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María BLANCO
Benjamin VAN DOORSLAER
Wolfgang BRITZ
Peter WITZKE

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Contact information
Benjamin Van Doorslaer
Address: Joint Research Centre, Edificio Expo, c/ Inca Garcilaso 3, E-41092 Sevilla, Spain
E-mail: benjamin.van-doorslaer@ec.europa.eu
Tel.: +34 954488318
Fax: +34 954488300

http://ipts.jrc.ec.europa.eu/
http://www.jrc.ec.europa.eu/

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Authors of this report and contact details

Authors: María Blanco (UPM), Benjamin Van Doorslaer (IPTS), Wolfgang Britz (UBO), Peter Witzke (EuroCARE)

Contact: María Blanco

Institution: Technical University of Madrid (UPM)

Address: Department of Agricultural Economics
ETSI Agrónomos
Avda. Complutense s/n, 28040 Madrid, Spain

Email: maria.blanco@upm.es

Contact: Benjamin Van Doorslaer

Institution: Institute for Prospective Technological Studies (IPTS)

Address: c/ Inca Garcilaso 3
41092 Sevilla, Spain

Email: benjamin.van-doorslaer@ec.europa.eu

Contact: Wolfgang Britz

Institution: University of Bonn (UBO)

Address: Institute for Food and Resource Economics
Faculty of Agriculture
Nußallee 21, 53115 Bonn, Germany

Email: wolfgang.britz@ilr.uni-bonn.de

Contact: Heinz-Peter Witzke

Institution: EuroCARE GmbH

Address: Rheinallee 56
53179 Bonn, Germany

Email: peter.witzke@eurocare-bonn.de

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Executive summary

Although numerous modelling efforts have integrated food and water considerations at the farm or river basin level, very few agro-economic models are able to jointly assess water and food policies at the global level. The present report explores the feasibility of integrating water considerations into the CAPRI model.

First, a literature review of modelling approaches integrating food and water issues has been conducted. Because of their capability to assess the impacts of water and food policies at the global level, three agro-economic models (IMPACT, WATERSIM and GLOBIOM) have been analysed in detail. These models handle water supply and demand issues quite differently. GLOBIOM shows a high flexibility to incorporate crop-water relationships but focuses on agricultural water and uses a rough proxy to account for competition between agricultural and non-agricultural water use. In contrast, IMPACT and WATERSIM show less flexibility to model crop-water links; however, as these models integrate a global food model and a global water model, they encompass constraints on water availability at the river basin level, interregional water flows and competition between agricultural and non-agricultural water use. In addition, biophysical and hydrological models estimating agricultural water use have also been studied, in particular the global hydrological model WATERGAP and the LISFLOOD model.

Second, the potentiality of CAPRI to model water has been assessed. Thanks to the programming approach of its supply module, CAPRI shows a high potentiality to integrate environmental indicators as well as to enter new resource constraints (land potentially irrigated, irrigation water) and input-output relationships. At least in theory, the activity-based approach of the regional programming model in CAPRI allows differentiating between rainfed and irrigated activities.

In practice, however, CAPRI is a complex model build upon a large and consistent database, with data series dating from the early 1980s. Since no distinction is made in the CAPRI database between rainfed and irrigated crops, building an irrigation module implies a great bulk of data work. Furthermore, data on irrigation water use and crop-water relationships are mostly unavailable in official datasets or only available at non-administrative spatial scales, adding difficulties to their integration in agro-economic models. Regarding sectoral water use, although a consistent scheme to collect data exists at EU level, the published datasets are often incomplete.

The suggested approach to include water into the CAPRI model involves creating an irrigation module and a water use module. The development of the CAPRI water

module will enable to provide scientific assessment on agricultural water use within the EU and to analyse agricultural pressures on water resources.

The feasibility of the approach has been tested in a pilot case study including two NUTS 2 regions (Andalucia in Spain and Midi-Pyrenées in France); its choice having been mainly motivated by data availability. Preliminary results are presented, highlighting the interrelations between water and agricultural developments in Europe.

