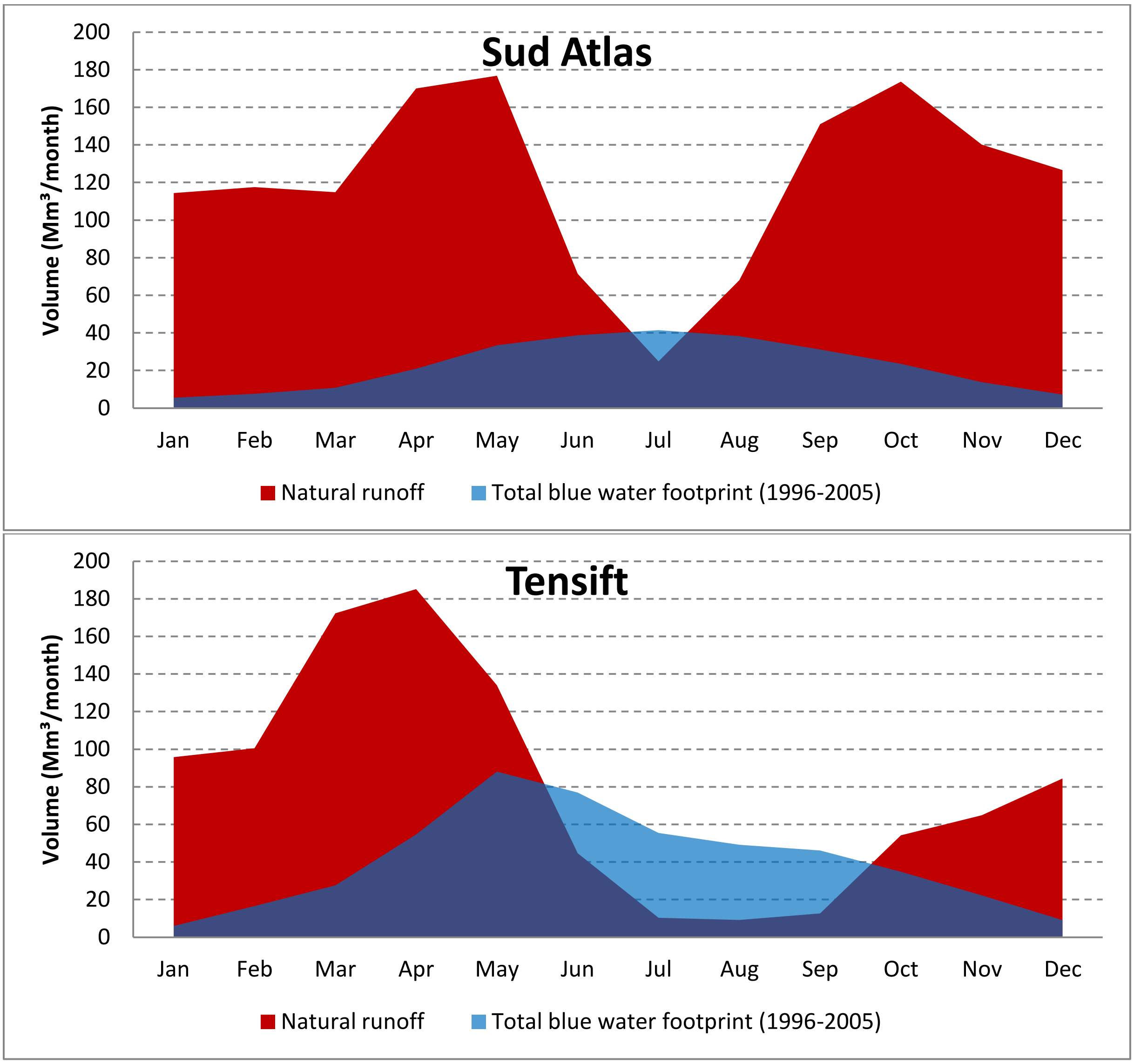


Figure 3-12 (continued): Total blue water footprint and natural runoff per river basin.

The ground-WF in the context of groundwater availability per river basin is presented in Figure 3-13 and Table 3-15. The total ground-WF in Morocco constitutes about half of the country's groundwater availability. Groundwater stress is severe in all river basins, except for the basins of Loukkos and Sud Atlas. In the Bouregreg basin, the annual ground-WF exceeds annual groundwater availability. Most of the aquifers in this basin are indeed overexploited, especially the main aquifers of Berrechid and Chaouia côtière (ABH Bouregreg et de la Chaouia, 2012). For the other basins, the assessment of inflow-outflow balances per aquifer (incl. withdrawals) in the corresponding river basin plans shows a different picture than obtained here, generally more severe. In Loukkos, these balances are al negative or around zero, although ABH Loukkos (2011) states there are no signs of overexploitation yet. Also in the basins of Oum Er Rbia, Sebou, Moulouya and Tensift most of the aquifers suffer from abstractions that exceed natural inflows, particularly the aquifers of Bahira and Haouz (ABH Moulouya, 2011; ABH Oum Er Rbia, 2011; ABH Sebou, 2011; ABH Tensift, 2011). The groundwater reserves in the Souss Massa basin are also seriously deteriorated (EMWIS, 2012). The picture shown here may be milder than what emerges from the river basin plans, because the ground-WF estimates relate to the period 1996-2005, while most balances in the river basin plans include more recent withdrawals, which are likely to be larger. Moreover, the unit of analysis in this study (river basin agency action zone) is larger than the unit used in the river basin plans (individual aquifers), whereby in this study overexploitation of one aquifer might be masked by low exploitation of another.

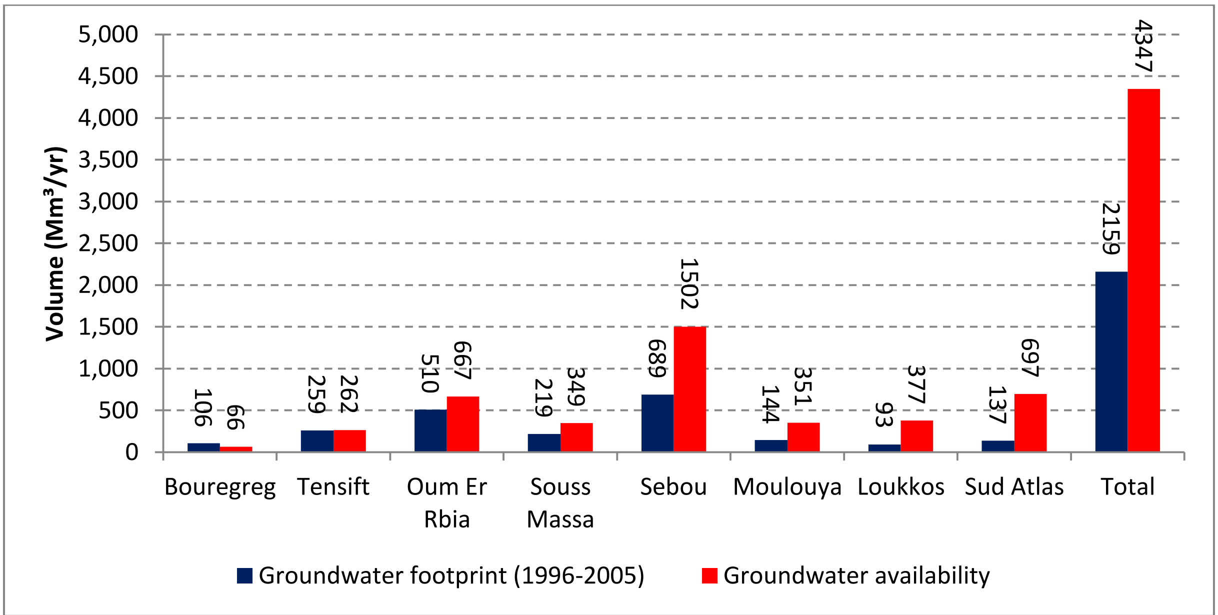


Figure 3-13: Groundwater footprint in context of groundwater availability per river basin (in Mm³/yr). Basins are sorted left-right from highest to lowest scarcity.

Table 3-15: Blue water scarcity related to groundwater. Basins are sorted top-down from highest to lowest scarcity.

River basin	Groundwater footprint (Mm^3/yr)	Groundwater availability (1996-2005) (Mm^3/yr)	Blue water scarcity (-)	Level of water scarcity
Bouregreg	106	66	1.60	Severe
Tensift	259	262	0.99	Severe
Oum Er Rbia	510	667	0.77	Severe
Souss Massa	219	349	0.63	Severe
Sebou	689	1,502	0.46	Severe
Moulouya	144	351	0.41	Severe
Loukkos	93	377	0.25	Moderate
Sud Atlas	137	697	0.20	Moderate
Total	2,159	4,347		

3.7 Grey water footprint of crop production in context of available waste assimilation capacity

The grey WF of crop production represents the water needed to assimilate the nitrogen fertilizers that reach the water systems due to leaching or runoff, given an ambient (i.e. environmental) water quality standard of 10 mg/l of nitrate-nitrogen (NO_3-N), which corresponds with 44 mg/l of nitrate (NO_3) (Self and Waskom, 2013). This grey WF is compared with available waste assimilation capacity, which is equal to actual groundwater availability (groundwater availability minus ground-WF in Table 3-15, section 3.6), because according to most river basin plans nitrate pollution mainly occurs in groundwater. The comparison is shown in Figure 3-14 and Table 3-16 along with the water pollution level included in the latter.

The ground-WF exceeds groundwater availability in the Bouregreg basin, so there is no waste assimilation capacity left, which results in an infinite water pollution level. In the basins of Tensift and Oum Er Rbia waste assimilation capacity is also exceeded, even by 43 times the natural groundwater availability in the Tensift basin. Nitrate pollution of groundwater in these basins is indeed severe according to the river basin plans of these basins. The aquifers in the basin of Bourgreg are located in areas with intensive agriculture and suffer from diffuse nitrate pollution by the irrational use of nitrogen fertilizers, being worst in the aquifers Chaouia côtière and Témara (ABH Bouregreg et de la Chaouia, 2007). Groundwater quality degradation by nitrates in the basin of Tensift is largest in the aquifers of Bahira and Essaouira (ABH Tensift, 2011). ABH Oum Er Rbia (2009) states that levels of nitrates exceed the maximum permissible limit in drinking water (50 mg/l), especially in the aquifers of Tadla, Bahira, Sahel-Doukkala and Turonian Tadla. The most contaminated areas are usually located at the base of the irrigated perimeters of Tadla and are the result of the intensive use of chemical fertilizers (ABH Oum Er Rbia, 2009). In the Sahel-Doukkala aquifer (near the Atlantic coast in the Oum Er Rbia river basin agency action zone) nitrate levels up to even 100 mg/l were measured in 2004, caused by excessive use of chemical fertilizers, but also by the infiltration of untreated domestic wastewater from the various cities in the basin (ABH Oum Er Rbia, 2009). Also in the basins in which waste assimilation capacity is not yet reached according to this study, nitrate pollution is locally severe according to the river basin plans. Part of the aquifers in the basins of Moulouya and Loukkos suffer from significant nitrate pollution (ABH Loukkos, 2011; ABH Moulouya, 2011). In the Sebou basin, 34% of the groundwater quality measuring stations indicates a very bad quality, again mainly due to nitrate pollution as a cause of heavy agricultural activity in the basin (ABH Sebou, 2011). Water pollution according to the river basin plans can be worse, because the water quality measurements recorded in these plans are partly more recent than the period to which the grey WF relates and they are measured at specific points, whereas this study considered homogeneous distribution of nitrates in the groundwater.

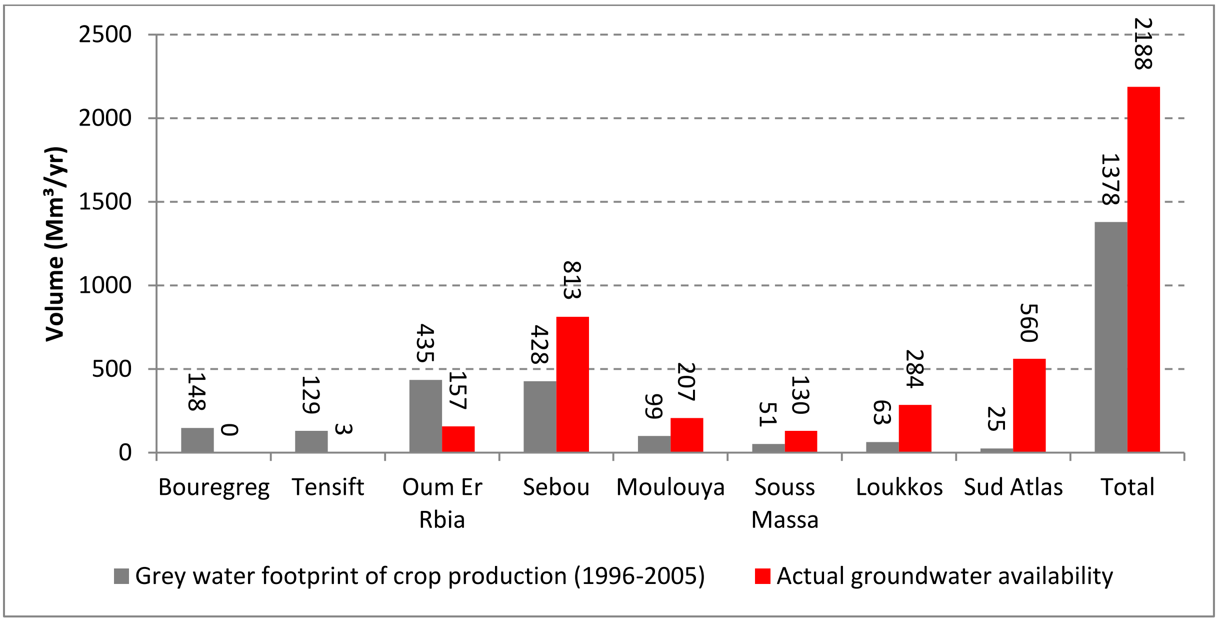


Figure 3-14: Grey water footprint of crop production in the context of actual groundwater availability (in Mm³/yr). Basins are sorted left-right from highest to lowest pollution level.

Table 3-16: Water pollution level related to nitrate-nitrogen in groundwater. Basins are sorted top-down from highest to lowest pollution level.

River basin	Grey water footprint of crop production (1996-2005) (Mm³/yr)	Actual groundwater availability / Waste assimilation capacity (Mm³/yr)	Water pollution level (-)	Waste assimilation capacity exceeded?
Bouregreg	148	0	∞	Yes
Tensift	129	3	43.2	Yes
Oum Er Rbia	435	157	2.78	Yes
Sebou	428	813	0.53	No
Moulouya	99	207	0.48	No
Souss Massa	51	130	0.39	No
Loukkos	63	284	0.22	No
Sud Atlas	25	560	0.04	No
Total	1,378	2,188	0.63	No

Source: Grey water footprint of crop production from Mekonnen and Hoekstra (2010b)

4 Response options

In the previous chapters the water footprint (WF) of activities in Morocco is analysed and placed in the context of water availability and Morocco's virtual water balance and WF of consumption are discussed. In this chapter possible response options to alleviate water scarcity in Morocco are examined. Firstly, options to reduce the WF of crop production (the largest contributor to the WF within Morocco) are considered and associated water savings are quantified (section 4.1). Secondly, the idea of establishing WF caps per river basin to limit increasing WFs in the already water scarce basins of Morocco is discussed in section 4.2. Next, a potential different allocation of land and water resources to crops is discussed in order to make more economically efficient use of these resources (section 4.3). Lastly, a discourse is provided about water scarcity and allocation in Morocco in relation to the country's virtual water balance (section 4.4).

4.1 Reducing the water footprint of crop production

As shown in section 3.1, crop production contributes the most to the WF of national production. For the 12 crops that together constituted 87% of the total water consumption of crops in the period 1996-2005 (24,625 Mm³/yr), the potential water savings are estimated by changing the allocation of production across river basins (section 4.1.1), an overall improvement of water productivities (section 4.1.2) and benchmarking water productivity (section 4.1.3). The analysed crops are: almonds, barley, dates, grapes, maize, olives, oranges, sugar beets, sugar cane, mandarins etc., tomatoes and wheat.

4.1.1 Reallocation of crop production across basins

Water consumption per ton of crop production varies across the different river basins of the country as shown in section 3.2. Changing the allocation of crop production over the basins may thus lead to water savings. These savings are assessed for the 12 analysed crops for two different cases; A and B. In case A, harvested land of all crops is interchangeable and restricted per river basin. In case B, only annual crops (barley, maize, sugar beets, tomatoes and wheat) can be reallocated, perennials cannot. Results are presented in Tables 4-1, 4-2 and 4-3. Complete results, the input data and base case are recorded in Appendix IX.

Potential water savings (green plus blue) are in the order of 1.9 and 1.2 billion m³ per year in case A and B, respectively. Blue water savings are 1,276 Mm³/yr in case A and 697 Mm³/yr in case B. These are significant savings when put in the context of the actions plans in Morocco's national water strategy to mobilize 1.7 billion m³/yr by 2030 through the construction of 60 large and 1000 small local dams and the North-South inter-basin water transfer of 0.8 billion m³ of raw water each year.

Largest potential water savings can be obtained by reallocation of the production of maize and wheat. Reallocation of crop production in case A results in decreased WFs (green plus blue) in all basins, except for the basin of Bouregreg where the WF increases. In case B, the WFs in the basins Bouregreg, Sebou and Loukkos increase, while the WFs in the other basins decrease. Precipitation in the latter two basins is generally richer than in other parts of Morocco (Ministry of Energy, Mining, Water and Environment of Morocco, Department of Water, 2011).

Though the total blue WF in Morocco decreases in both cases, it increases in some basins. The blue WF in the Bouregreg basin increases in both cases, even with almost one billion m³ per year in case A. In case B, the blue WF also increases in the basin of Moulouya and slightly in the Sud Atlas basin. An increased blue WF in the Bouregreg basin is of serious concern. Although this basin is among the least water stressed on an annual scale, it is the most water stressed basin on a monthly scale, especially in July and August, and the annual ground-WF in the basin exceeds annual groundwater availability (see section 3.6). River runoff in the Moulouya basin is also seriously depleted at the moment.

It should be noted that this optimization only looked at potential water savings on an annual scale. When considering reallocation of crop production it is necessary to assess how the green and blue WFs of crops manifest themselves on a monthly scale. Since most crops consume more water during a specific time of the year (varying from crop to crop), an annual optimization of crop production allocation might well aggravate monthly water scarcity in some river basins. This is particularly relevant for blue water consumption, but it also important to assess whether green water resources (rain) are sufficient.

Table 4-1: Water savings by reallocation of crop production per crop.