As a next step, it is foreseen to further develop the CAPRI water module to account for competition between agricultural and non-agricultural water use. This will imply building a water use sub-module to compute water use balances.

Abbreviations and Acronyms

AGLINK	Worldwide Agribusiness Linkage Program
AGMEMOD	Agricultural Member State Modelling for the EU and Eastern European Countries
CAPRI	Common Agricultural Policy Regional Impact Analysis
CROPWAT	Computer Program for Irrigation Planning and Management, FAO, Land and Water Development Division
ESIM	European Simulation Model
EU-FASOM	EUropean Forest and Agricultural Optimisation Model
GAEZ	Global agro-ecological zones
FAO	Food and Agriculture Organization of the United Nations
FASOM	Forest and Agricultural Sector Optimization Model
GCWM	Global Crop Water Model
GLOBIOM	Global Biomass Optimization Model
GSWP2	Global Soil Wetness Project
GTAP-W	Global Trade Analysis Project-Water
IFPRI	Food Policy Research Institute
IIASA	International Institute for Applied Systems Analysis
iMAP	Integrated Modelling Platform for Agro-economic Commodity and Policy Analysis
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
IPCC	Intergovernmental Panel on Climate Change (WMO/UNEP)
JRC-IES	EC Joint Research Centre - Institute for Environmental Studies
JRC-IPTS	EC Joint Research Centre - Institute for Prospective and Technological Studies
NUTS	Nomenclature of Units For Territorial Statistics
OECD	Organisation for Economic Co-operation and Development
SWAP	Statewide Agricultural Production Model
UNEP	United Nations Environment Programme
WATERGAP	Water – Global Assessment and Prognosis
WATERSIM	Water, Agriculture, Technology, Environment and Resources Simulation Model

1. Introduction

Water is vital for agriculture and thus food security. Also, significant impacts on water resources are caused by agricultural activities. As stated by a number of authors, more effort is required to analyse the challenges faced by agriculture, and the range of policies, institutions and investments needed to secure adequate access to water for food today and in the future (Rosegrant et al. 2009).

In Europe, irrigation water use by agriculture has been identified as one of the major sustainable water management issues in the implementation of the Water Framework Directive (European Commission 2000). Agriculture accounts for an estimated 24% of total water abstraction in Europe, although in parts of southern Europe this figure can reach up to 80% (EEA 2009). Moreover, unlike other sectors like energy production, the majority of the water abstracted for agriculture is consumed (evaporation, transpiration, loses) and hence not returned to the water bodies (70% according to the EEA).

Since 1985, the area of irrigated land in southern Europe has increased by 20%, contributing to the fact that the balance between water demand and availability has reached a critical level in many irrigated areas of Europe. But concerns about water scarcity and drought are not longer limited to the Mediterranean. In addition, more and more areas are adversely affected by changes in the hydrological cycle and climate change will almost certainly exacerbate these adverse impacts in the future, with more frequent and severe droughts expected across Europe and the neighbouring countries (Ciscar 2009, IPCC 2012).

The Commission Communication on the Common Agricultural Policy towards 2020 (European Commission 2010a), while acknowledging agriculture's contribution to a greater resilience to flooding and drought, also recognised negative environmental externalities of farming such as soil depletion, water shortages, pollution, and loss of biodiversity. In order to strengthen a more sustainable agricultural water use, it proposes to include the Water Framework Directive (WFD) into cross-compliance for the Common Agricultural Policy (CAP) so that a farmer non-compliant with the WFD would lose part of the CAP subsidies.

In order to analyse agricultural water use and its relation with the CAP, other policies or market developments, water issues need to be covered in tools used for policy impact assessment. The strong linkages between water, food, and environment call for an integrated and multidisciplinary modelling approach.