	Base case	Case A		Case B	
	green plus blue water footprint (Mm^3/yr)	Saving (green+ blue) (Mm^3/yr)	Relative saving (%)	Saving (green+ blue) (Mm^3/yr)	Relative saving (%)
Almonds	641	14	2%	0	0%
Barley	6,787	-116	-2%	-202	-3%
Dates	449	131	29%	0	0%
Grapes	367	183	50%	0	0%
Maize	1,148	939	82%	939	82%
Olives	2,951	58	2%	0	0%
Oranges	440	15	3%	0	0%
Sugar Beets	353	157	44%	157	44%
Sugar Cane	200	91	46%	0	0%
Mandarins	209	7	3%	0	0%
Tomatoes	99	2	2%	2	2%
Wheat	10,981	413	4%	278	3%
Total	24,625	1,896	8%	1,174	5%

Table 4-2: Water savings by reallocation of crop production per river basin.

	Base case	Case A		Case B	
	green plus blue water footprint (Mm^3/yr)	Saving (green+ blue) (Mm^3/yr)	Relative saving (%)	Saving (green+ blue) (Mm^3/yr)	Relative saving (%)
Sud Atlas	306	189	62%	12	4%
Souss Massa	903	175	19%	14	2%
Tensift	2,525	388	15%	124	5%
Oum Er Rbia	8,498	1,229	14%	821	10%
Bouregreg	2,813	-994	-35%	-95	-3%
Moulouya	1,737	605	35%	412	24%
Sebou	6,905	154	2%	-95	-1%
Loukkos	939	151	16%	-19	-2%
Total	24,625	1,896	8%	1,174	5%

Table 4-3: Blue water savings by reallocation of crop production per river basin.

	Case A		Case B	
	in Mm³/yr	% of natural runoff	in Mm³/yr	% of natural runoff
Sud Atlas	144	10%	-1	0%
Souss Massa	157	26%	5	1%
Tensift	323	33%	115	12%
Oum Er Rbia	1,161	46%	769	30%
Bouregreg	**-982**	**-144%**	**-175**	**-26%**
Moulouya	85	8%	-58	-6%
Sebou	283	7%	38	1%
Loukkos	104	6%	4	0%
Total	1,276	10%	697	5%

4.1.2 Overall improvement of water productivities of crops

Improving water productivities of crops, i.e. reduce their water consumption per ton of production, is a way to reduce the WF of crop production. Currently, 80% of Morocco's usable agricultural surface is occupied by tradition and food crop agriculture and only 20% is used for agriculture with modern technology (ADA, 2013). Therefore it is not unthinkable that water productivities of crops can be improved with 10 or 20 per cent by using more efficient techniques to reduce water use and/or improve yields. Room for improvement is also illustrated by comparison of the yields and WFs of the main water consuming crops in Morocco with these parameters in other North African Mediterranean countries, e.g. average maize yields in the period 1996-2005 were 4 and 12 times higher in Algeria and Egypt than in Morocco, respectively (see table 4-4).

If a 10 or 20 per cent improvement in water productivity would be achieved for the analysed 12 crops, it would lead to the water savings recorded in Table 4-5. Obviously, largest potential water savings can be obtained by improving the water productivities of the main-water consuming crops (especially wheat and barley) in the main production areas. In case water productivities of the 12 main crops are improved by 10% in all basins, the total green plus blue water saving is estimated at 2,462 Mm³/yr of which 371 Mm³/yr is blue water. Logically, water savings are double if productivities where to be improved by 20%.

The Ministry of Energy, Mining, Water and Environment of Morocco, Department of Water (2011) estimates that a potential volume of 2 Gm³/yr can be saved by conversion to drip irrigation with a conversion rate of 44,000 ha/yr and an additional volume of 400 Mm³/yr by improved efficiency of irrigation supply networks. However, no documentation is available on how these savings are estimated. The estimated savings in Table 4-5, by improvement of the water productivities of the 12 main crops that together constitute 73% of the total blue WF of crops in the period 1996-2005, are significantly lower. Improved irrigation efficiency does not necessarily mean a reduction in WF (Hoekstra, 2013). It is highly doubtful that the assumed savings of 2.4 Gm³/yr by conversion to drip irrigation and improved efficiency of the irrigation supply network are actual savings in the WF sense (i.e. reduced evaporative losses). The total WF of the irrigation supply network (from surface water body to crop field to plant) is estimated in this study at 549 Mm³/yr, which is only 23% of the assumed 2.4 Gm³/yr. Moreover, the total blue WF of crop production in the period 1996-2005 is 5.1 Gm³/yr. Conversion to drip irrigation can only reduce the soil evaporation part of this WF and not the part which is transpired through crops. Hsiao and Xu (2005) even show that under some conditions drip irrigation might result in larger evaporation from the soil compared to furrow irrigation.

Table 4-4: Comparison of yields and green plus blue water footprints of the four main water consuming crops in Morocco with other North African-Mediterranean countries. Period 1996-2005.

Crop	Country	Yield (ton/ha)	Times yield in Morocco	Green plus blue WF (m^3/ton)	Times green plus blue WF in Morocco
Wheat	Morocco	1.27	1.0	10,981	1.0
	Algeria	1.15	0.9	3,355	0.3
	Egypt	6.23	4.9	1,118	0.1
	Tunisia	1.56	1.2	2,447	0.2
Barley	Morocco	0.83	1.0	6,787	1.0
	Algeria	1.13	1.4	2,859	0.4
	Egypt	2.58	3.1	2,314	0.3
	Tunisia	0.91	1.1	3,636	0.5
Olives	Morocco	1.17	1.0	2,951	1.0
	Algeria	1.41	1.2	4,279	1.4
	Egypt	6.78	5.8	1,922	0.7
	Tunisia	0.53	0.5	9,115	3.1
Maize	Morocco	0.63	1.0	1,148	1.0
	Algeria	2.69	4.3	964	0.8
	Egypt	7.51	12.0	1,219	1.1
	Tunisia	-	-	0	0.0

Source: Data for Morocco from Mekonnen and Hoekstra (2010b)
For other countries, yield data from FAO (2013d), water footprint data from Mekonnen and Hoekstra (2010b)

Table 4-5: Water savings by improving water productivities of main crops per river basin.

	Water productivity improved with 10%			Water productivity improved with 20%		
	Saving (green+blue) (Mm^3/yr)	Saving (blue) (Mm^3/yr)	Saving (blue) (% of natural runoff)	Saving (green+blue) (Mm^3/yr)	Saving (blue) (Mm^3/yr)	Saving (blue) (% of natural runoff)
Sud Atlas	31	19	1%	61	39	3%
Souss Massa	90	16	3%	181	31	5%
Tensift	252	32	3%	505	65	7%
Oum Er Rbia	850	151	6%	1,700	302	12%
Bouregreg	281	10	1%	563	19	3%
Moulouya	174	23	2%	347	46	4%
Sebou	690	108	3%	1,381	216	6%
Loukkos	94	12	1%	188	25	1%
Total	2,462	371	3%	4,925	743	6%

4.1.3 Benchmarking water productivity of crops

According to Hoekstra (2013), based on the variability of WFs found across regions and among farms within regions, for all crops, certain benchmarks can be established that can act as a reference or target for all farmers that have WFs above the benchmark. Benchmarks can be defined as a certain WF that is achieved by the best 10 or 20 per cent of the producers or alternatively, as the WF associated with the 'best-available technology' (Hoekstra, 2013).

Since water consumption of crops (in m^3/ton) varies across the different river basins of Morocco (as shown in section 3.2), it is worthwhile to develop reasonable benchmarks for the WF of crops within Morocco. Here, potential water savings are estimated when for each basin and crop WFs are lowered down to benchmarks (i.e. water productivities (in ton/m^3) are increased). For each basin, benchmarks are set as the lowest water consumption of a specific crop which is achieved in a river basin in Morocco with comparable reference evapotranspiration (see Table 2-5, section 2.8). The benchmarked green plus blue WFs are recorded in Table 4-6. The water savings when in each basin the WFs of the main crops are lowered down to these benchmarks are presented in Table 4-7.

The total green plus blue water saving is 2,768 Mm^3/yr, a reduction of 11%. Fifty-two per cent of this saving is related to improved water productivities in the Sebou basin alone. Largest potential water savings are associated with the benchmarking of the water productivities of cereals, especially wheat. Blue water savings are estimated at 422 Mm^3/yr and are largest in the basins of Sebou and Oum Er Rbia.

Table 4-6: Benchmarked green plus blue water footprint* (in m^3/ton).

Basin	Loukkos	Boure-greg	Sebou	Oum Er Rbia	Tensift	Moulou-ya	Souss Massa	Sud Atlas
Almonds	**9,295**	9,295	9,295	**10,061**	10,061	**9,450**	9,450	10,309
Barley	**3,043**	3,043	3,043	3,882	**3,882**	2,498	**2,498**	1,451
Dates	**4,716**	4,716	4,716	7,295	**7,295**	5,917	**5,917**	4,222
Grapes	655	**655**	655	1,420	**1,420**	**1,002**	1,002	1,366
Maize	**3,178**	3,178	3,178	5,746	**5,746**	**1,219**	1,219	3,015
Olives	**4,651**	4,651	4,651	**5,063**	5,063	**4,756**	4,756	5,209
Oranges	**487**	487	487	**532**	532	**502**	502	545
Sugar Beets	65	**65**	65	**124**	-	**106**	-	-
Sugar Cane	105	**105**	105	-	-	**175**	-	-
Tang.Mand.	**471**	471	471	**515**	515	**486**	486	528
Tomatoes	**89**	89	89	**97**	97	**92**	92	100
Wheat	**2,329**	2,329	2,329	3,079	**3,079**	**2,595**	2,595	1,088
ET_0 (mm/yr)	1,212	1,239	1,266	1,387	1,389	1,409	1,450	1,652

* Column separators indicate which basins are considered comparable based on reference evapotranspiration (ET_0), see also section 2.8. Water footprint of each crop in the basin that sets the benchmark for comparable basins is printed **bold**.
Source: ET_0 from FAO (2013e)

Table 4-7: Potential water savings by benchmarking water productivities of main crops (in Mm³/yr).

	Sud Atlas	Souss Massa	Tensift	Oum Er Rbia	Boure-greg	Moulou-ya	Sebou	Loukkos	Total
Almonds	0	2	1	0	3	0	8	0	14
Barley	0	0	0	100	158	222	238	0	717
Dates	0	0	0	10	0	4	48	0	63
Grapes	0	20	0	5	0	0	18	4	48
Maize	0	13	0	175	32	0	33	0	254
Olives	0	9	4	0	10	0	35	0	59
Oranges	0	1	1	0	1	0	6	0	9
Sugar Beets	0	0	0	0	0	0	70	4	73
Sugar Cane	0	0	0	0	0	0	79	10	89
Tang.Mand.	0	1	0	0	0	0	3	0	4
Tomatoes	0	0	0	0	1	0	1	0	3
Wheat	0	14	0	102	417	0	904	0	1,436
Total(gn+bl)	0	60	6	392	623	226	1,444	18	2,768
Total(blue)*	0	23	2	113	11	2	258	12	422
Total(blue) (% of natural runoff)	0%	4%	0%	4%	2%	0%	7%	1%	3%

* Assuming that the green/blue water ratio remains the same for all basins and crops.

4.1.4 Overview potential water savings in crop production

Table 4-8 summarizes the estimated potential water savings by changing the allocation of production, improving overall water productivity and benchmarking water productivity. All these measures are aimed at more efficient use of water resources. These savings are all under the assumption that the total production of crops does not increase. In order to actually obtain the water savings presented here, and for them to lead to environmental gains, it would be necessary to combine the proposed measures with measures to constrain the continued growth of total water demand (see also section 4.2).

Table 4-8: Potential water savings in crop production.

	Reallocation of crop production		Overall improved water productivity		Bench-marking
	All analysed crops*	Only annual crops**	By 10%	By 20%	
Absolute saving (green+blue) (Mm³/yr)	1,896	1,174	2,462	4,925	2,768
Relative saving (green+blue) (%)	8%	5%	10%	20%	11%
Absolute saving (blue) (Mm³/yr)	1,276	697	371	743	422
% of total natural runoff in Morocco	10%	5%	3%	6%	3%

* Analysed crops are: almonds, barley, dates, grapes, maize, olives, oranges, sugar beets, sugar cane, mandarins etc., tomatoes and wheat.
** Annual crops are: barley, maize, sugar beets, tomatoes and wheat.

4.2 Water footprint caps per river basin

In all studied river basins natural runoff is seriously modified during a significant period of the year. In order to move towards sustainable use of blue water in these basins, discussing and agreeing on a blue WF cap would be useful. A 'WF cap' is to be understood as a maximum WF not to be exceeded (Hoekstra, 2013). Such a cap is needed in addition to WF reducing measures as discussed in section 4.1, because these measures might not be achieved as quickly as needed and, in case of increased water productivity of crops, it is likely that farmers will increase their production volume once they require less water per unit of production (Hoekstra, 2013).

Ideally, a blue WF cap is set for each river basin in Morocco (and sub-basins) and for each month of the year. The urge for a cap on the blue WF seems large for all Moroccan river basins given the water scarcity levels in section 3.6. Caps should also be defined for dry, humid and wet years separately. The danger of defining a cap for an average year is that it becomes an impossible target in drier years (Hoekstra *et al*., 2013). Therefore the level of the cap should be considered carefully on a regular basis, also taking into account climate change. In defining the maximum sustainable level of consumptive water use, it should be taken into account that part of the natural runoff needs to be reserved to sustain minimal flows in the river (Poff *et al*., 2010). Local case studies are required to determine these environmental flow requirements for each of the Moroccan rivers and the effects of violating them (see also section 3.6). Moreover, the maximum sustainable level of consumptive water use would need to be defined for surface and groundwater bodies separately. If the cap is only set for one of them, it might lead to an accelerated exploitation of the other. This happened for example in the Murray-Darling basin (Australia), where the use of groundwater accelerated after adoption of a cap on surface water diversions (Hoekstra, 2013). The current national water strategy of the Ministerial Department of Water already proposes to limit the pumping from overexploited aquifers by revision of the pricing system, reduction of allowed withdrawal thresholds, cancelling subsidies that provide incentive for overexploitation and designating areas of prohibited or restricted pumping (Ministry of Energy, Mining, Water and Environment of Morocco, Department of Water, 2011). These plans are also adopted in the river basin plans.

Setting a cap is a political matter and the level of the cap will depend on negotiations and trading off different interests (Hoekstra, 2013). Morocco's High Council for Water and Climate seems an appropriate forum for discussing and agreeing on the proposed caps. All national actors concerned by water issues have seat in the Council, where they debate on the national policy and main policy directions in water resource management (INECO, 2009). One of the Council's tasks is to elaborate and formulate an opinion on the allocation of water among the various user sectors and the diverse regions of the country or of a single basin (Official State Gazette, 1995). Since overexploitation of Morocco's water resources is severe at this moment, it is more realistic to agree on blue WF caps that gradually move in time from the current blue WFs in the basins to levels that can be regarded as sustainable (Hoekstra, 2013), at which natural surface runoff is less modified and groundwater levels are maintained on the long-term.

The Moroccan government will need to put regulations in place to ensure that the actual total blue WF in each river basin remains below the cap. Reinforcement of the control and sanction system for overexploitation, particularly by reinforcing the water police and encouraging satellite monitoring and aerial surveillance, is part of the national water strategy (Ministry of Energy, Mining, Water and Environment of Morocco, Department of Water, 2011). In order to adequately control whether the actual total blue WF in each river basin remains below the cap, the WF of activities in the basin would need to be estimated on a regular basis (monthly for caps per month). A close cooperation between the river basins agencies and the regional offices for agricultural development (Office Régional de Mise en Valeur Agricole – ORMVA) might be suitable for this task. The ORMVA of the irrigated perimeter of Tadla in the Oum Er Rbia basin already estimates daily reference evapotranspiration in their region and determines the water allocation to the farmers based on calculations of crop water requirements.

It would be wise to cap the grey WF as well. In section 3.7 is shown that nitrate pollution by excessive use of fertilizers is large in most river basins and exceeds waste assimilation capacity in the groundwaters of the basins Bouregreg, Tensift and Oum Er Rbia. In Morocco, ambient water quality standards for nitrates (and other chemicals) in surface and groundwater bodies already exist (ABH Oum Er Rbia, 2009). These would have to be translated to critical loads and regulations should be put in place to make sure these are not exceeded. When critical loads are reached the grey WF equals river runoff (or groundwater availability regarding aquifers). Currently, there are plans to reduce pollution by agriculture. The river basin agency of Oum Er Rbia for example, has a quite elaborate (and funded) plan to gain knowledge about the behaviour of agricultural pollutants in Moroccan and local conditions (e.g. soil type) and how they contaminate the water, develop best practices in fertilizer use and conduct demonstration projects and campaigns to raise awareness among farmers and policy makers to extend the best practices (ABH Oum Er Rbia, 2011). In addition to these plans, a cap on the grey WF of agriculture should be agreed upon to make sure pollution does not exceed the waste assimilation capacity of the rivers and aquifers. This is necessary, because best practices in fertilizer use can lead to increased yields, which might give incentive for extension of the area on which fertilizers are applied, possibly leading to an increase in the total load of pollutants that reaches water bodies.

4.3 Resource allocation to different crops

In section 4.1, the optimization of physical water productivities (i.e. more crop per drop) is assessed. In a broader context, one should also look at optimizing economic water productivity (i.e. more value per drop) (Hoekstra, 2013). In a case study for the Lake Naivasha Basin in Kenya, Mekonnen *et al*. (2012) state that although an equitable allocation of water is required, decisions should also take into account the different economic water productivities of crops. One could argue the same for economic land productivity of crops, regarding decisions on the appropriation of land to different crops or other purposes.

In the period 1996-2005, Morocco's water resources were mainly used to produce relatively low-value water-intensive (in US$/m³) crops such as cereals, olives and almonds. These crops also took the largest share in the country's harvested area in the same period, although they had the lowest value per hectare cultivated (in US$/ha). More economic return per drop and per hectare of land cultivated is generated by production of grapes, sugar beets, citrus fruits (oranges and mandarins etc.) and tomatoes in particular.

In this sense, a different allocation of water and land resources to crops which yield more value per drop and per hectare of land cultivated is desirable. It would be worthwhile to consider a different mix of crops to grow, which uses land and water resources more efficiently from a purely economic point of view, for example by producing more citrus fruits and tomatoes instead of cereals, olives and almonds. From a water resources point of view, it is wise to base such choices also on the timing of crop water requirements (low in the dry season, higher in the wet season). For example, wheat (with low economic water productivity) has no blue WF in the severely water scarce month July, whereas citrus fruits (with high economic water productivity) have a large blue WF in this month.

The Green Morocco Plan to strengthen the position and increase the importance of Moroccan agriculture includes plans to transform current production systems, essentially dominated by cereal production, into high value-added crops, such as olives (77%), almonds (9%), figs, etc (ADA, 2013).

Looking at the value of these crops per unit of water and cultivated land instead of per unit of production (see section 3.3), producing olives and almonds instead of cereals does not seem to be a step towards more economically efficient use of water and land.

Greenhouse cultivation of tomatoes (and other crops) should be encouraged, particularly in combination with rainwater harvesting. Yields in greenhouses are generally higher than on open fields and greenhouse cultivation allows for off season cultivation. From a water resources perspective, it would be useful to optimize the latter in such a way that the moments when crops need water better coincide with rainfall and natural runoff, thereby improving use of rainwater and modifying the natural flow regime less severe than currently. Of course, the choice for the cultivation season is also influenced by other production factors (light and temperature) and, for export products, trade barriers during certain periods of the year.

Marketing of wheat, barley, sugar beets and sugar cane are currently subsidized per unit of production and subsidies exist for seed handling and storage units for cereals and sugar beets (Ministry of Agriculture and Fisheries of Morocco, 2011). Acquisition of olive plants and date palms is also subsidized as well as the creation of new citrus fruit plantations (per hectare) (Ministry of Agriculture and Fisheries of Morocco, 2011). The current subsidy system thus still provides incentive for the production of relatively low-value water-intensive (in US$/m³) cereals and olives.

The Green Morocco Plan is built on the principal of aggregation, which is a form of organization based on the bringing together of agriculturists for the implementation of agricultural investment projects (ADA, 2013). However, subsidies for these aggregation projects regarding cereals and olives production are higher for projects in irrigated production than the same projects regarding rain-fed production. For example, aggregation projects regarding rain-fed production of olives around a complex for trituration and bottling are subsidized for 450 DH/ha, while the same projects regarding irrigated production of olives are subsidized for 1,100 DH/ha (Ministry of Agriculture and Fisheries of Morocco, 2011). Of course, aggregation projects in irrigated agriculture can lead to more efficient use of irrigation water thanks to modern technology brought by the aggregator. Nevertheless, this difference in subsidy amount might give incentive for aggregators to invest in and develop irrigated production instead of rain-fed production. Given the high pressure on Moroccan blue water resources, wise use of rainwater should be encouraged. Increasing green water productivities in Morocco's rain-fed areas reduces the need for irrigated production in water-scarce basins, and thus the blue WF (Hoekstra, 2013). This is relevant for the modern agriculture in favourable rain-fed lands, but also for the tradition and food crop agriculture located in non-irrigated, unfavourable and mountainous areas or oases, which remains strongly dependent on rainfall (ADA, 2013). The Green Morocco Plan also proposes the experimental use of semi-desert zones to increase the usable agricultural surface area (ADA, 2013), which will inevitably increase pressure on blue water resources, because crop growing in the semi-desert is likely to fully rely on irrigation water.

It should be noted that the choice of which crops to produce (i.e. the cropping pattern) is of course closely linked to the demand for crops (national and global) and significant changes in the amount of crops produced are likely to influence the prices and thus economic water and land productivities. Moreover, the cropping pattern is part of the national strategy regarding food security. Although the cropping pattern in the large irrigated perimeters of Morocco is officially liberalized (Ait Kadi, 2002), the previously discussed subsidies influence the farmers' choices on what to plant.

4.4 Wise virtual water trade

In this chapter Morocco's virtual water import and use of domestic water resources for producing export products is discussed from a water resources point of view. An important note is, however, that water cannot be used as the only indicator for judging the rationality of trade patterns, because international trade in agricultural commodities mainly depends on factors such as availability of land, labour, technology, other resource endowments, the costs of engaging in trade, opportunity costs, national food policies and international trade agreements (Hoekstra and Chapagain, 2008; Kumar and Singh, 2005).

4.4.1 Virtual water import

Morocco already achieved fairly large water savings by virtual water import in the period 1996-2005 (see section 3.4.3). This is a cause of Morocco's agricultural strategy which has shifted from the food self-sufficiency objective to the food security objective, meaning that domestic food needs are met through strategic levels of national agricultural production and the gap is covered by relying on the international market (Ait Kadi, 2002). Further externalizing the Moroccan WF through virtual water import could relieve pressure on Moroccan water resources. There are, however, a number of drawbacks of virtual water import that need to be considered (Hoekstra, 2013). First, Morocco should be able to generate sufficient foreign exchange to afford import of water-intensive agricultural commodities. Second, food self-sufficiency might be reduced even further when food imports increase. Moroccan agriculture is directly responsible for the food security of 30 million consumers (ADA, 2013). Third, import of agricultural commodities is bad for the Moroccan agricultural sector and will lead to reduced employment in this sector and result in economic decline and worsening of land management in rural areas. This will have huge impact in Morocco as agriculture currently accounts for 15% of GDP and employs 41% of the labour force (The World Bank, 2012), the latter is even 80% in rural areas (Ministry of Agriculture and Fisheries of Morocco, 2010). Fourth, as said, 80% of the 14 million rural inhabitants depend on revenues from the agricultural sector (ADA, 2013), promoting food imports might threaten the livelihoods of those people and reduce access to food for the poor. Lastly, virtual water imports may reduce pressure on Moroccan water resources, but it may create extra pressure in the countries where the imports come from.

Increasing food (virtual water) imports to relieve pressure on Moroccan water resources increases food dependency and has negative effects on the domestic agricultural sector, which plays a critical role in the economic and social stability of Morocco. Decisions regarding import of water-intensive commodities should carefully take into account these drawbacks. Moreover, increasing food imports seems to conflict with the aim of the Green Morocco Plan to strengthen the Moroccan agricultural sector and make it a lever for social and economic development.

The question remains whether the virtual water import in the period 1996-2005 was efficient from a water-economics point of view. In the period 1996-2005, the average cost of imports was 0.98 US/m³ (equivalent to 1.02 m³ of virtual water per US$ spent) and 0.17 US$/m³ for crop products (equivalent to 5.88 m³ of virtual water per US$ spent). The average value of export products in the same period was 1.66 US$/m³ (equivalent to 0.60 m³ of virtual water per US$ earned) and 0.87 US$/m³ for crop products (equivalent to 1.15 m³ of virtual water per US$ earned). It can be said that the imported products required relatively a lot of water per unit of money spent, while the exported products produced required relatively little water per unit of money earned.

Since the largest part of imports comes from United States of America, France, Argentina, Brazil, Canada, Russian Federation, China and Ukraine, Morocco has a dependency against these countries in terms of virtual water trade (see also section 3.4.1). This might be a risk if food supplies from these countries would cease for whatever reason.

4.4.2 Virtual water export

About 4% of the water used in the Moroccan agricultural and industrial sector is used for making export products. The remainder of the water is applied for producing products that are consumed by the Moroccan population. As pointed out by Hoekstra and Chapagain (2007), it seems appropriate, from a water resources point of view, that most of the scarcely available water in Morocco is being used for the production of commodities that are consumed domestically and not for export.

From an economic point of view, the question is whether the exported commodities yield a relatively high income of foreign currency per unit of water used. As shown in section 3.4.2, most of the virtual water export from Moroccan resources relates to the export of products with a relatively low economic value per m³ water exported, such as wheat (0.02 US$/m³), sugar beets (0.04 US$/m³), olives (0.10 US$/m³) and with more value per drop, oranges (0.84 US$/m³). Of the main export crop products analysed in this study only mandarins (1.37 US$/m³) and tomatoes (7.13 US$/m³) yielded a value larger than the average for crop products. These figures imply it might be wise to use Morocco's scarce water resources to produce mandarins and tomatoes for export instead of low-value water-intensive (in US$/m³) crops. However, it should be noted that demand for specific crop products on the world market is limited and large-scale changes in the production for export are likely to have their effect on food prices (thus affecting the economic value per m³ of water exported).

Part of the Green Morocco plan is to increase the export earnings by 5.5 fold in the upcoming 10 to 15 years in the sectors where Morocco is competitive: citrus fruits, olives, fruits and vegetables (ADA, 2013). The current system of state subsidies supports this by subsidizing the export of citrus fruits and tomatoes per ton exported (Ministry of Agriculture and Fisheries of Morocco, 2011). Export of olive oil and strawberries are subsidized similarly. Looking at its export value per unit of water consumed, olive production for export does not seem to be the most beneficial purpose to allocate water to.

It remains unanswered whether the foreign currency earned by export products covers the costs of the water consumption in Morocco for making these products. This might not be the case considering the costs of the construction and maintenance of the large dams and intra- and inter-basin water transfers in the country. Moreover, costs are even higher if one takes into account the costs associated with the negative externalities of water (over)consumption, such as the salt-intrusion in Morocco's coastal aquifers. An in-depth review of the export policy from a water resources point of view is therefore recommended.

5 Added value of water footprint assessment for national water policy

The water footprint (WF) assessment of Morocco carried out in this study served the overall objective of the study, namely: to find out the added value of knowledge on the WF of activities in Morocco and the virtual water flows from and to Morocco in formulating national water policy. As mentioned in the introduction of this report, various aspects determine this added value, but here the focus is on whether the assessment of the WF of Morocco provides new insights and response options that are currently not considered in the country's national water strategy and river basin plans. This chapter summarises these new insights and response to arrive at a statement on the added value of WF assessment for formulating national water policy in Morocco.

Several insights and response options emerged from the WF assessment, which are currently not considered in the national water strategy of Morocco and the country's river basin plans. They include:

I. New insights in the water balance of Morocco and the country's main river basins:

- The evaporative losses from storage reservoirs constitute the second largest form of blue water consumption nationally. Therefore these losses should be taken into account in the cost-benefit analysis of newly planned dams. Evaporation from the existing reservoirs in Morocco is taken into account in the water resources development plans (Siham Laraichi, personal communication, August 1, 2013), but for newly planned dams in the national water strategy and river basin plans it is not explicitly considered. When the evaporative losses are taken into account in the cost-benefit analysis of dams, this might favour local groundwater dams over surface water dams, because groundwater dams enhance underground water storage in alluvial aquifers and thereby loose less water by evaporation (Al-Taiee, 2012).
- Blue water scarcity on a monthly scale is severe and hidden by annual analysis of demand versus supply, which is the common scale of analysis in the Moroccan river basin plans. Seasonal shortages result in high alteration of natural runoff. The effects of heavily modified river flows and stream desiccation on aquatic and riparian ecosystems, and the livelihoods that depend on these systems, require attention and local case studies should be carried out to map these effects. Existing plans to limit the abstractions from groundwater should be accompanied by a limit to the surface-WF to prevent an accelerated depletion of river runoff.

II. New insights in how economically efficient water and land resources are used:

- Analysis of the economic value of crop products per unit of water and land used in the period 1996-2005 indicate that agricultural policy may be better brought in line with water policy by reconsidering which crops to grow. In this period, Morocco's water resources were namely mainly used to produce relatively low-value water-intensive (in US$/m^3) crops such as cereals, olives and almonds. These crops also took the largest share in the country's harvested area in the same period, although they had the lowest value per hectare cultivated (in US$/ha). More economic return per drop and per hectare of land cultivated was generated by production of grapes, sugar beets, citrus fruits (oranges and mandarins etc.) and tomatoes.
- It is shown that the export policy in this period was not optimal from a water-economics point of view, which raises the question whether the foreign income generated by export covers the direct and indirect costs of mobilization and (over)exploitation of Moroccan water resources. Morocco uses its scarce water resources mainly to produce products that are consumed domestically. However, most of the virtual water export from Moroccan resources relates to the export of products with a relatively low economic value per m^3 water exported. This raises the question whether the foreign income generated by export covers the direct and indirect costs of mobilization and (over)exploitation of Moroccan water resources.

III. New response options to reduce the WF of crop production:

- Analysis of the WF of the main crops in Morocco and its variation across the river basins offers new ways of looking at reducing water consumption in the agricultural sector. The estimated potential water savings by reallocation of crops to basins where they consume less water and by lowering WFs of crops down to benchmarks are significant compared to demand reducing and supply increasing measures considered in the national water strategy.

The assessment of the WF of Morocco gives an overview of how water resources are allocated over different purposes and products and reveals new insights in the water balance and the extent to which water resources are used economically efficient, as well as new response options to reduce the WF. In this sense, knowledge on the WF of activities in Morocco and the virtual water flows from and to Morocco has an added value for formulating national water policy.

The assessment provides a comprehensive water balance and allows critical analysis of the water allocation to different purposes. This is relevant from a physical point of view by comparing the water consumption of activities and crops across different regions and farms, which exposes new views on reducing WFs, but also from an economic point of view by considering if available water resources are used economically efficient and if the production value per unit of water outweighs the (in)direct costs of water (over)exploitation. Furthermore, considering the green and grey components of a WF provides new perspectives on blue water scarcity, because pressure on blue water resources might be reduced by more efficient use of green water and by less pollution.

WF assessment forces to look at end-users and -purposes of freshwater, which is key in determining efficient and equitable water allocation within the boundaries of environmentally sustainable water use, both on the river basin and on the national level. This is especially relevant for water-scarce countries such as Morocco.

Regarding the added value of knowledge of the WF and virtual water balance of Morocco for policy making in practice, it is worthwhile to investigate whether the results and response options formulated in this study are perceived useful and beneficial by policy makers in Morocco and by the consultants who prepare the national water strategy and river basin plans.

6 Discussion

The water footprint (WF) estimates presented in this study include uncertainties that reflect the uncertainties in input data and assumptions used and the limitations of the study. No data are available to compare with the estimates of the green and grey WFs. Estimates from this study on the total WF of irrigation (i.e. the blue WF of crop production plus the WF of the irrigation supply network, however, excluding a share in the WF of storage reservoirs) are compared with the volume of water supplied to farmers for irrigation in the current situation (2010, for most basins) as recorded in the river basin plans, see Figure 6-1. They correlate quite well, but the number of data points is limited. The WF of irrigation is consistently lower than the water supply to irrigation. The precise reason for this cannot be pointed out, since the blue WF of crop production is largely influenced by the input data used and assumptions made by Mekonnen and Hoekstra (2010b), but their blue WF estimates can easily contain an uncertainty of ±20% (Hoff *et al*., 2010; Mekonnen and Hoekstra, 2010a,b). However, it seems logical that the WF of irrigation is lower for three reasons: 1) the basin data are more recent and irrigation demands have increased in the past decade; 2) the WF of the irrigation supply network is a conservative estimate, because it is based on targeted field and conveyance efficiencies (see section 2.4); 3) the water that is lost in the irrigation water supply network by percolation and the excess water applied to the crop field that percolates are not included in the WF estimates, since they are not evaporative losses (see section 2.4). On the contrary, the estimates of the blue WF of crop production are based on the assumption that actual irrigation is sufficient to meet the irrigation demand, though this is not always the case in Morocco due to limited water availability.

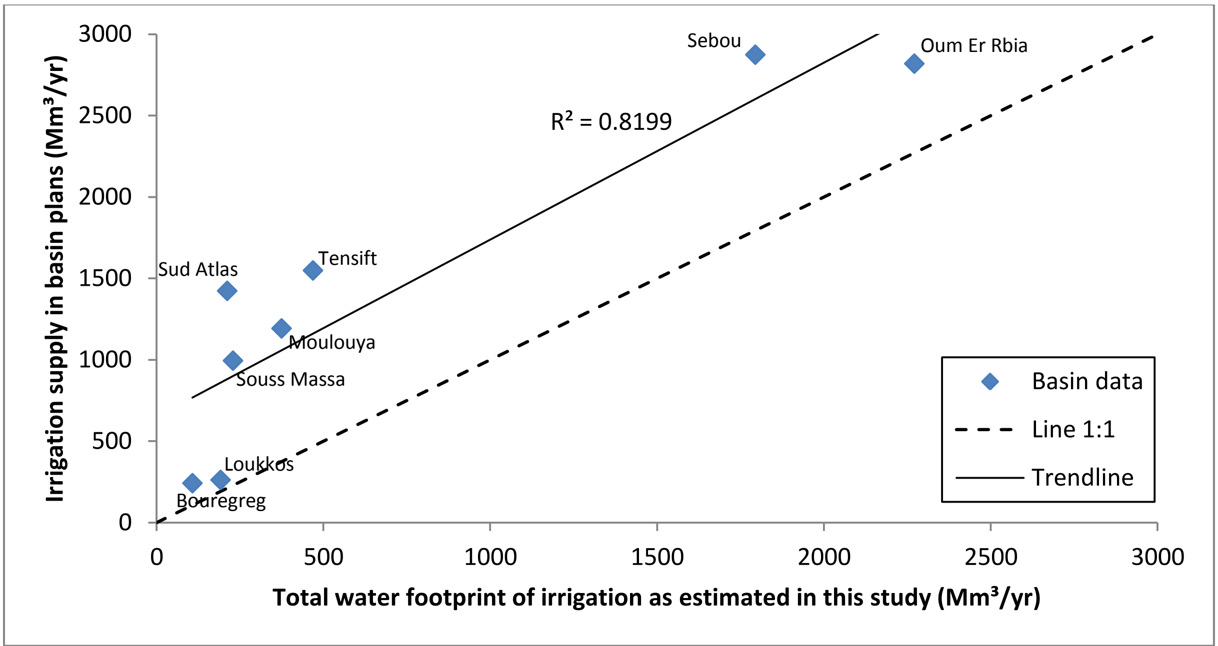


Figure 6-1: Comparison of the water footprint of irrigation as estimated in this study (i.e. blue WF of crop production plus WF of irrigation supply network) with the volumes of water supplied to farmers for irrigation as recorded in the river basin plans.

The WFs of industrial production and domestic water supply are very sensitive to the consumptive fractions applied. The WF of storage reservoirs in the basins for which no reservoir-specific data are available probably contain uncertainty due to the input data used (especially regarding the surface area of reservoirs), but this is hard to quantify. Note that the estimated WFs of storage reservoirs in these basins are relatively small compared to the estimates for the basins for which reservoir-specific data are available. Furthermore, the WF of storage reservoirs is a conservative estimate, because a fraction of 43% of the evaporation at upper storage level is taken as estimate of the WF.

The WF estimates in this study can be improved by using local data, especially by calculating the WF of crops at field level with data from e.g. the regional offices for agricultural development on which crops are grow when and where, evapotranspiration and fertilizer use. Moreover, the WF estimates here are averages over the period 1996-2005. For further research it is recommended to estimate the WF of activities and specific crops taking into account inter-annual variability (e.g. estimates for dry years, average years and humid years) and using more recent data and future projections. The current and future WFs are probably larger due to growth of the Moroccan population and growing water needs as projected in the river basin plans. Combined with the effects of climate change this will also increase water scarcity.