Extensive work has been done on integrated assessment of water and food related policies, but most of these studies are site specific and analyse policy impacts at the farm or irrigation district level (Blanco and Iglesias 2005, Bazzani 2005). Some of these studies use a bio-economic framework, which combines economic and bio-physical modelling. For instance, Moore et al. (2011) develop a modelling system that integrates two biophysical models and a whole-farm economic model to assess the sustainability of alternative farming systems in Australia. However, as these studies remain at the farm or regional level, feedbacks through market prices and water flows across modelling units are lacking.

At the global level, very few agro-economic models deal with water issues. A few exceptions exist, which will be reviewed in section three of this report. While global coverage entails a lot of simplifying assumptions, there are compelling arguments to choose a global level framework:

- Markets for agricultural and derived products are globally highly integrated while at the same time trade and domestic support policies affecting agriculture are developed in the context of bi- and multilateral agreements and negotiations.
- Key bio-physical processes and concerns are of global or at least supra-national nature such as climate change, hydrological cycles or biodiversity concerns.

Within Europe, as a rule, the policy support tools currently used for ex ante assessment of EU policies do not take into account water constraints. This is the case with agro-economic models representing the agricultural sector like AGLINK (OECD 2006), ESIM (Banse et al. 2005), CAPRI (Britz and Witzke, 2008) and AGMEMOD (AGMEMOD Partnership 2007), as well as with integrated decision support tools focusing at broader issues like EURURALIS (WUR/MNP 2007), SENSOR SIAT (Sieber et al. 2008) and LUMOCAP (Van Delden et al. 2010).

Therefore, a study was commissioned within the iMAP[1] framework, in order to explore the feasibility of integrating water issues into the CAPRI model, proposing an approach to model agricultural water use and testing the suggested approach for a particular case study. In a previous attempt to include water indicators in CAPRI, crop-specific water balances were included as passive environmental indicators. Here, we investigate the possibility of expanding the CAPRI model with a module for irrigated agriculture, in which irrigation water will be treated as endogenous in the model.

The set-up of this report is as follows: section two gives definitions and describes the water concepts used in this report. A review of past work on integrating water into agro-economic models is presented in section three. Section four discusses the potential approaches that could be used to include water into CAPRI. The suggested approach to include water into the CAPRI model is depicted in sections five and six and tested for a particular case study in section seven. Lastly, section eight discusses the limitations of the approach and suggests future advancement pathways.

[1] iMAP, "An integrated Modelling Platform for Agro-economic commodity and Policy analysis – a look back and the way forward" (2012), EUR25267

2. Concepts and terminology

The water concepts and terminology used in this report follow as close as possible the terminology used in official water statistics and, in particular, the EUROSTAT, FAOSTAT and OECD data sources. However, since some discrepancies exist across data sources, hereafter we clarify the terminology adopted in this report.

At the global level, the *water cycle* - also known as the hydrological cycle - describes the continuous circulation of water within the Earth's hydrosphere, mainly driven by solar radiation. Water moves through the cycle by the physical processes of precipitation, evaporation, transpiration, infiltration, runoff, and subsurface flow. Human activities also greatly affect the individual components of the hydrological cycle, through actions such as water abstraction from ground and surface waters.

At national or regional level, computing water resources requires to make a distinction between internal and total renewable water resources[2]. *Internal renewable water resources* (IRWR) refer to the water resources resulting from precipitation within the borders of the region and are a combination of surface water and groundwater. *Total renewable water resources* (TRWR) are obtained by adding incoming surface water and groundwater flows to the internal renewable water resources.

The internal water resources figures are the only quantities that can be added together for regional or continental assessment. The computation of total renewable water resources requires the assessment of interregional water flows. By definition, total water resources are not additive at the MS or EU level.

Water use balance refers to the influence of human activities on the water cycle. Here, a distinction is made between water withdrawal and water use. Also, the following conventions for water-user sectors will be used in this report:

- Domestic: water use of households and other municipal water uses.
- Industrial: water used in the manufacturing, mining and electricity generation sectors.
- Irrigation: water used by irrigation.
- Livestock: water used by livestock.