Although figures on water availability are obtained from the river basin plans or directly from the Ministerial Depart of Water Morocco, the way they are estimated exactly is often unclear and so is the uncertainty in them. River basin plans are developed by consultants in commission of the river basin agencies. The Water Law prescribes that these plans should include, among others, an assessment of the quantitative evolution of the hydrological resources in the basin (Official State Gazette, 1995). However, methods and definitions to do so are not formally established.

In general, the river basin plans indicate larger pressure on groundwater resources than suggested in this study. This might be caused by the fact that the river basin plans include more recent withdrawals and because the unit of analysis in this study (river basin agency action zone) is larger than the unit used in the river basin plans (individual aquifers), whereby in this study overexploitation of one aquifer might be masked by low exploitation of another. Also local pollution according to the river basin plans is sometimes worse than the water pollution level estimated here. This could be explained by the fact that the water quality measurements recorded in the basin plans are partly more recent and are measured at specific points, whereas this study considered homogeneous distribution of nitrates in the groundwater.

Given the uncertainties and limitations of the study, the presented WF estimates and water scarcity values should be interpreted with care. Nevertheless, the order of magnitude of the estimates in this study gives a good indication to which activities and crops Morocco’s water resources are allocated, in which months and basins the WFs are relatively large or small and where and when this leads to highest water scarcity.

The economic water and land productivities of crops (EWP and ELP) are, apart from the WFs and yields, dependent on the producer prices. Variations in these prices largely influence the EWP and ELP of crops. The results presented in this study showed Moroccan water and land could have been used economically more efficient in the period 1996-2005. Potential future changes in which crops are grown in order to make more economically efficient use of water and land resources should be based on an elaborate analysis of current (and future) WFs and prices. The same holds for the earnings per m^3 water exported (and costs per m^3 water imported).

Uncertainties in the estimated potential savings by reallocation of crop production are closely linked to the uncertainties in the estimates of the WF of crop production. Details on the areas of land located to specific crops and the associated production and WFs should be interpreted very carefully. However, the order of magnitude of the estimated savings gives a rough indication of the potential of this measure. When considering reallocation of crop production it is necessary to assess how the green and especially blue WFs of crops manifest themselves on a monthly scale. This study looked at annual water savings, but the associated reallocation of crops might well aggravate monthly water scarcity in some river basins. Furthermore, the feasibility and desirability of reallocation of crop production are of course largely determined by social and economic factors which should be taken into account as well.

7 Conclusions

Main results of the water footprint (WF) assessment are:

- The total WF of Moroccan production in the period 1996-2005 was 38.8 Gm³/yr (77% green, 18% blue, 5% grey). Crop production is the largest contributor to this WF, mainly related to the production of wheat and barley, followed by olives and maize. Evaporation from storage reservoirs accounts for the second largest form of blue water consumption nationally, after irrigated crop production. Largest WFs are found in the basins Oum Er Rbia and Sebou, the main agricultural areas. The green WF is largest in the rainy period December-May, whereas the blue WF is largest in the period April-September when irrigation demands increase.
- In the period 1996-2005, Morocco's water resources were mainly used to produce relatively low-value water-intensive (in US$/m³) crops such as cereals, olives and almonds. These crops also took the largest share in the country's harvested area in the same period, although they had the lowest value per hectare cultivated (in US$/ha). More economic return per drop and per hectare of land cultivated was generated by production of grapes, sugar beets, citrus fruits (oranges and mandarins etc.) and tomatoes.
- Morocco was a net virtual water importer in the period 1996-2005. Virtual water import was 12,643 Mm³/yr with an average cost of 0.98 US$/m³ and virtual water export was 4,307 Mm³/yr with an average earning of 1.66 US$/m³. Only 31% of the virtual water export originated from Moroccan water resources (remainder was re-export). Virtual water import and export were for 95% and 91% related to trade in crop products, respectively. By import of products instead of producing them domestically, Morocco saved 27.8 Gm³/yr (75% green, 21% blue and 4% grey) of domestic water, equivalent to 72% of the WF within Morocco.
- Blue water scarcity on a monthly scale is severe in all river basins. Seasonal shortages result in high alteration of natural runoff. Also groundwater scarcity and pollution are significant in most basins, especially in the basins of Bouregreg, Oum Er Rbia and Tensift. In order to move towards sustainable use of Morocco's blue water resources, discussing and agreeing on blue WF caps, per river basin, per month and for surface and groundwater separately, would be useful.
- Potential green plus blue water savings by reallocation of crop production across basins are in the order of 1.9 and 1.2 billion m³ per year when all main crops or only annual crops are reallocated, respectively. Lowering the WFs of the main crops in each river basin down to benchmarks (which are defined as the lowest water consumption of a crop in a comparable basin) can lead to estimated green plus blue water savings of 2,768 Mm³/yr. When the water productivities of the twelve main water-consuming crops were to be improved by 10% throughout Morocco, it could potentially save 2,462 Mm³/yr of water (green plus blue).
- Morocco obtained fairly large savings by food (virtual water) imports in the period 1996-2005 (27.8 Gm³/yr, see above). Increasing food imports to relieve pressure on domestic water resources increases food dependency and has negative effects on the domestic agricultural sector, which plays a critical role in the economic and social stability of Morocco.
- About 4% of the water used in the Moroccan agricultural and industrial sector is used for making export products (period 1996-2005). The remainder is applied for producing products that are consumed by the Moroccan population. However, most of the virtual water export from Moroccan resources relates to the export of products with a relatively low economic value per m³ water exported (in US$/m³).

Several insights and response options emerged from the WF assessment, which are currently not considered in the national water strategy of Morocco and the country's river basin plans. They include:

I. New insights in the water balance of Morocco and the country's main river basins:

- The evaporative losses from storage reservoirs are not explicitly considered for newly planned dams in Morocco, but these losses should be taken into account in the cost-benefit analysis of the new dams, since they account for a significant part of the blue WF within Morocco.
- Blue water scarcity on a monthly scale is severe and hidden by annual analysis of demand versus supply, which is the common scale of analysis in the Moroccan river basin plans. The effects of heavily modified river flows and stream desiccation on aquatic and riparian ecosystems, and the livelihoods that depend on these systems, require attention and local case studies should be carried out to map these effects.

II. New insights in how economically efficient water and land resources are used:

- Analysis of the economic value of crop products per unit of water and land used in the period 1996-2005 indicate that agricultural policy may be better brought in line with water policy by reconsidering which crops to grow.
- It is shown that the export policy in this period was not optimal from a water-economics point of view, which raises the question whether the foreign income generated by export covers the direct and indirect costs of mobilization and (over)exploitation of Moroccan water resources.

III. New response options to reduce the WF of crop production:

- Analysis of the WF of the main crops in Morocco and its variation across the river basins offers new ways of looking at reducing water consumption in the agricultural sector. The estimated potential water savings by reallocation of crops to basins where they consume less water and by lowering WFs of crops down to benchmarks are significant compared to demand reducing and supply increasing measures considered in the national water strategy.

Given these new insights and response options, it can be said that knowledge on the WF of activities in Morocco and the virtual water flows from and to Morocco has an added value for formulating national water policy. WF assessment forces to look at end-users and -purposes of freshwater, which is key in determining efficient and equitable water allocation within the boundaries of what is environmentally sustainable, both on the river basin and on the national level. This is especially relevant for water-scarce countries such as Morocco. Furthermore, considering the green and grey components of a WF provides new perspectives on blue water scarcity, because pressure on blue water resources might be reduced by more efficient use of green water and by less pollution.

References

ABH Bouregreg et de la Chaouia. (2007). PDAIRE Mission I.3: Evaluation qualitative des ressources en eau et des écosystèmes aquatiques : Rapport définitif.

ABH Bouregreg et de la Chaouia. (2008). PDAIRE Mission II: Evaluation des besoins en eau et des utilisations potentielles des ressources en eau et des écosystèmes aquatiques: Volet demande Agricole.

ABH Bouregreg et de la Chaouia. (2009). PDAIRE Mission II: Evaluation des besoins en eau et des utilisations potentielles des ressources en eau et des écosystèmes aquatiques: Volet demande AEPI.

ABH Bouregreg et de la Chaouia. (2012). Le plan directeur d'aménagement intégré des ressources en eau du bassin hydraulique du Bouregreg et de la Chaouia: Rapport de synthèse.

ABH Loukkos. (2011). Projet du plan directeur intégré des ressources en eau des bassins du Loukkos, du Tangerois et côtiers méditerranéens: Rapport final.

ABH Moulouya. (2011). Etude du plan directeur d'aménagement intégré des ressources en eau du bassin de la Moulouya (PDAIRE): Rapport de synthèse.

ABH Oum Er Rbia. (2009). PDAIRE Sous Mission I.3.3.

ABH Oum Er Rbia. (2011). Etude du plan directeur d'aménagement intégré des ressources en eau du bassin de l'Oum Er Rbia et des bassins côtiers atlantiques: Résumé synthétique.

ABH Sebou. (2011). Etude d'actualisation du plan directeur d'amenagement integre ses ressources en eau du bassin hydraulique de Sebou: Rapport du PDAIRE.

ABH Souss Massa Draa. (n.d.a). PDAIRE Draa Arabic summary.

ABH Souss Massa Draa. (n.d.b). PDAIRE Souss Massa Arabic summary.

ABH Tensift. (2011). Etude de revision du plan directeur d'amenagement integre des ressources en eau (PDAIRE) du bassin du Tensift Ksob et Iguezoullen: Note de synthese.

ADA. (2013). Green Morocco Plan, http://www.ada.gov.ma/en/Plan_Maroc_Vert/plan-maroc-vert.php (consulted 12 July 2013).

Ait Kadi, M. (2002). Irrigation water pricing policy in Morocco's large scale irrigation projects, In : Hamdy A. (ed.), Lacirignola C. (ed.), Lamaddalena N. (ed.), Water valuation and cost recovery mechanisms in the developing countries of the Mediterranean region, Bari: CIHEAM, 2002, p. 51-71, (Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 49), Seminar: Water Valuation and Cost Recovery Mechanisms in the Developing Countries of the Mediterranean Region, 2002/06/15/17, Agadir (Morocco), http://om.ciheam.org/om/pdf/a49/02001533.pdf (retrieved 17 July 2013).

Aldaya, M.M., Garrido, A., Llamas, M.R., Varelo-Ortega, C., Novo, P., and Casado, R.R. (2010a). Water footprint and virtual water trade in Spain, In: Garrido, A. and Llamas, M.R. (eds.), Water policy in Spain, CRC Press, Leiden, The Netherlands, p. 49-59.

Aldaya, M.M., Martinez-Santos, P. and Llamas, M.R. (2010b). Incorporating the water footprint and virtual water into policy: Reflections from the Mancha Occidental Region, Spain, *Water Resources Management*, 24(5): 941-958.

Al-Taiee, T. M. (2012). Groundwater Dams: a Promise Option for Sustainable Development of Water Resources in Arid and Semi-Arid Regions, In: UNESCO, Proceedings of the Second International Conference on integrated water resources management and challenges of the sustainable development, Agadir, 24-26 March 2010, IHP-VII Series on Groundwater No. 4, UNESCO, p.35-41.

Chahed, J., Besbes, M. and Hamdane, A. (2011). Alleviating water scarcity by optimizing "Green Virtual-Water": the case of Tunisia, In: Hoekstra, A.Y., Aldaya, M.M. and Avril, B. (eds.), Proceedings of the ESF Strategic Workshop on accounting for water scarcity and pollution in the rules of international trade, Amsterdam, 25-26 November 2010, Value of Water Research Report Series No. 54, UNESCO-IHE, p.99-113.

Chapagain, A.K. and Hoekstra, A.Y. (2003). 'Virtual water flows between nations in relation to trade in livestock and livestock products', Value of Water Research Report Series No.13, UNESCO-IHE.

Direction de la Region Hydraulique du Guir Rheris Ziz.(2012). Actualisation du Plan Directeur Intégré des Ressources en Eau des bassin de Guir Ziz Rhéris et Maîder: Resumé du PDAIRE.

EMWIS. (2012). *EMWIS Flash*, N105, November 2012, http://www.emwis.net/thematicdirs/eflash/flash105 (retrieved 8 December 2012).

FAO. (2003). Review of World Water Resources by Country, Water Reports 23, Food and Agriculture Organization, Rome, http://www.fao.org/docrep/005/y4473e/y4473e0c.gif (retrieved 4 June 2013).

FAO. (2013a). AQUASTAT online database, Country Fact Sheet: Morocco, Food and Agriculture Organization, Rome, www.fao.org/nr/aquastat/ (retrieved 22 February 2013).

FAO. (2013b). AQUASTAT online database, Geo-referenced database of African dams, Food and Agriculture Organization, Rome, http://www.fao.org/nr/water/aquastat/dams/region/D_Africa.xlsx (retrieved 28 March 2013).

FAO. (2013c). AQUASTAT online database, Water Balance Sheet: Morocco, Food and Agriculture Organization, Rome, www.fao.org/nr/aquastat/ (retrieved 22 February 2013).

FAO. (2013d). FAOSTAT online database, Food and Agriculture Organization, Rome, http://faostat.fao.org (retrieved 6 July 2013).

FAO. (2013e). Global map of monthly reference evapotranspiration - 10 arc minutes. GeoNetwork: grid database, Food and Agriculture Organization, Rome, www.fao.org/geonetwork/srv/en/resources.get?id=7416&fname=ref_evap_fao_10min.zip&access=private (retrieved 19 March 2013).

Hachimi, M. (2009). Agences de Bassins Hydrauliques & Gouvernance de l'eau [PDF document, presentation slides], www.oecd.org/mena/governance/43316384.pdf (retrieved 8 December 2012).

Hsiao,T.C. and Xu, L. (2005). Evapotranspiration and Relative Contribution by the Soil and the Plant, California Water Plan Update 2005, 4: 129-160.

Hoekstra, A.Y. (ed.). (2003). Virtual water trade: Proceedings of the International Expert Meeting on Virtual Water Trade, Delft, The Netherlands, 12-13 December 2002, Value of Water Research Report Series No.12, UNESCO-IHE, Delft, The Netherlands, www.waterfootprint.org/Reports/Report12.pdf

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

Hoekstra, A.Y. and Chapagain, A.K. (2007). The water footprints of Morocco and the Netherlands: Global water use as a result of domestic consumption of agricultural commodities, *Ecological Economics*, 64(1): 143-151.

Hoekstra, A.Y. and Chapagain, A.K. (2008). Globalization of water: Sharing the planet's freshwater resources, Blackwell Publishing, Oxford, UK.

Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M. and Mekonnen, M.M. (2011). The water footprint assessment manual: Setting the global standard, Earthscan, London, UK.

Hoekstra, A.Y. and Mekonnen, M.M. (2011). Global water scarcity: monthly blue water footprint compared to blue water availability for the world's major river basins, Value of Water Research Report Series No.53, UNESCO-IHE.

Hoekstra, A.Y., Mekonnen, M.M., Chapagain, A.K., Mathews, R.E. and Richter, B.D. (2012). Global monthly water scarcity: Blue water footprints versus blue water availability, *PLoS ONE*, 7(2): e32688.

Hoff, H., Falkenmark, M., Gerten, D., Gordon, L., Karlberg, L. and Rockström, J. (2010). Greening the global water system, *Journal of Hydrology*, 384: 177–186.

INECO. (2009). Institutional framework and decision-making practices for water management in the Oum Er Rbia Basin, Morocco: Towards the development of a strategy for increasing efficiency in irrigation water use, http://environ.chemeng.ntua.gr/ineco/UserFiles/File/Deliverables/Publishable%20Report%20-%20Morocco.pdf (retrieved 14 November 2012).

ITC. (2007). SITA version 1996–2005 in SITC [DVD-ROM], International Trade Centre, Geneva.

IUCN. (2010). Integration of biodiversity in the decision-making process: Lessons learnt from the Moulouya Projects, Data compiled by Professor Mohammed Melhaoui, University of Oujda, Morocco, 65 pages, http://cmsdata.iucn.org/downloads/moulouya_lessons_learned.pdf (retrieved 18 July 2013).

JICA, MATEE and ABHT. (2007). Etude du plan de gestion intégrée des ressources en eau dans la plaine du Haouz, Royaume du Maroc, Rapport intermédiaire.

Kumar, M.D. and Singh, O.P. (2005). Virtual water in global food and water policy making: is there a need for rethinking?, *Water Resources Management*, 19: 759–789, doi: 10.1007/s11269-005-3278-0

Laouina, A. (2001). Compétition irrigation/eau potable en region de stress hydrique: le cas de la region d'Agadir (Maroc), In: Camarda D. (ed.), Grassini L. (ed.). Interdependency between agriculture and urbanization: Conflicts on sustainable use of soil and water, Bari: CIHEAM, 2001, p. 17-31, (Options Méditerranéennes: Série A. Séminaires Méditerranéens; n . 44).

Mekonnen, M.M. and Hoekstra, A.Y. (2010a). A global and high-resolution assessment of the green, blue and grey water footprint of wheat, *Hydrology and Earth System Sciences*, 14(7), 1259–1276.

Mekonnen, M.M. and Hoekstra, A.Y. (2010b). The green, blue and grey water footprint of crops and derived crop products, Value of Water Research Report Series No.47, UNESCO-IHE.

Mekonnen, M.M. and Hoekstra, A.Y. (2010c). The green, blue and grey water footprint of farm animals and animal products, Value of Water Research Report Series No.48, UNESCO-IHE.

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

Mekonnen, M.M., Hoekstra, A.Y. and Becht, R. (2012). Mitigating the water footprint of export cut flowers from the Lake Naivasha Basin, Kenya, *Water Resources Management*, 26: 3725–3742.

Ministry of Agriculture and Fisheries of Morocco. (2010). l'Agriculture Marocaine en chiffres.

Ministry of Agriculture and Fisheries of Morocco. (2011). Fonds de Developpement Agricole: Les Aides Financières de l'Etat pour l'encouragement des investissements agricoles, Edition Avril 2011.

Ministry of Energy, Mining, Water and Environment of Morocco, Department of Water. (2011). Stratégie Nationale de l'Eau, www.minenv.gov.ma/PDFs/EAU/strategie_eau.pdf (retrieved 21 January 2013).

Ministry of Energy, Mining, Water and Environment of Morocco, Department of Water. (2012a). Les eaux souterraines, http://www.water.gov.ma/index.cfm?gen=true&id=12&ID_PAGE=42 (consulted 8 December 2012).

Ministry of Energy, Mining, Water and Environment of Morocco, Department of Water. (2012b). Présentation générale, http://www.water.gov.ma/index.cfm?gen=true&id=12 (consulted 8 December 2012).

Ministry of Energy, Mining, Water and Environment of Morocco, Department of Water. (2013a). Data AEP modulation PWS: Version 9 [Microsoft Excel document].