Water withdrawal is the gross amount of water extracted from any source, either permanently or temporarily, for use in any sector (irrigation, livestock, industrial

[2] The term “renewable” here is used as opposed to fossil waters, which have a negligible rate of recharge on the human scale and can thus be considered “non-renewable”.

and domestic). Water withdrawal is sometimes also called water abstraction. It can be either diverted towards distribution networks or directly used. It includes consumptive use, conveyance losses[3] and return flow.

Water use is the amount of water used in any sector. It is the part of the water withdrawn that reaches the final user. In turn water use is split into consumptive water use and non-consumptive water use.

Consumptive water use is the part of the water lost to the immediate water environment through evaporation, plant transpiration, incorporation in products or crops, or consumption by humans and livestock. Water consumption is sometimes called water depletion.

The difference between total water use and consumptive water use is the non-consumptive water use, or return flow, the part of the water that is not consumed and returns to either the surface water or the groundwater, and thus becomes available for use again. For most water use sectors, only a small amount of water is actually consumed, whereas most of the water withdrawn is returned, probably with reduced quality, to the environment for subsequent use.

Water-use efficiency is the ratio of consumptive water use to water withdrawal. Efficiency may be measured at different spatial scales, and figures may differ because of water reuse throughout the water cycle. In irrigation, we will define water use efficiency as the ratio of the consumptive water to the water abstracted for irrigation. Water use efficiency may be broken down into water distribution efficiency (ratio of total water delivered to the total water diverted for irrigation; sometimes differentiated into conveyance efficiency and distribution channels efficiency) and water application efficiency (ratio of the effective irrigation water evapotranspirated to the field water applied, driven mainly by the irrigation method used).

Water stress measures the pressure put on water resources and aquatic ecosystems by the users of these resources. A conventional measure of water stress is the withdrawal-to availability ratio. This is the ratio of total annual water withdrawals to total water availability.

Crop water requirement, irrigation requirement, irrigation water use and irrigation water abstraction are often used synonymously or without clear

[3] Loss includes water that is lost to the supply, at the point of measurement, from a non-productive use, including evaporation from surface-water bodies and non-recoverable deep percolation.

distinction. To avoid confusion, the terminology used in this study is presented hereafter.

Crop water requirement (CWR) is the total amount of water required for transpiration by a well managed crop grown under optimum growth conditions without water- and nutrient-stress. For practical purposes, the CWR is calculated as the potential crop evapotranspiration (PET) avoiding the problem of clearly defining optimum growth conditions and optimum crop yield (FAO 1996).

Net irrigation requirement (NIR) is the amount of water that has to be applied in addition to rainfall to serve crop water requirements. It is expressed in millimetres per year or in m3/ha per year (1 mm = 10 m3/ha). NIR is commonly determined as the difference between CWR (i.e. potential crop evapotranspiration) and the actual crop evapotranspiration under rainfed conditions or effective precipitation (EP)[4].

Gross irrigation requirement (GIR) is the quantity of water to be applied to the field, taking into account water losses at the field level. Part of irrigation water may be lost by percolation rather than by crop evapotranspiration. Therefore it can potentially be reused for irrigation or recharge other water bodies.

Gross irrigation requirement constitute only a part of the total water abstracted for irrigation purposes. Additional water abstraction results from the need to compensate for losses during transport (infiltration and percolation or evaporation).

Another common classification of water resources is the classification into blue and green water flows. *Blue water* refers to water in rivers, lakes and groundwater. *Green water* refers to water in the rooted zone of the soil originating directly from rainfall that is available to plants. According to this classification, crop evapotranspiration originating from effective precipitation is also referred to as green water or soil water. The part of crop water requirements met by irrigation water is called blue water.

In agriculture, *potential yield* is defined as the maximum yield a variety can achieve under no input restriction conditions.

Crop water productivity is the ratio of net benefits from crop production to the amount of water used. Physical water productivity is the crop output per unit of

[4] In irrigation, effective precipitation is that portion of the total precipitation which is retained by the soil so that it is available for use for crop production.

water used (often expressed in kg/m3), while economic water productivity is defined as the value derived per unit of water used. Water productivity can be expressed either per unit of water used or per unit of water consumed. Economic water productivity per unit of water use will be retained in this study.

3. Previous work on agricultural water modelling

3.1. Introduction

In this section, we review the agro-economic models dealing with water with the final aim of exploring the feasibility of integrating water considerations into the CAPRI model. Hence, this is not a comprehensive review of food-water modelling systems; on the contrary, the selection of models is based on the potential to apply the methodology in the framework of the CAPRI model. Therefore, priority is given to models with global coverage and relevant for assessing EU policies as well as to global and EU-wide hydrological models estimating agricultural water demand.

The focus will be on global agro-economic models dealing with water issues. Global coverage entails a lot of simplifying assumptions (regional and sectoral aggregation, limited data, etc.). Yet, there are compelling arguments to choose a global level framework: 1) some economic processes are global (i.e. impact of world market prices, trade policies); 2) some physical processes are of global nature (i.e. climate change, hydrological cycles).

Conventional water demand and supply projections usually do not sufficiently account for economic processes and feedback mechanisms, or do so only implicitly. The IMPACT model, developed by the International Food Policy Research Institute (IFPRI) was one of the first global models to integrate a global food projections model with a global water model to jointly analyze water and food supply and demand into the future under various policy scenarios (Cai and Rosegrant 2002).

Developed under a common initiative of IFPRI and IWMI (International Water Management Institute), the WATERSIM modelling framework enables a more disaggregated and comprehensive analysis of the future world food and water situations (De Fraiture 2007). WATERSIM takes the global food model from IMPACT and links it to a water balance approach at the river basin level.

More recently, GLOBIOM, an agricultural and forest sectors model developed at IIASA, has also integrated water considerations.

3.2. Water modelling in global agro-economic models

3.2.1. Water representation in the IMPACT model

The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) is a partial equilibrium agricultural sector model developed at the Food Policy Research Institute (IFPRI) in the early 1990s as a response to a lack of long-term vision and consensus among policy makers and researchers regarding the actions required to feed the world in the future and protect the environment (Rosegrant et al. 1995). In 1995 the first results using IMPACT were published as a 2020 Vision discussion paper (Rosegrant et al. 1995), in which the effects of population, investment, and trade scenarios on food security were analysed. Recognizing that water could be one of the major constraints to future food production, the IMPACT model was extended in 2002 and combined with a newly developed Water Simulation Model (WSM) that balances water availability and uses within various economic sectors, at the global and regional scale (Rosegrant et al. 2002).

Table 1. Main characteristics of the IMPACT modelling system

Approach	Global recursive-dynamic partial equilibrium agricultural model
Responsibility	Food Policy Research Institute (IFPRI)
Spatial scope	Global coverage 115 socio-economic units (food module) intersected with 126 hydrological units (water module) A total of 281 food producing units, including EU-15 and eastern Europe
Temporal scope	Long-term projections (usually 30-year projections), with annual time steps Base year: 2000 Projections to 2020/2025/2050, depending on the study
Sectoral scope	Agricultural and fisheries sectors 40 crop activities 16 livestock, sugar, fruit and vegetables and fish activities
Model type	Integrated model (food module and water module)
Input (key drivers)	Income and population growth (to determine food and non-agricultural water demand) Crop productivity Change in available agricultural area over time Climate parameters and water supply information Trade policies
Output (key variables)	Crop area and livestock numbers, yield, production Demand for food, feed and other uses, Prices and net trade Percentage and number of malnourished preschool children Per-capita calorie availability from foods
Software	GAMS

IMPACT-Water[5] – through the combination of the IMPACT and WSM models – incorporates water availability as a driving variable with observable flows and storage to examine the impact of water availability on food supply, demand and prices. This framework allows exploration of the relationship between water availability and food demand at a variety of spatial scales, ranging from river basins, countries and more aggregated regions, to the global level (Rosegrant et al. 2008). A further update of IMPACT in 2006 included much greater spatial

5 As IMPACT-Water has become the common version of the IMPACT model, we will use the term IMPACT from now on.

disaggregation to 281 Food Producing Units (FPUs) and improved the connection between the food and water simulation components.