Ministry of Energy, Mining, Water and Environment of Morocco, Department of Water. (2013b). Historical runoff time series [RIBASIM data file], spreadsheet "Time series Inflow V5.xls".

Ministry of Energy, Mining, Water and Environment of Morocco, Department of Water. (2013c). Open water evaporation per reservoir (average values for each year) [RIBASIM data file], spreadsheet "Rainfall and evaporation time series for dams V1.xlsx".

Minoia, P. (2012). Mega-irrigation and neoliberalism in postcolonial states: evolution and crisis in the Gharb Plain (Morocco), *Geografiska Annaler: Series B, Human Geography*, 94 (3): 269-286.

NIMA. (2013). Digital Terrain Elevation Data (DTED) Level 0 [Data file], GeoCommunity, GIS Depot, http://data.geocomm.com/catalog/MO/group121.html (retrieved 8 March 2013).

Official State Gazette. (1995). Royal Decree no. 1-95-154 promulgating Law no. 10-95 on water, http://ebookbrowse.com/royal-decree-no-1-95-154-promulgating-law-on-water-en-pdf-d211458096 (retrieved 3 January 2013).

Poff, N.L., Richter, B.D., Aarthington, A.H., Bunn, S.E., Naiman, R.J., Kendy, E., Acreman, M., Apse, C., Bledsoe, B.P., Freeman, M.C., Henriksen, J., Jacobson, R.B., Kennen, J.G., Merritt, D.M., O'Keeffe, J.H., Olden, J.D., Rogers, K., Tharme, R.E. and Warner, A. (2010). The ecological limits of hydrologic alteration (ELOHA): A new framework for developing regional environmental flow standards, *Freshwater Biology*, 55(1): 147-170.

Riad, S. (2003). Typologie et analyse hydrologique des eaux superficielles à partir de quelques bassins versants représentatifs du Maroc, (Unpublished thesis), Université Lille1 - Sciences et Technologies, http://ori-nuxeo.univ-lille1.fr/nuxeo/site/esupversions/e5d351a6-ce4c-4b64-b891-84d85f3d8f02 (retrieved 19 June 2013).

Self, J.R. and Waskom, R.M. (2013). Nitrates in Drinking Water: fact sheet no. 0.517, Colorado State University Extension, http://www.ext.colostate.edu/pubs/crops/00517.pdf (retrieved 10 July 2013).

Shahin, M. (2007). Water Resources and Hydrometeorology of the Arab Region, Spinger, Dordrecht, The Netherlands, http://dx.doi.org/10.1007/1-4020-5414-9 (retrieved 14 December 2012).

Sperna Weiland, F. C., van Beek L. P. H., Kwadijk, J. C. J. and Bierkens, M. F. P. (2010). The ability of a GCM-forced hydrological model to reproduce global discharge variability, *Hydrology and Earth System Sciences*, 14: 1595-1621, doi:10.5194/hess-14-1595-2010

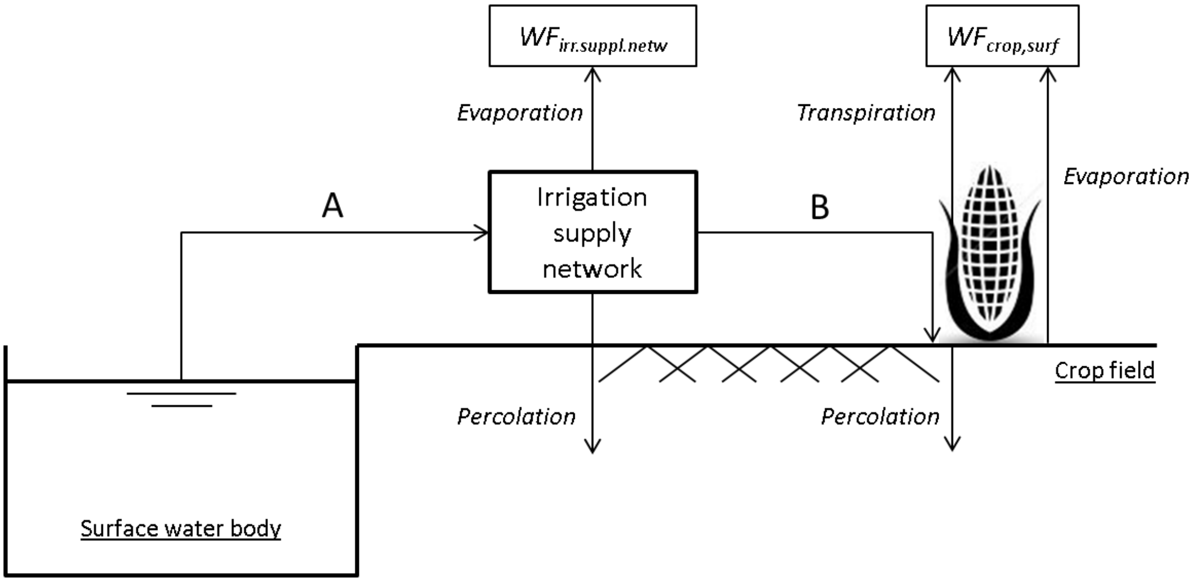
Tekken, V. and Kropp, J.P. (2012). Climate-Driven or Human-Induced: Indicating Severe Water Scarcity in the Moulouya River Basin (Morocco), *Water*, 4: 959-982, doi:10.3390/w4040959

The World Bank (2012). World dataBank online database, World Development Indicators & Global Development Finance, http://databank.worldbank.org/ddp/home.do?Step=2&id=4 (retrieved 28 November 2012).

Appendix I: Derivation K-factor in water footprint of irrigation supply network

Definitions

A	= volume withdrawn for irrigation from surface water body
B	= volume of water applied to the crop field
e_a	= field application efficiency
e_c	= conveyance efficiency
f_E	= fraction of losses in network that evaporates (remainder percolates)
K	= fraction of surface water footprint of crop production at field level that is lost by evaporation from the irrigation supply network
$WF_{crop,surf}$	= surface water footprint of crop production at field level (i.e. the part of the irrigation water that originates from surface water and is lost at the crop field through evapotranspiration)
$WF_{irr.suppl.netw}$	= water footprint of irrigation supply network (i.e. evaporative losses from network)



Derivation

$$e_a = \frac{WF_{crop,surf}}{B} \rightarrow B = \frac{WF_{crop,surf}}{e_a}$$

$$e_c = \frac{B}{A} \rightarrow A = \frac{B}{e_c} = \frac{WF_{crop,surf}}{e_a \times e_c}$$

$$WF_{irr.suppl.netw} = (A - B) \times f_E = \left[\frac{WF_{crop,surf}}{e_a \times e_c} - \frac{WF_{crop,surf}}{e_a}\right] \times f_E = \left[\frac{1}{e_a \times e_c} - \frac{1}{e_a}\right] \times f_E \times WF_{crop,surf}$$

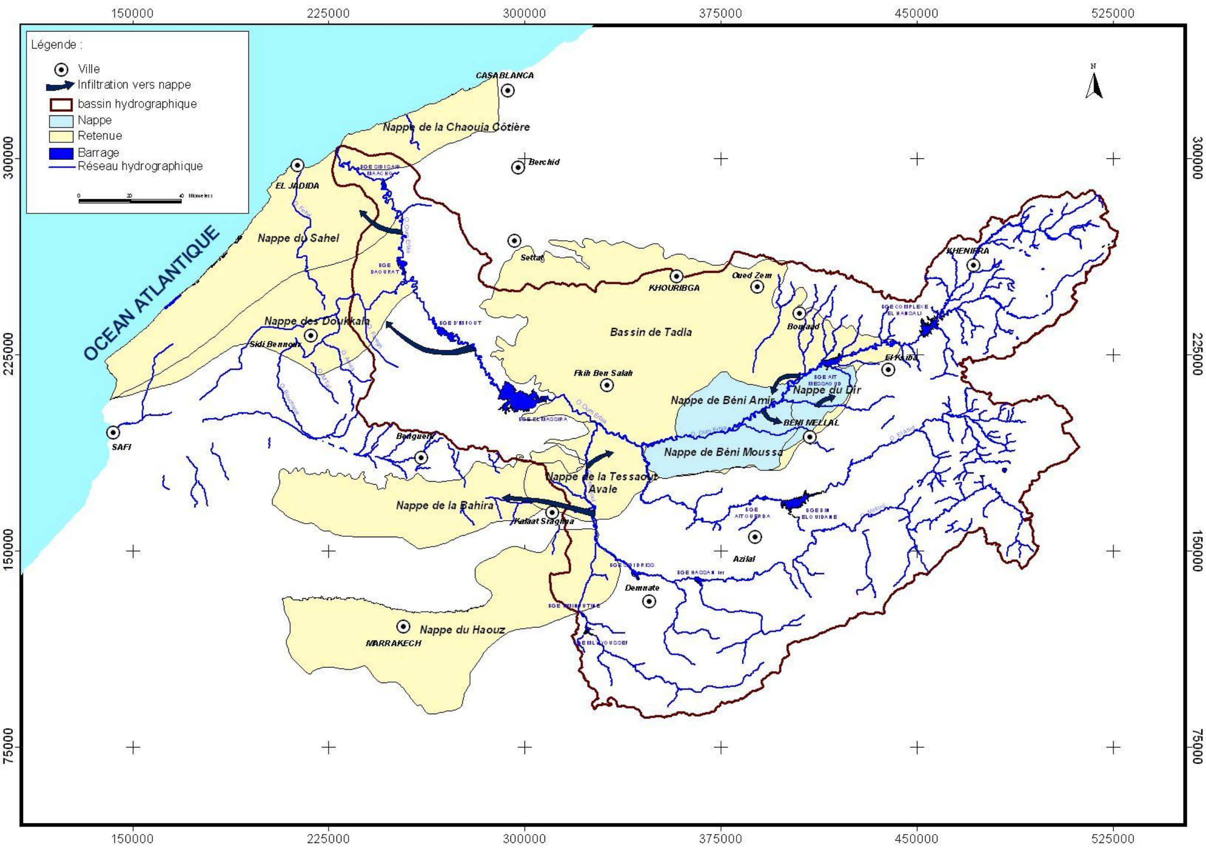
$$WF_{irr.suppl.netw} = K \times WF_{crop,surf} \quad with \quad K = \left[\frac{1}{e_a \times e_c} - \frac{1}{e_a}\right] \times f_E$$

Appendix II: Best estimates for the fraction of total blue water supply withdrawn from groundwater

River basin	Best estimate fraction withdrawn from groundwater for domestic and industrial purposes (%)	Description	Data from year	Source
Boure-greg	4	% of groundwater abstractions in the water abstracted for the production of potable water.	2006	ABH Bouregreg et de la Chaouia (2009)
Loukkos	22	% of groundwater abstractions for drinking and industrial water in the total demand for drinking and industrial water.	2010	ABH Loukkos (2011)
Moulouya	50	% of groundwater abstractions for drinking and industrial water in the total of abstractions for drinking water (also for livestock) and industrial water.	2010	ABH Moulouya (2011)
Oum Er Rbia	38	% of groundwater abstractions for drinking and industrial water in the total of abstractions for drinking and industrial water.	Current situation (2011)	ABH Oum Er Rbia (2011)
Sebou	88	% of groundwater abstractions for drinking water in the total demand for drinking water.	2010	ABH Sebou (2011)
Souss Massa	71	% of groundwater abstractions for drinking water, water for tourism and industrial water in the total of abstractions for drinking water, water for tourism and industrial water.	2010	ABH Souss Massa Draa (n.d.b)
Sud Atlas	47	% of abstractions from groundwater in the total of abstractions for drinking, industrial and irrigation water for agriculture. Based on data for Guir-Ziz Rheris only (assumed to be representative for whole Sud Atlas).	2010	Direction de la Region Hydraulique du Guir Rheris Ziz (2012)
Tensift	45	% of abstractions from groundwater in the total of abstractions for drinking, industrial and irrigation water for agriculture and for golf spaces and parks.	2010	ABH Tensift (2011)

River basin	Best estimate fraction abstracted from groundwater for irrigation (%)	Description	Data from year	Source
Boure-greg	88	% of groundwater abstractions for irrigation in total of abstractions for irrigation.	2006	ABH Bouregreg et de la Chaouia (2008)
Loukkos	34	% of groundwater abstractions for irrigation in total of abstractions for irrigation.	2010	ABH Loukkos (2011)
Moulouya	21	% of groundwater abstractions for irrigation in total of abstractions for irrigation.	2010	ABH Moulouya (2011)
Oum Er Rbia	20	% of groundwater abstractions for irrigation in total of abstractions for irrigation.	Current situation (2011)	ABH Oum Er Rbia (2011)
Sebou	25	% of groundwater abstractions for irrigation in total of abstractions for irrigation.	Current situation (2010)	ABH Sebou (2011)
Souss Massa	63	% of groundwater abstractions for irrigation in total of abstractions for irrigation.	Current situation (proba-bly 2010)	ABH Souss Massa Draa (n.d.b)
Sud Atlas	43	% of groundwater abstractions for irrigation in total of abstractions for irrigation. Based on data for Guir-Ziz Rheris only (assumed to be representative for whole Sud Atlas).	2010	Direction de la Region Hydraulique du Guir Rheris Ziz (2012)
Tensift	45	% of abstractions from groundwater in the total of abstractions for drinking, industrial and irrigation water for agriculture and for golf spaces and parks.	2010	ABH Tensift (2011)

Appendix III: Map of aquifers (partially) in action zone ABH Oum Er Rbia



Source: ABH Oum Er Rbia (2011)

Appendix IV: Open water evaporation from different sources

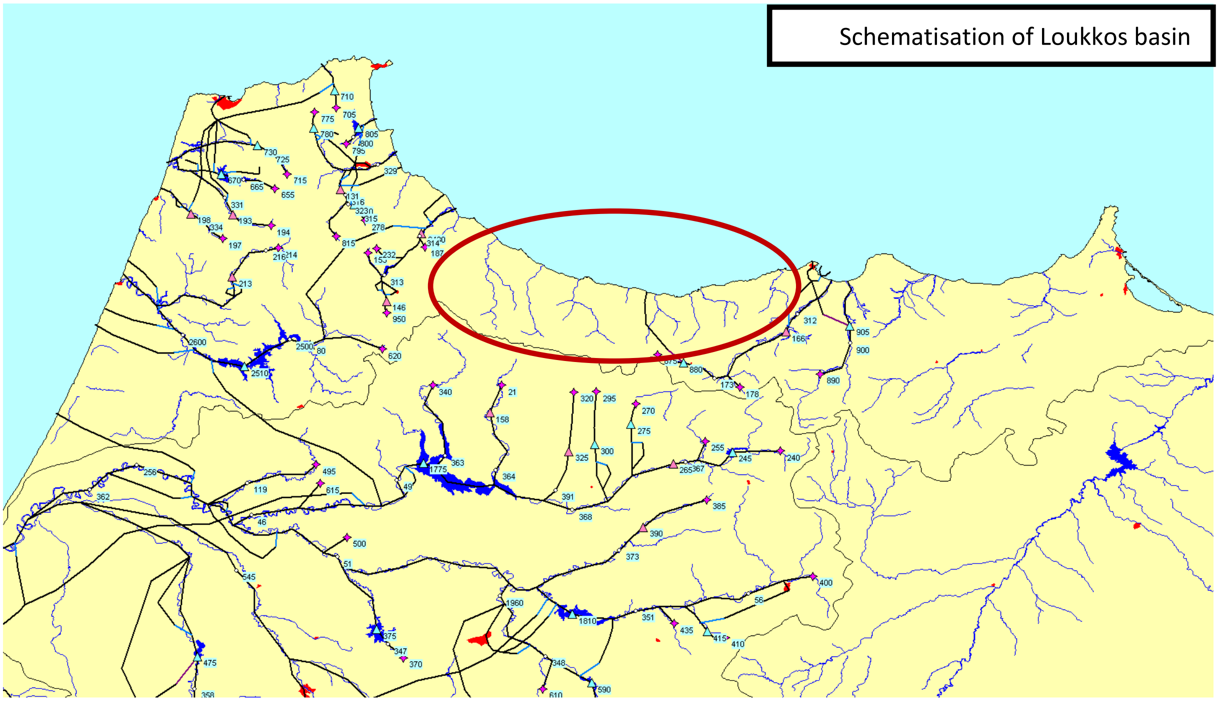
The table below shows how the best estimates of open water evaporation in the river basins compare with each other and with reference evapotranspiration. The first main column relates to the estimates used in this study, namely reservoir specific data from the Ministry of Energy, Mining, Water and Environment of Morocco, Department of Water (2013c) for four basins and estimates from the global hydrological model PCR-GLOBWB for the other basins (Sperna Weiland *et al*., 2010). The second column shows the variation in estimates across the basins according to PCRGLOB-WB estimates only. For comparison, the third column shows variation in reference evapotranspiration across the basins.