The combined food-water modelling framework has been used to analyse water availability, food security, and environmental conservation at basin, country, and global scales (Sulser et al. 2010).

The model incorporates data from FAOSTAT (FAO, 2003); commodity, income, and population data and projections from the World Bank (2000), the Millennium Ecosystem Assessment (UNEP 2005), the UN (2000) and USDA (2000); and a system of supply and demand elasticities from literature reviews and expert estimates (Rosegrant et al. 2001).

In the food module, water stress is taken into account in the area and yield response functions:

- Crop area function: Harvested area is specified as a response to the crop's own price, the prices of other competing crops, the projected exogenous trend in harvested area (capturing non-prices effects such as population pressure and soil degradation), and a water stress factor. Water is integrated in crop area functions through the term "reduction of crop area", which captures the effects of extreme water shortages on the crop area decisions.
- Crop yield function: Yield is a function of the commodity price, the prices of labour and capital, a projected exogenous trend factor and a water stress factor. The trend factor reflects productivity growth driven by technology improvements. Water is integrated through a reduction of yield factor, based on seasonal water availability.

The level of irrigation investment is externally determined (Nelson et al. 2009) and irrigation investment costs are taken from the literature.

The water module divides the world in 126 river basins, to allow for a representation of water supply and demand at the hydrological level. The 115 socio-economic regional units of the food module are intersected with the 126 river basins, generating results for 281 Food Producing Units (FPUs). Of the countries represented within the IMPACT model, China, India and the United States have the highest level of sub-national disaggregation (and are divided into 9, 13 and 14 major river basins, respectively), while the other countries or regions covered by the model are combined into the remaining 90 basins (Rosegrant et al. 2008).

Water supply and demand are determined for each food producing unit (FPU):

- Water demands are simulated as functions of year-to-year hydrologic fluctuations, irrigation development, growth of industrial and domestic water uses, and environmental and other flow requirements (committed flow).
- Off-stream water supply for the domestic, industrial, livestock, and irrigation sectors is determined based on water allocation priorities, treating irrigation water as a residual. Environmental flows are included as constraints.

Water demand is accounted for major water uses:

- Irrigation water demand is computed based on hydrologic and agronomic characteristics:
    - Net crop water requirements (NCWR) in a basin are calculated based on empirical crop water requirement functions.
    - Part or all of crop water demand can be satisfied by effective rainfall (PE), which is the rainfall infiltrated into the root zone and available for crop use. Effective rainfall for crop growth can be increased through rainfall harvesting technology. Net crop water demand (NCWD) takes into account effective rainfall use.
    - Total irrigation water demand represented in water depletion (CWD) is calculated as net irrigation water demand divided by basin efficiency (BE). BE measures the ratio of beneficial water depletion (crop evapotranspiration and salt leaching) to the total irrigation water depletion at the river basin scale.
    - The projection of irrigation water demand depends on the changes of irrigated area and cropping patterns, water use efficiency, and rainfall harvest technology.
- Livestock water demand (*LWD*) in the base year is estimated based on livestock numbers and water consumptive use per unit of livestock. For all of the livestock products it is assumed that the projection of livestock water demand in each basin, country, or region follows the same growth rate of livestock production.
- Industrial water demand (IWD) depends on income and water use technology improvement. A linear relationship between industrial water demand intensity (IWDI) and GDP per capita is estimated by regression based on historical records and adjusted according to future perspectives on industrial water demand in different regions and countries.
- Domestic water demand (DWD) in the base year is estimated based on the same sources and methods as those used for industrial water demand

assessment. Domestic water demands in future years are projected based on projections of population and income growth.

- Committed Flow for Environmental, Ecological, and Navigational Uses (EWD) is specified as a percentage of average annual runoff. Data is lacking on this variable for most basins and countries, so an iterative procedure is used to specify this variable where data is lacking.