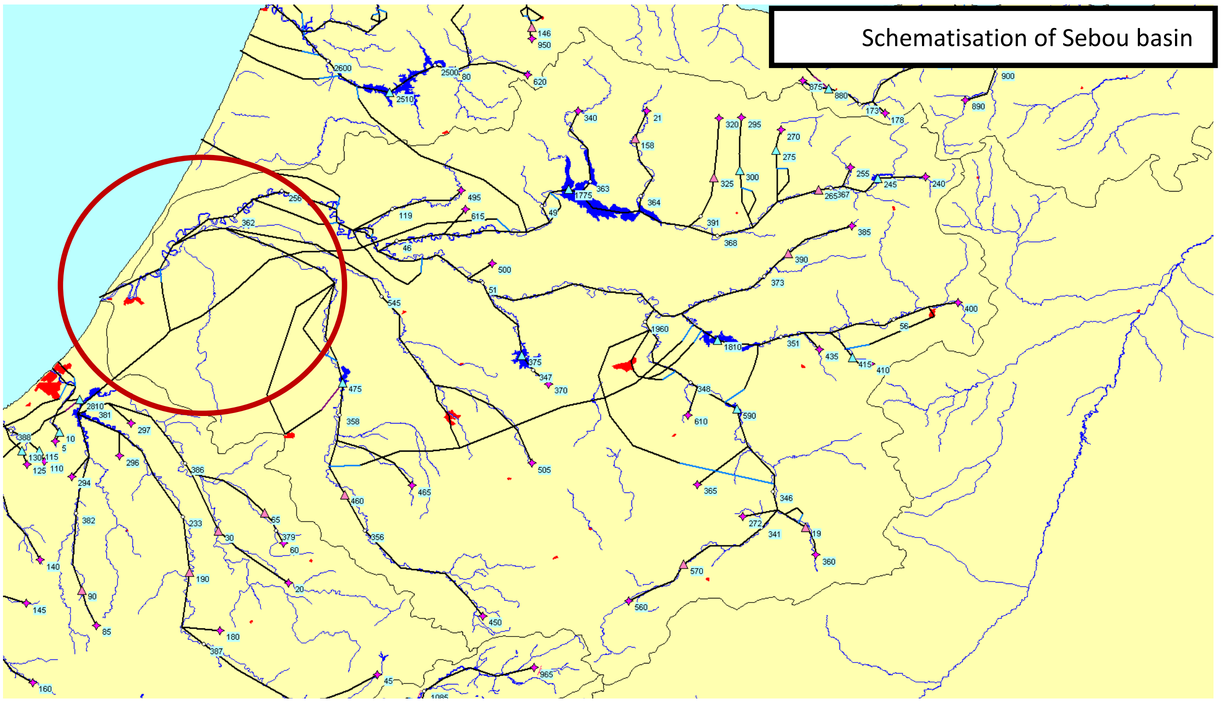
Ministry of Energy, Mining, Water and Environment of Morocco, Department of Water (1939-2011) (*) & PCRGLOB-WB (1961-1990)			PCRGLOB-WB (1961-1990)			Reference evapotranspiration (1961-1990)		
Rank	Basin	E_O (mm/yr)	Rank	Basin	E_O (mm/yr)	Rank	Basin	ET_0 (mm/yr)
1	Souss Massa	2,193	1	Souss Massa	2,193	1	Sud Atlas	1,652
2	Oum Er Rbia*	1,956	2	Tensift	1,850	2	Souss Massa	1,450
3	Tensift	1,850	3	Sud Atlas	1,702	3	Moulouya	1,409
4	Sud Atlas	1,702	4	Oum Er Rbia	1,597	4	Tensift	1,389
5	Bouregreg*	1,529	5	Bouregreg	1,326	5	Oum Er Rbia	1,387
6	Loukkos*	1,472	6	Sebou	1,257	6	Sebou	1,266
7	Sebou*	1,390	7	Moulouya	1,228	7	Bouregreg	1,239
8	Moulouya	1,228	8	Loukkos	1,159	8	Loukkos	1,212

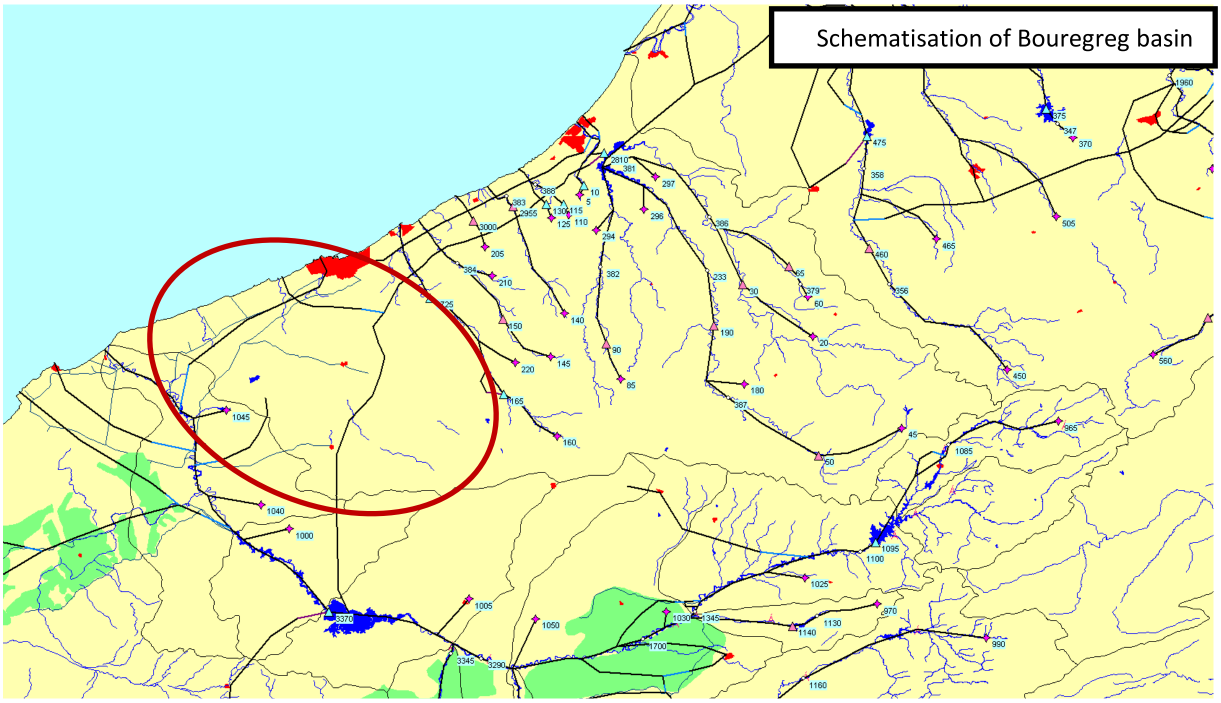
Source: Open water evaporation for basins with (*) from Ministry of Energy, Mining, Water and Environment of Morocco, Department of Water (2013c)
Open water evaporation from PCRGLOB-WB simulation from Sperna Weiland *et al*. (2010)
Reference evapotranspiration from FAO (2013e)

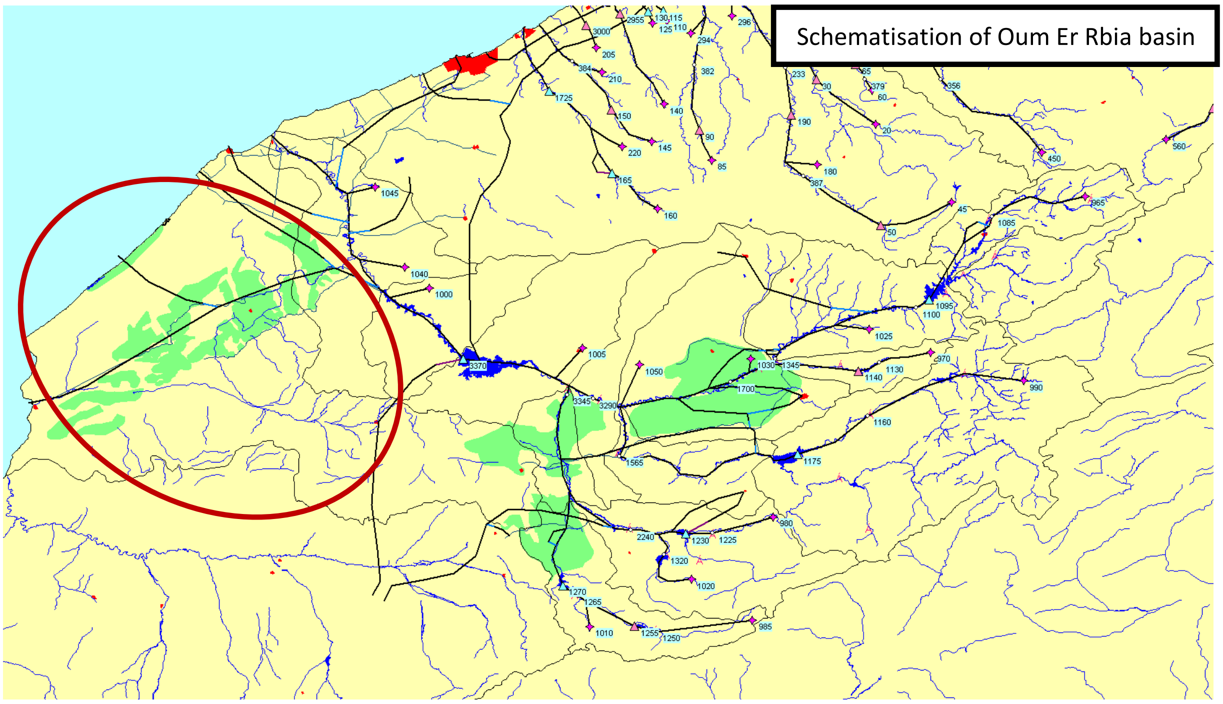
Appendix V: Inflow sub-catchments

The actual inflow volumes per sub-catchment used to estimate the natural runoff for the basins Loukkos, Sebou, Bouregreg and Oum Er Rbia are recorded at the inflow nodes (✦) in the figures below. The uncovered areas discussed in section 2.7 are circled.





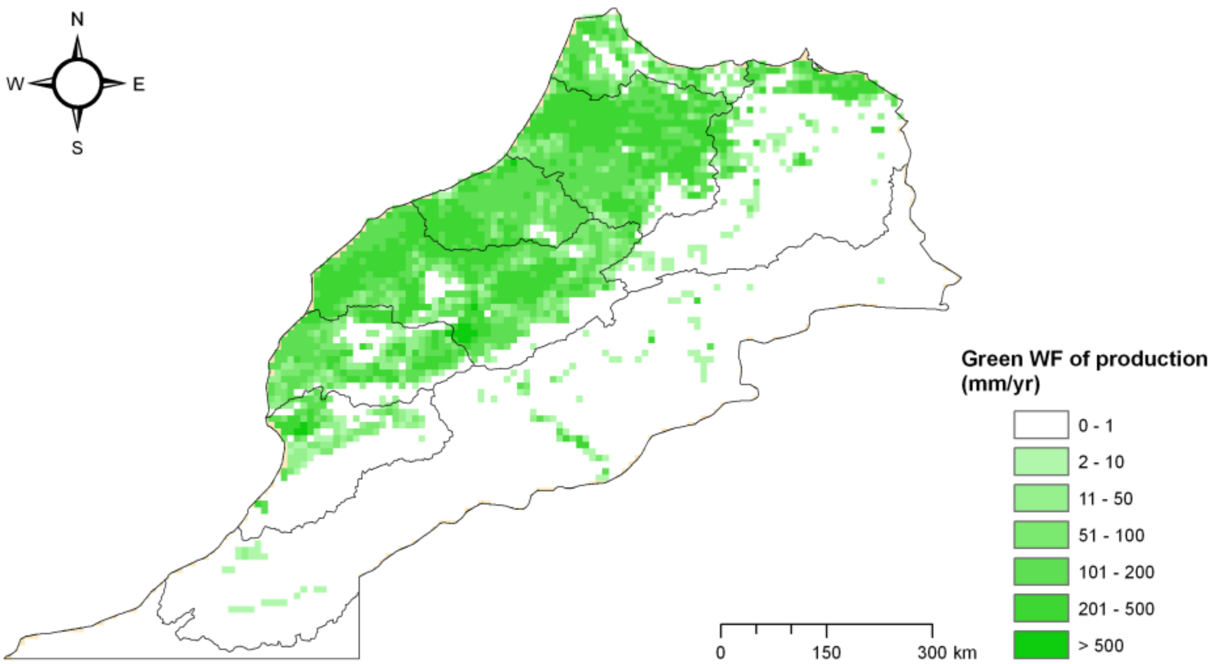

Schematisation of Bouregreg basin

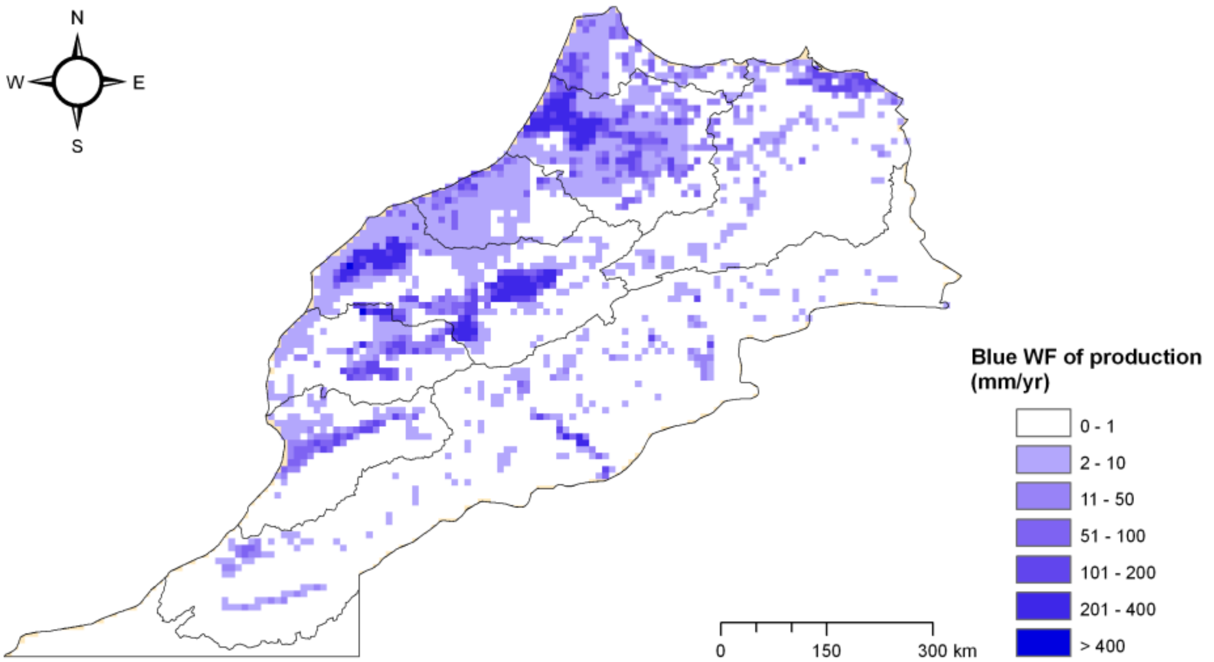

Schematisation of Oum Er Rbia basin

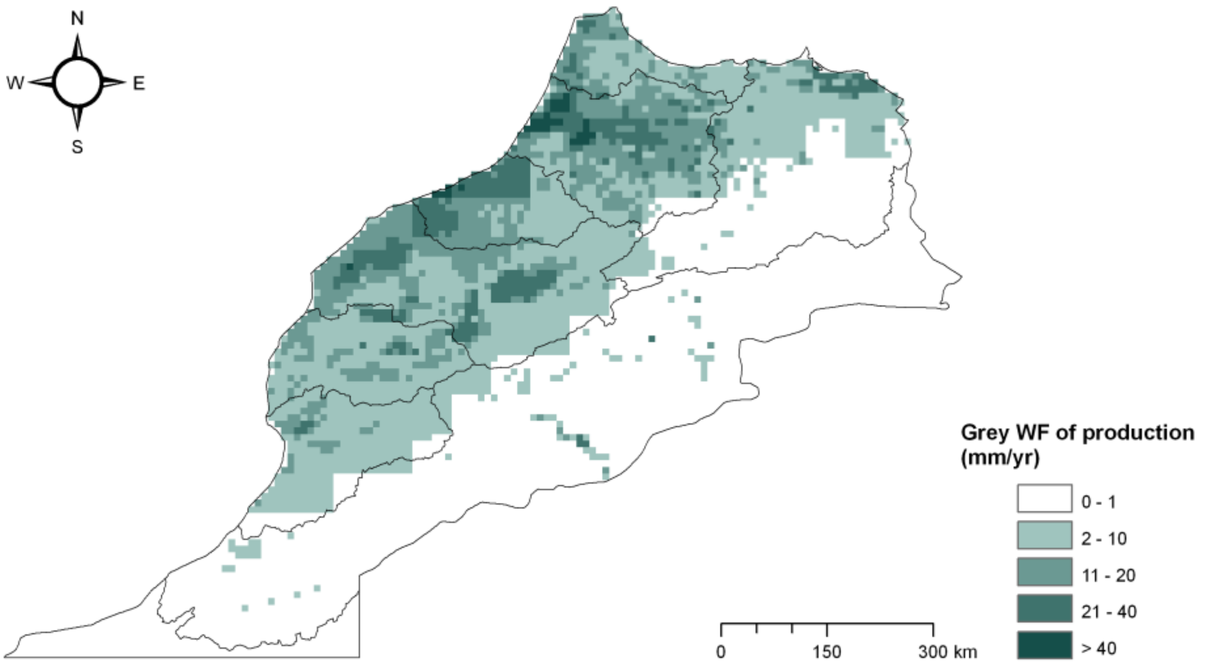
Appendix VI: Water footprint of production at 5x5 arc minute resolution

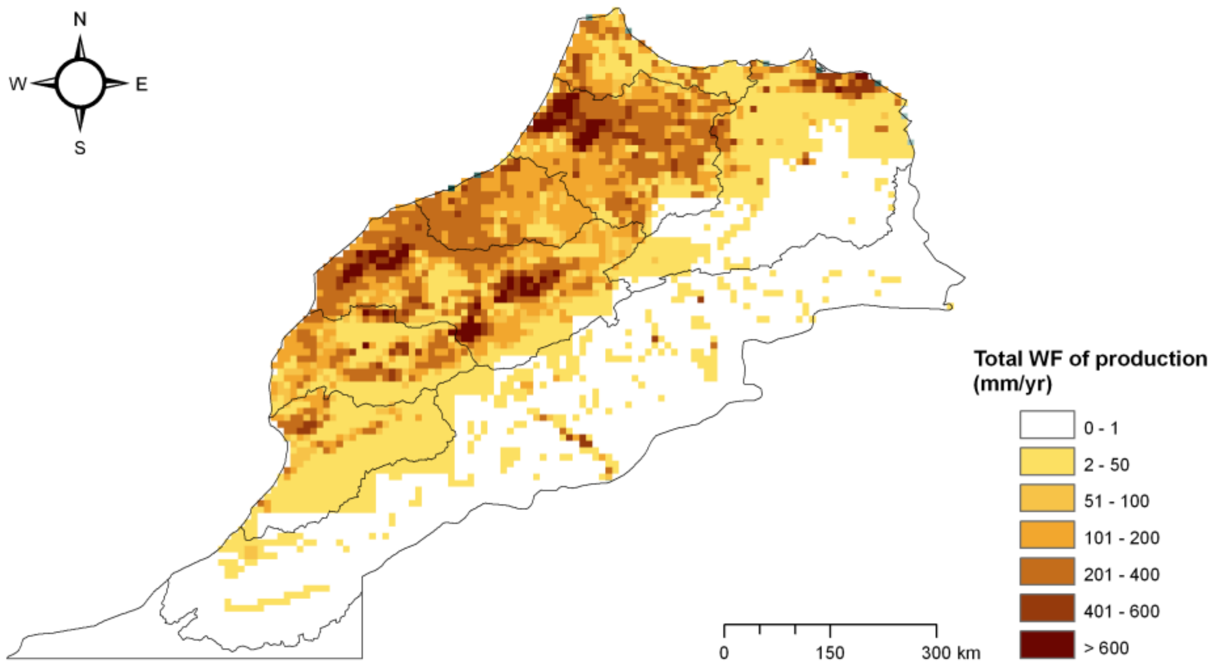
Period of data: 1996-2005
Source: Mekonnen and Hoekstra (2011)

Data include the water footprints of crop production, industrial production and domestic water supply only, since other estimates are not available on grid scale. Data per grid cell are calculated as the water footprint within a grid cell (in m^3/yr) divided by the area.






N
W
E
S
Grey WF of production
(mm/yr)
0 - 1
2 - 10
11 - 20
21 - 40
> 40
0
150
300 km


N
W
E
S
Total WF of production
(mm/yr)
0 - 1
2 - 50
51 - 100
101 - 200
201 - 400
401 - 600
> 600
0
150
300 km

Appendix VII: Water footprint of main crops per river basin

Period of data: 1996-2005

River basin	FAO crop code	Crop	Water footprint per ton of crop (m³/ton)				Total water footprint (Mm³/yr)			
			Green	Blue	Grey	Total	Green	Blue	Grey	Total
Bouregreg	221	Almonds	9,311	308	1,118	10,737	84	3	10	97
	44	Barley	4,003	0	146	4,148	659	-	24	683
	577	Dates	2,839	1,999	342	5,181	10	7	1	18
	900a	Fodder crops	377	0	20	397	57	-	3	60
	560	Grapes	201	454	101	756	1	2	1	4
	56	Maize	5,139	1,308	305	6,752	50	13	3	66
	260	Olives	4,354	482	52	4,888	245	27	3	275
	490	Oranges	212	287	35	534	10	14	2	26
	157	Sugar Beets	19	47	20	85	0	0	0	0
	156	Sugar Cane	26	79	15	120	2	6	1	9
	495	Tang.Mand.etc	205	278	34	517	5	7	1	12
	388	Tomatoes	42	51	12	106	7	8	2	17
	15	Wheat	3,097	18	116	3,231	1,644	10	62	1,715
Loukkos	221	Almonds	8,236	1,059	843	10,138	34	4	3	42
	44	Barley	3,043	0	125	3,168	172	-	7	179
	577	Dates	2,477	2,239	331	5,047	12	11	2	24
	900a	Fodder crops	275	0	14	290	20	-	1	21
	560	Grapes	432	635	101	1,169	5	7	1	12
	56	Maize	3,040	138	262	3,440	1	0	0	1
	260	Olives	3,633	1,018	37	4,688	142	40	1	183
	490	Oranges	264	222	35	522	16	13	2	31
	157	Sugar Beets	34	67	20	121	4	7	2	13
	156	Sugar Cane	47	99	15	161	11	23	3	37
	495	Tang.Mand.etc	256	215	34	505	8	6	1	15
	388	Tomatoes	49	39	12	101	3	2	1	6
	15	Wheat	2,270	59	97	2,426	410	11	18	438
Moulouya	221	Almonds	7,554	1,897	856	10,306	30	8	3	41
	44	Barley	3,405	0	135	3,539	832	-	33	865
	577	Dates	2,800	3,840	331	6,971	17	23	2	41
	900a	Fodder crops	337	0	18	355	19	-	1	20
	560	Grapes	322	680	100	1,102	13	27	4	44
	56	Maize	955	264	196	1,415	1	0	0	1
	260	Olives	3,186	1,571	37	4,793	144	71	2	217
	490	Oranges	227	275	35	537	18	21	3	42
	157	Sugar Beets	32	75	20	126	4	10	3	16
	156	Sugar Cane	43	132	15	189	2	5	1	7
	495	Tang.Mand.etc	220	267	34	520	8	10	1	20
	388	Tomatoes	44	47	12	104	3	3	1	6
	15	Wheat	2,312	283	100	2,695	435	53	19	507

River basin	FAO crop code	Crop	Water footprint per ton of crop (m³/ton)				Total water footprint (Mm³/yr)			
			Green	Blue	Grey	Total	Green	Blue	Grey	Total
Oum Er Rbia	221	Almonds	8,585	1,476	1,041	11,102	167	29	20	216
	44	Barley	4,054	0	148	4,201	2,356	-	86	2,442
	577	Dates	2,917	4,891	333	8,142	55	93	6	155
	900a	Fodder crops	388	0	21	409	108	-	6	114
	560	Grapes	418	1,129	101	1,648	17	45	4	66
	56	Maize	3,486	3,901	230	7,617	372	417	25	814
	260	Olives	3,511	1,552	43	5,106	643	284	8	936
	490	Oranges	208	324	35	567	48	75	8	131
	157	Sugar Beets	33	91	20	144	44	122	27	193
	156	Sugar Cane	-	-	-	-	-	-	-	-
	495	Tang.Mand.etc	201	313	34	548	23	35	4	62
	388	Tomatoes	44	54	12	110	14	17	4	36
	15	Wheat	2,826	342	107	3,275	3,247	393	123	3,763
Sebou	221	Almonds	8,575	1,137	919	10,631	162	22	17	201
	44	Barley	3,955	0	133	4,088	1,032	-	35	1,066
	577	Dates	3,236	3,725	332	7,293	69	80	7	156
	900a	Fodder crops	359	0	16	376	111	-	5	116
	560	Grapes	439	750	101	1,290	15	25	3	44
	56	Maize	3,221	3,328	206	6,755	32	33	2	67
	260	Olives	3,688	1,166	40	4,894	640	202	7	849
	490	Oranges	248	261	35	544	72	76	10	159
	157	Sugar Beets	33	82	20	134	46	116	28	191
	156	Sugar Cane	59	162	15	235	40	111	10	161
	495	Tang.Mand.etc	240	253	34	526	34	36	5	75
	388	Tomatoes	47	47	12	106	13	13	3	30
	15	Wheat	2,730	271	101	3,103	3,670	364	136	4,170
Souss Massa	221	Almonds	7,956	2,185	1,136	11,277	20	6	3	29
	44	Barley	2,498	0	108	2,606	475	-	20	495
	577	Dates	1,700	4,216	333	6,250	5	13	1	19
	900a	Fodder crops	335	0	24	360	12	-	1	13
	560	Grapes	279	1,133	101	1,513	14	56	5	75
	56	Maize	6,732	332	411	7,475	15	1	1	17
	260	Olives	2,967	2,135	45	5,148	80	58	1	139
	490	Oranges	162	373	35	570	6	14	1	21
	157	Sugar Beets	-	-	-	-	-	-	-	-
	156	Sugar Cane	-	-	-	-	-	-	-	-
	495	Tang.Mand.etc	157	361	34	551	3	7	1	10
	388	Tomatoes	37	61	12	111	2	3	1	5
	15	Wheat	2,883	25	131	3,039	126	1	6	133

River basin	FAO crop code	Crop	Water footprint per ton of crop (m³/ton)				Total water footprint (Mm³/yr)			
			Green	Blue	Grey	Total	Green	Blue	Grey	Total
Sud Atlas	221	Almonds	4,946	5,364	814	11,124	3	3	0	7
	44	Barley	1,451	0	141	1,592	36	-	4	40
	577	Dates	922	3,300	329	4,551	1	5	1	7
	900a	Fodder crops	134	0	24	159	1	-	0	1
	560	Grapes	227	1,140	102	1,468	21	105	9	135
	56	Maize	662	2,353	171	3,187	5	19	1	26
	260	Olives	2,061	3,148	35	5,245	22	34	0	57
	490	Oranges	151	394	35	580	3	8	1	11
	157	Sugar Beets	-	-	-	-	-	-	-	-
	156	Sugar Cane	-	-	-	-	-	-	-	-
	495	Tang.Mand.etc	146	382	34	561	1	4	0	5
	388	Tomatoes	31	69	12	113	0	1	0	1
	15	Wheat	634	454	118	1,206	19	14	4	37
Tensift	221	Almonds	8,536	1,674	1,120	11,330	56	11	7	74
	44	Barley	3,882	0	154	4,036	1,225	-	48	1,274
	577	Dates	2,527	4,768	333	7,628	17	32	2	51
	900a	Fodder crops	376	0	24	399	34	-	2	36
	560	Grapes	327	1,093	101	1,522	4	12	1	17
	56	Maize	3,896	1,849	278	6,024	128	61	9	197
	260	Olives	3,354	1,768	46	5,167	208	110	3	321
	490	Oranges	188	350	35	573	16	30	3	48
	157	Sugar Beets	-	-	-	-	-	-	-	-
	156	Sugar Cane	-	-	-	-	-	-	-	-
	495	Tang.Mand.etc	182	339	34	554	8	14	1	23
	388	Tomatoes	41	57	12	111	5	7	1	13
	15	Wheat	2,826	254	115	3,194	536	48	22	606

Source: Mekonnen and Hoekstra (2010b)

Appendix VIII: Economic water and land productivity of crops per river basin

Period of data: 1996-2005

River basin	FAO crop code	Crop	Green plus blue water footprint (m³/ton)	Yield (ton/ha)	Average annual producer price (US$/ton)	Economic water productivity (US$/m³)	Economic land productivity (US$/ha)
Bouregreg	221	Almonds	9,618	0.43	233	0.02	100
	44	Barley	4,003	0.80	184	0.05	147
	577	Dates	4,839	1.72	1,014	0.21	1,744
	900a	Fodder crops	377	-	-	-	-
	560	Grapes	655	5.65	337	0.51	1,904
	56	Maize	6,447	0.50	209	0.03	104
	260	Olives	4,835	0.94	321	0.07	302
	490	Oranges	499	16.35	201	0.40	3,279
	157	Sugar Beets	65	50.99	33	0.51	1,706
	156	Sugar Cane	105	69.87	23	0.22	1,582
	495	Tang.Mand.etc	483	16.90	271	0.56	4,582
	388	Tomatoes	93	47.85	173	1.86	8,300
	15	Wheat	3,115	1.16	254	0.08	296
Loukkos	221	Almonds	9,295	0.57	233	0.03	132
	44	Barley	3,043	0.93	184	0.06	172
	577	Dates	4,716	1.78	1,014	0.22	1,802
	900a	Fodder crops	275	-	-	-	-
	560	Grapes	1,067	5.81	337	0.32	1,956
	56	Maize	3,178	0.58	209	0.07	121
	260	Olives	4,651	1.33	321	0.07	429
	490	Oranges	487	16.80	201	0.41	3,368
	157	Sugar Beets	101	51.01	33	0.33	1,706
	156	Sugar Cane	146	69.84	23	0.16	1,581
	495	Tang.Mand.etc	471	17.36	271	0.58	4,707
	388	Tomatoes	89	47.87	173	1.95	8,304
	15	Wheat	2,329	1.39	254	0.11	353
Moulouya	221	Almonds	9,450	0.56	233	0.02	130
	44	Barley	3,405	0.86	184	0.05	159
	577	Dates	6,640	1.78	1,014	0.15	1,805
	900a	Fodder crops	337	-	-	-	-
	560	Grapes	1,002	5.78	337	0.34	1,945
	56	Maize	1,219	0.77	209	0.17	161
	260	Olives	4,756	1.35	321	0.07	433
	490	Oranges	502	16.71	201	0.40	3,350
	157	Sugar Beets	106	51.14	33	0.31	1,711
	156	Sugar Cane	175	69.91	23	0.13	1,583
	495	Tang.Mand.etc	486	17.26	271	0.56	4,678
	388	Tomatoes	92	46.90	173	1.89	8,134
	15	Wheat	2,595	1.34	254	0.10	341

River basin	FAO crop code	Crop	Green plus blue water footprint (m³/ton)	Yield (ton/ha)	Average annual producer price (US$/ton)	Economic water productivity (US$/m³)	Economic land productivity (US$/ha)
Oum Er Rbia	221	Almonds	10,061	0.46	233	0.02	107
	44	Barley	4,054	0.79	184	0.05	145
	577	Dates	7,808	1.77	1,014	0.13	1,791
	900a	Fodder crops	388	-	-	-	-
	560	Grapes	1,547	5.81	337	0.22	1,955
	56	Maize	7,387	0.66	209	0.03	137
	260	Olives	5,063	1.14	321	0.06	366
	490	Oranges	532	16.79	201	0.38	3,367
	157	Sugar Beets	124	51.05	33	0.27	1,708
	156	Sugar Cane	-	-	23	-	-
	495	Tang.Mand.etc	515	17.36	271	0.53	4,705
	388	Tomatoes	97	47.85	173	1.78	8,300
	15	Wheat	3,168	1.26	254	0.08	321
Sebou	221	Almonds	9,712	0.52	233	0.02	122
	44	Barley	3,955	0.88	184	0.05	161
	577	Dates	6,961	1.77	1,014	0.15	1,799
	900a	Fodder crops	359	-	-	-	-
	560	Grapes	1,189	5.80	337	0.28	1,954
	56	Maize	6,549	0.73	209	0.03	153
	260	Olives	4,854	1.25	321	0.07	403
	490	Oranges	509	16.78	201	0.39	3,364
	157	Sugar Beets	114	50.96	33	0.29	1,705
	156	Sugar Cane	220	69.82	23	0.10	1,581
	495	Tang.Mand.etc	492	17.34	271	0.55	4,702
	388	Tomatoes	94	47.87	173	1.85	8,304
	15	Wheat	3,001	1.33	254	0.08	339
Souss Massa	221	Almonds	10,141	0.42	233	0.02	98
	44	Barley	2,498	1.08	184	0.07	199
	577	Dates	5,917	1.77	1,014	0.17	1,793
	900a	Fodder crops	335	-	-	-	-
	560	Grapes	1,412	5.81	337	0.24	1,955
	56	Maize	7,063	0.37	209	0.03	77
	260	Olives	5,102	1.09	321	0.06	350
	490	Oranges	535	16.78	201	0.37	3,365
	157	Sugar Beets	-	-	33	-	-
	156	Sugar Cane	-	-	23	-	-
	495	Tang.Mand.etc	517	17.34	271	0.52	4,702
	388	Tomatoes	99	47.82	173	1.76	8,295
	15	Wheat	2,908	1.03	254	0.09	262

River basin	FAO crop code	Crop	Green plus blue water footprint (m³/ton)	Yield (ton/ha)	Average annual producer price (US$/ton)	Economic water productivity (US$/m³)	Economic land productivity (US$/ha)
Sud Atlas	221	Almonds	10,309	0.59	233	0.02	138
	44	Barley	1,451	0.83	184	0.13	152
	577	Dates	4,222	1.79	1,014	0.24	1,811
	900a	Fodder crops	134	-	-	-	-
	560	Grapes	1,366	5.79	337	0.25	1,950
	56	Maize	3,015	0.88	209	0.07	184
	260	Olives	5,209	1.40	321	0.06	449
	490	Oranges	545	16.78	201	0.37	3,364
	157	Sugar Beets	-	-	33	-	-
	156	Sugar Cane	-	-	23	-	-
	495	Tang.Mand.etc	528	17.34	271	0.51	4,701
	388	Tomatoes	100	47.65	173	1.73	8,265
	15	Wheat	1,088	1.15	254	0.23	291
Tensift	221	Almonds	10,210	0.43	233	0.02	99
	44	Barley	3,882	0.76	184	0.05	139
	577	Dates	7,295	1.76	1,014	0.14	1,789
	900a	Fodder crops	376	-	-	-	-
	560	Grapes	1,420	5.80	337	0.24	1,954
	56	Maize	5,746	0.54	209	0.04	114
	260	Olives	5,122	1.08	321	0.06	347
	490	Oranges	538	16.78	201	0.37	3,366
	157	Sugar Beets	-	-	33	-	-
	156	Sugar Cane	-	-	23	-	-
	495	Tang.Mand.etc	521	17.35	271	0.52	4,704
	388	Tomatoes	98	47.84	173	1.77	8,299
	15	Wheat	3,079	1.17	254	0.08	299

Source: Water footprint and yield from Mekonnen and Hoekstra (2010b)
Producer prices from FAO (2013d)

Appendix IX: Reallocation of crop production

Period of data: 1996-2005

Input data

Harvested area (ha/yr)

	Sud Atlas	Souss Massa	Tensift	Oum Er Rbia	Boure-greg	Moulou-ya	Sebou	Loukkos	Total
Almonds	1029	6134	15250	42293	21104	7100	36069	7287	136266
Barley	30157	175491	416469	738109	206054	283397	297810	60381	2207868
Dates	898	1761	3789	10761	1984	3311	12092	2645	37240
Grapes	15941	8488	1889	6869	945	6839	5817	1820	48608
Maize	9351	6186	60246	162690	19791	838	13449	480	273031
Olives	7720	24776	57564	160838	59719	33627	138541	29257	512042
Oranges	1138	2232	5029	13746	2979	4662	17391	3566	50744
Sugar Beets	-	-	-	26333	113	2550	27864	2044	58905
Sugar Cane	-	-	-	-	1047	556	9844	3334	14781
Tang.Mand.	540	1060	2388	6528	1415	2206	8259	1694	24091
Tomatoes	172	940	2390	6802	3286	1209	5802	1141	21741
Wheat	26769	42330	161419	908866	456184	140497	1008460	129951	2874475
Total	93714	269397	726433	2083836	774620	486793	1581397	243601	6259791

Source: Mekonnen and Hoekstra (2010b)

Yield (ton/ha)

	Sud Atlas	Souss Massa	Tensift	Oum Er Rbia	Boure-greg	Moulou-ya	Sebou	Loukkos	Average
Almonds	0.59	0.42	0.43	0.46	0.43	0.56	0.52	0.57	0.48
Barley	0.83	1.08	0.76	0.79	0.80	0.86	0.88	0.93	0.83
Dates	1.79	1.77	1.76	1.77	1.72	1.78	1.77	1.78	1.77
Grapes	5.79	5.81	5.80	5.81	5.65	5.78	5.80	5.81	5.79
Maize	0.88	0.37	0.54	0.66	0.50	0.77	0.73	0.58	0.63
Olives	1.40	1.09	1.08	1.14	0.94	1.35	1.25	1.33	1.17
Oranges	16.78	16.78	16.78	16.79	16.35	16.71	16.78	16.80	16.75
Sugar Beets	-	-	-	51.05	50.99	51.14	50.96	51.01	51.01
Sugar Cane	-	-	-	-	69.87	69.91	69.82	69.84	69.83
Tang.Mand.	17.34	17.34	17.35	17.36	16.90	17.26	17.34	17.36	17.31
Tomatoes	47.65	47.82	47.84	47.85	47.85	46.90	47.87	47.87	47.80
Wheat	1.15	1.03	1.17	1.26	1.16	1.34	1.33	1.39	1.27

Source: Mekonnen and Hoekstra (2010b)

Water footprint, green plus blue (m³/ton)

	Sud Atlas	Souss Massa	Tensift	Oum Er Rbia	Boure-greg	Moulou-ya	Sebou	Loukkos	Average
Almonds	10,309	10,141	10,210	10,061	9,618	9,450	9,712	9,295	9,833
Barley	1,451	2,498	3,882	4,054	4,003	3,405	3,955	3,043	3,692
Dates	4,222	5,917	7,295	7,808	4,839	6,640	6,961	4,716	6,824
Grapes	1,366	1,412	1,420	1,547	655	1,002	1,189	1,067	1,305
Maize	3,015	7,063	5,746	7,387	6,447	1,219	6,549	3,178	6,724
Olives	5,209	5,102	5,122	5,063	4,835	4,756	4,854	4,651	4,941
Oranges	545	535	538	532	499	502	509	487	517
Sugar Beets	-	-	-	124	65	106	114	101	118
Sugar Cane	-	-	-	-	105	175	220	146	193
Tang.Mand.	528	517	521	515	483	486	492	471	501
Tomatoes	100	99	98	97	93	92	94	89	95
Wheat	1,088	2,908	3,079	3,168	3,115	2,595	3,001	2,329	3,003

Source: Mekonnen and Hoekstra (2010b)

Fraction of blue water footprint in total green plus blue water footprint (-)

	Sud Atlas	Souss Massa	Tensift	Oum Er Rbia	Boure-greg	Moulou-ya	Sebou	Loukkos	Average
Almonds	0.52	0.22	0.16	0.15	0.03	0.20	0.12	0.11	0.13
Barley	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dates	0.78	0.71	0.65	0.63	0.41	0.58	0.54	0.47	0.59
Grapes	0.83	0.80	0.77	0.73	0.69	0.68	0.63	0.60	0.76
Maize	0.78	0.05	0.32	0.53	0.20	0.22	0.51	0.04	0.47
Olives	0.60	0.42	0.35	0.31	0.10	0.33	0.24	0.22	0.28
Oranges	0.72	0.70	0.65	0.61	0.57	0.55	0.51	0.46	0.57
Sugar Beets	-	-	-	0.73	0.71	0.70	0.72	0.66	0.72
Sugar Cane	-	-	-	-	0.75	0.75	0.73	0.68	0.73
Tang.Mand.	0.72	0.70	0.65	0.61	0.57	0.55	0.51	0.46	0.57
Tomatoes	0.69	0.62	0.58	0.55	0.55	0.52	0.51	0.44	0.54
Wheat	0.42	0.01	0.08	0.11	0.01	0.11	0.09	0.03	0.08

Source: Mekonnen and Hoekstra (2010b)

Base case

Base case production (ton/yr)

	Sud Atlas	Souss Massa	Tensift	Oum Er Rbia	Boure-greg	Moulou-ya	Sebou	Loukkos	Total
Almonds	609	2574	6508	19418	9074	3962	18924	4140	65210
Barley	24913	189940	315619	581262	164643	244467	260827	56426	1838097
Dates	1603	3113	6686	19004	3412	5894	21452	4700	65864
Grapes	92300	49277	10956	39877	5344	39506	33745	10569	281574
Maize	8249	2274	32750	106810	9805	646	9858	277	170670
Olives	10792	26962	62141	183272	56165	45346	173512	39008	597197
Oranges	19091	37457	84407	230810	48713	77874	291783	59895	850030
Sugar Beets	-	-	-	1344220	5761	130415	1420080	104291	3004767
Sugar Cane	-	-	-	-	73146	38886	687318	232889	1032239
Tang.Mand.	9372	18387	41435	113303	23913	38069	143235	29402	417116
Tomatoes	8173	44955	114324	325499	157217	56714	277728	54611	1039221
Wheat	30661	43637	189649	1149090	530853	188271	1344090	180404	3656655
Total	205761	418574	864475	4112566	1088047	870050	4682552	776613	13018639

Source: Mekonnen and Hoekstra (2010b)

Base case water footprint, green plus blue (Mm^3/yr)

	Sud Atlas	Souss Massa	Tensift	Oum Er Rbia	Boure-greg	Moulou-ya	Sebou	Loukkos	Total
Almonds	6	26	66	195	87	37	184	38	641
Barley	36	475	1,225	2,356	659	832	1,032	172	6,787
Dates	7	18	49	148	17	39	149	22	449
Grapes	126	70	16	62	3	40	40	11	367
Maize	25	16	188	789	63	1	65	1	1,148
Olives	56	138	318	928	272	216	842	181	2,951
Oranges	10	20	45	123	24	39	149	29	440
Sugar Beets	0	0	0	166	0	14	162	11	353
Sugar Cane	0	0	0	0	8	7	151	34	200
Tang.Mand.	5	10	22	58	12	19	71	14	209
Tomatoes	1	4	11	32	15	5	26	5	99
Wheat	33	127	584	3,640	1,654	489	4,034	420	10,981
Total	306	903	2,525	8,498	2,813	1,737	6,905	939	24,625

Source: Mekonnen and Hoekstra (2010b)

Optimization results – Case A

Allocated production (ton/yr)

	Sud Atlas	Souss Massa	Tensift	Oum Er Rbia	Boure-greg	Moulou-ya	Sebou	Loukkos	Total
Almonds	0	0	0	0	65210	0	0	0	65210
Barley	0	291577	550524	995996	0	0	0	0	1838097
Dates	0	0	0	0	65864	0	0	0	65864
Grapes	0	0	0	0	281574	0	0	0	281574
Maize	0	0	0	0	0	170670	0	0	170670
Olives	0	0	0	0	341180	0	256018	0	597197
Oranges	0	0	0	0	850030	0	0	0	850030
Sugar Beets	0	0	0	0	3004767	0	0	0	3004767
Sugar Cane	0	0	0	0	1032239	0	0	0	1032239
Tang.Mand.	0	0	0	0	417116	0	0	0	417116
Tomatoes	0	0	0	0	1039221	0	0	0	1039221
Wheat	107340	0	0	1019953	0	355926	1835258	338178	3656655
Total	107340	291577	550524	2015949	7097201	526595	2091276	338178	13018639

Allocated land (ha/yr)

	Sud Atlas	Souss Massa	Tensift	Oum Er Rbia	Boure-greg	Moulou-ya	Sebou	Loukkos	Total
Almonds	0	0	0	0	151660	0	0	0	151660
Barley	0	269397	726433	1264754	0	0	0	0	2260584
Dates	0	0	0	0	38289	0	0	0	38289
Grapes	0	0	0	0	49810	0	0	0	49810
Maize	0	0	0	0	0	221184	0	0	221184
Olives	0	0	0	0	362767	0	204418	0	567185
Oranges	0	0	0	0	51989	0	0	0	51989
Sugar Beets	0	0	0	0	58932	0	0	0	58932
Sugar Cane	0	0	0	0	14775	0	0	0	14775
Tang.Mand.	0	0	0	0	24680	0	0	0	24680
Tomatoes	0	0	0	0	21718	0	0	0	21718
Wheat	93714	0	0	806726	0	265609	1376979	243601	2786629
Total	93714	269397	726433	2071480	774620	486793	1581397	243601	6247435
Harvested area – allocated land	0	0	0	12356	0	0	0	0	

Water footprint, green plus blue (Mm³/yr)

	Sud Atlas	Souss Massa	Tensift	Oum Er Rbia	Boure-greg	Moulou-ya	Sebou	Loukkos	Total
Almonds	0	0	0	0	627	0	0	0	627
Barley	0	728	2,137	4,037	0	0	0	0	6,903
Dates	0	0	0	0	319	0	0	0	319
Grapes	0	0	0	0	184	0	0	0	184
Maize	0	0	0	0	0	208	0	0	208
Olives	0	0	0	0	1,650	0	1,243	0	2,892
Oranges	0	0	0	0	425	0	0	0	425
Sugar Beets	0	0	0	0	196	0	0	0	196
Sugar Cane	0	0	0	0	108	0	0	0	108
Tang.Mand.	0	0	0	0	202	0	0	0	202
Tomatoes	0	0	0	0	97	0	0	0	97
Wheat	117	0	0	3,231	0	924	5,508	788	10,568
Total	117	728	2,137	7,268	3,808	1,132	6,751	788	22,729

Optimization results – Case B

Allocated production (ton/yr)

	Sud Atlas	Souss Massa	Tensift	Oum Er Rbia	Boure-greg	Moulou-ya	Sebou	Loukkos	Total
Almonds	609	2574	6508	19418	9074	3962	18924	4140	65210
Barley	0	243467	485418	1109212	0	0	0	0	1838097
Dates	1603	3113	6686	19004	3412	5894	21452	4700	65864
Grapes	92300	49277	10956	39877	5344	39506	33745	10569	281574
Maize	0	0	0	0	0	170670	0	0	170670
Olives	10792	26962	62141	183272	56165	45346	173512	39008	597197
Oranges	19091	37457	84407	230810	48713	77874	291783	59895	850030
Sugar Beets	0	0	0	0	3004767	0	0	0	3004767
Sugar Cane	0	0	0	0	73146	38886	687318	232889	1032239
Tang.Mand.	9372	18387	41435	113303	23913	38069	143235	29402	417116
Tomatoes	0	0	0	0	1039221	0	0	0	1039221
Wheat	76110	0	0	525850	703768	277800	1803810	269317	3656655
Total	209876	381236	697551	2240747	4967524	698006	3173779	649920	13018639

Allocated land (ha/yr)

	Sud Atlas	Souss Massa	Tensift	Oum Er Rbia	Boure-greg	Moulou-ya	Sebou	Loukkos	Total
Almonds	1029	6134	15250	42293	21104	7100	36069	7287	136266
Barley*	0	224946	640523	1408520	0	0	0	0	2273990
Dates	898	1761	3789	10761	1984	3311	12092	2645	37240
Grapes	15941	8488	1889	6869	945	6839	5817	1820	48608
Maize*	0	0	0	0	0	221184	0	0	221184
Olives	7720	24776	57564	160838	59719	33627	138541	29257	512042
Oranges	1138	2232	5029	13746	2979	4662	17391	3566	50744
Sugar Beets*	0	0	0	0	58932	0	0	0	58932
Sugar Cane	0	0	0	0	1047	556	9844	3334	14781
Tang.Mand.	540	1060	2388	6528	1415	2206	8259	1694	24091
Tomatoes*	0	0	0	0	21718	0	0	0	21718
Wheat*	66448	0	0	415918	604777	207308	1353385	193998	2841833
Total	93714	269397	726433	2065474	774620	486793	1581397	243601	6241429
Annuals*	66448	224946	640523	1824438	685427	428491	1353385	193998	5417657
Perennials	27266	44450	85910	241035	89193	58301	228013	49603	823771
Harvested area (annuals) – allocated land (annuals)	0	0	0	18362	0	0	0	0	

Water footprint, green plus blue (Mm³/yr)

	Sud Atlas	Souss Massa	Tensift	Oum Er Rbia	Boure-greg	Moulou-ya	Sebou	Loukkos	Total
Almonds	6	26	66	195	87	37	184	38	641
Barley	0	608	1,884	4,496	0	0	0	0	6,989
Dates	7	18	49	148	17	39	149	22	449
Grapes	126	70	16	62	3	40	40	11	367
Maize	0	0	0	0	0	208	0	0	208
Olives	56	138	318	928	272	216	842	181	2,951
Oranges	10	20	45	123	24	39	149	29	440
Sugar Beets	0	0	0	0	196	0	0	0	196
Sugar Cane	0	0	0	0	8	7	151	34	200
Tang.Mand.	5	10	22	58	12	19	71	14	209
Tomatoes	0	0	0	0	97	0	0	0	97
Wheat	83	0	0	1,666	2,192	721	5,414	627	10,703
Total	294	890	2,400	7,676	2,908	1,325	7,000	958	23,451

Appendix X: Summary of national water strategy of Morocco

This appendix contains an English summary of the action plans in the national water strategy of Morocco, originally in French (Ministry of Energy, Mining, Water and Environment of Morocco, 2011).

The national water strategy is based on three levers, namely:

1. Much more ambitious goals to meet water needs in a sustainable way, but also durable protection against the effects of global warming.
2. Radical change in behaviour (use and management of water) through coordinated demand and resource management on:
    a. Securing measures for the protection and replenishment of groundwater reserves and lakes.
    b. Rationalisation of water demand.
    c. Generalization of wastewater treatment and reuse.
    d. A diverse portfolio of innovative solutions for mobilization of water, combining all relevant local solutions with better interconnection of regions.
    e. Pro-active protection measures (of the environment and the fight against flooding).
3. Real long-term water management:
    a. National visibility on long-term water needs and availability, regularly updated and improved.
    b. Political commitment and effort from all stakeholders, supported by a regulatory framework and adapted governance.
    c. More ambitious public and private funding.

The main action plans of the national water strategy are grouped along 6 axes:

1. <u>Demand management and valorisation of water</u>

    In the agricultural sector potential (irrigation) water savings are estimated at about 2.5 Gm^3/yr by:

    a. Conversion to drip irrigation: potential of 2 Gm^3/yr with a conversion rate of 44,000 ha/yr.
    b. Improved efficiency of irrigation supply networks: potential of about 400 Mm^3/yr.
    c. Adoption of a water-pricing system based on volumes.
    d. Awareness raising and supervision of farmers for water saving techniques.

    These efforts will be particularly significant in the four major agricultural areas of Morocco: Sebou, Oum Er Rbia, Tensift and Souss-Massa.

    In the sectors of public water supply, industry and tourism potential water savings are estimated at about 120 Mm^3/yr by:

    a. Improving the efficiency of supply networks: national average of 80%.
    b. Standardization and encouragement of the use of appropriate technologies for water savings: pipes, sanitary equipment, etc..
    c. Revision of the tariff system: pricing that gives incentive for more efficient use of water and better cost recovery.
    d. Improving the efficiency of water use in industry and tourism sector and encourage the reuse of water.
    e. Taking into account best practices in water-saving in construction standards.

2. Supply management and development
   Continuation of large-scale mobilization of water by:
   a. Realisation of another 60 large dams by 2030: aimed capacity of 7 Gm^3 in total, mobilizing an additional amount of 1.7 Gm^3/yr.
   b. North-South water transfer from basins Loukkos and Sebou to Bouregreg, Oum Er Rbia and Tensift: 1st phase, 400 Mm^3/yr from Sebou; 2nd phase, 400 Mm^3/yr from Loukkos. The inter-basin connection allows flexible allocation management to cope with sudden changes in inflow of the basins.

   Small-scale mobilization of new water resources is also planned, namely:
   a. Continuation of the program of small and medium dams: realisation of 1000 small dams by 2030. These dams play an important role in local development of irrigation, livestock watering and protection against flooding.
   b. Realise pilot projects on rainwater harvesting/capturing: a pilot in a basin before potential implementation on a large-scale (as done in India and Australia).

   Plans for unconventional mobilization of water resources are:
   a. Desalinisation of seawater and demineralization of brackish water: objective is to realize a potential production of potable water of 400 Mm^3/yr. On medium term it is expected to realize facilities in Agadir and Laayoune. On long-term also in Tiznit- Sidi Ifni, Chtouka, Essaouira, Safi, El Jadida, Casablanca, Al Hoceima and Saidia.
   b. Reuse of treated wastewater: 300 Mm^3/yr of treated wastewater for reuse in irrigation of golf courses, parks and crops in some cases, as well as for artificial recharge of groundwater.

   Other supply-related plans are:
   a. Strengthening the maintenance of existing water infrastructure and interconnection systems. This allows for the diversification of supply sources and therefore more secure and substantial gains in efficiency and synergy.
   b. In rural areas, widespread access to potable water will be pursued through the upgrading of existing public systems to secure their operation and realization of individual systems for isolated and dispersed population.

3. Preservation and protection of water resources, the natural environment and sensitive areas
   The strategy proposes the following for the protection and restoration of groundwater systems:
   1. Limitation of pumping from aquifers (revision of the pricing system, downward revision of allowed withdrawal thresholds for overexploited aquifers, cancel subsidies that provide incentive for overexploitation, areas of prohibited or restricted pumping, efficient techniques, establishment of a drilling permit).
   2. Reinforcement of the control and sanction system for overexploitation, particularly by reinforcing the water police and encouraging satellite monitoring and aerial surveillance.
   3. Reinforcement of the responsibility of the river basin agencies in management of aquifers and generalisation of aquifer contracts:
      a. Systematic use of alternative, conventional and unconventional, water resources to relieve pressure on groundwater resources.
      b. Programs of artificial groundwater recharge: storage of 180 Mm^3/yr.
      c. Reinjection of treated wastewater to coastal aquifers used for irrigation (100 Mm^3 by 2030).
      d. Substitution of groundwater by surface water as a source for water withdrawal by ONEP (drinking water service) (90 Mm^3 by 2030).

The strategy aims to prevent pollution and fight against it by:

1. Acceleration of the implementation of the national program of sanitation and wastewater treatment: target access level to sanitation of 90% by 2030.
2. Establishment of a national program for rural sanitation: target access level to sanitation of 90% by 2030.
3. Development of a national program of prevention and fight against industrial pollution.
4. Establishment of a national management plan for domestic and similar waste.

Protection of fragile wetlands, natural lakes, oases and the coast by:

1. Protection of watersheds upstream of dams against erosion.
2. A protection program for springs.
3. A protection program for wetlands and natural lakes.
4. Preservation of oases and the fight against desertification.
5. Protection of the coast.
6. Limitation and control of pumping from aquifers that directly affect natural lakes.
7. Improving the supply to lakes by diversion of rivers and development of thresholds and small dams upstream.

4. <u>Reduction of vulnerability to natural hazards related to water and climate change adaptation</u>
   Improving the protection of people and property against flooding by:
   1. Completion of the measures included in the national plan for protection against inundations: target of 20 protected sites per year.
   2. Incorporation of the inundation risk in spatial, urban and watershed planning.
   3. Improving knowledge in the fields of weather forecasting and urban hydrology.
   4. Development of flood warning systems and emergency plans.
   5. Development of financial mechanisms (insurance and natural disaster funds).

   Drought management plans at the river basin level, which aim for:
   1. Characterization of drought: identification and proposal of monitoring indicators.
   2. Implementation of structural measures: diversification of water supply sources.
   3. Elaboration of emergency plans.
   4. Development of financial mechanisms such as insurance and natural disasters funds.

5. <u>Further regulatory and institutional reforms</u>
   Proposed further regulatory and institutional reforms, supplementing the advances made after the establishment of the Water Law 10-95 in 1995, are:
   1. Completion of the legal framework necessary for the implementation of all provisions of Law 10-95, related to:
      a. Prevention of and fight against flooding.
      b. Declaration of the state of water scarcity and management during periods of drought.
      c. Implementation of the principle “the polluter pays”.
   2. Review of the Water Law and its implementation regulations to incorporate the domains it does not cover, namely:
      a. Wastewater discharges in sea.
      b. Desalination of sea water.
      c. Water conservation.

6. Modernisation of information systems and capacity building
   To support the implementation of the national water strategy, parallel development of human and material resources in the water sector by the administration should aim at:
    1. Modernisation of the administration and the development of information systems, particularly the implementation of a water information system for professionals and the public.
    2. Modernisation of the network of measures.
    3. Reinforcement of research and development.
    4. Capacity building.