The total demand for water withdrawal (TWW) is calculated as total water depletion demand (TWD) divided by the water depletion coefficient (DC):

$$TWW = \frac{TWD}{DC} = \frac{CWD + LWD + IWD + DWD}{DC}$$

The value of the water depletion coefficient in the context of the river basin mainly depends on the relative fraction of agricultural and non-agricultural water use (that is, larger agricultural water use corresponds to a higher value of water depletion coefficient), as well as water conveyance/distribution/recycling systems and pollution discharge and treatment facilities. In the base year, DC is calculated by given water depletion and water withdrawal, and in the future is projected as a function of the fraction of non-irrigation water use.

To account for the price impact on water demand, a classic Cobb-Douglas function is used to specify the relationship between water demand (W) and water price (P), based on price elasticity.

Water supply is determined for each spatial unit:

- Minimum environmental and ecological flow requirements enter the model as a predetermined constraint in water supply
- Off-stream water supply for domestic, industrial, livestock, and irrigation sectors is determined in two steps:
  - First, the total water supply represented as depletion/consumption (WDP) in each month of a year is determined.
  - Second, total water supply is allocated to different sectors. Irrigation water supply is further allocated to different crops in the basin.

For each FPU, the model simulates annually and seasonally how water supply meets demand with long-term monthly climatology and hydrology, projected water infrastructure capacities, and projected water demands of domestic, industrial, livestock and irrigation sectors based on drivers including population and income growth, changes of irrigated areas and cropping patterns, and improvement of water use efficiencies (Sulser et al. 2010).

For large river basins that include multiple FPUs, sub-models for FPUs within the same basin are coupled through upstream–downstream water routing. With these capacities, the model can take into account precipitation, evapotranspiration (ET), runoff, water use efficiency, flow regulation through reservoir and groundwater storage, non-agricultural water demand, water supply infrastructure and withdrawal capacity, and environmental requirements at the river basin, country, and regional levels (Sulser et al. 2010).

The food and water modules are solved in an iterative way (see Figure 1). First, for each year, the food module determines crop area harvested and crop yields assuming that there is no water shortage. Then, the water module calculates effective irrigation water supply in each basin by crop and by period over a 30-year time horizon. The results from the water module are then incorporated in the food module and crop areas and yields are adjusted accordingly (through the area and yield correction factors). In addition, net food trade and the global balance are calculated. If the trade balance is not closed, crop world prices are adjusted and a new iteration is undertaken. The loop stops when global net trade equals zero (Rosegrant et al. 2008).

3.2.2. WATERSIM as a variant of IMPACT

WATERSIM (Water, Agriculture, Technology, Environment and Resources Simulation Model) is a global scale model jointly developed by IFPRI and IWMI and designed to explore the impact of water and food related policies on water scarcity, food production, and environment.

WATERSIM is a recursive dynamic model consisting of two fully integrated modules: a food production and demand module based on a partial equilibrium model (IMPACT), and a water supply and demand module based on a water balance and accounting framework (De Fraiture et al. 2007).

The spatial scale differs between the food and water modules:

- To capture food economic phenomena, the world is divided into 115 socio-economic units (i.e., countries and country groups). The food module runs at the regional level.
- To capture hydrologic processes, the world is divided 128 hydrological units. The water module runs at the river basin level.
- To account for the interaction between food and water modules, the model includes 282 hybrid units (Food Producing Units, FPU) by intersecting regions and basins.

Table 2. Main characteristics of the WATERSIM modelling system

Approach	Global recursive-dynamic partial equilibrium agricultural model
Responsibility	Food Policy Research Institute (IFPRI) and International Water Management Institute (IWMI)
Spatial scope	Global coverage 115 socio-economic units (food module) 128 hydrological units (water module) 282 food producing units (FPU), intersecting regions and basins
Temporal scope	Long-term projections, with annual time steps Base year: 2000 Last year: 2025 and 2050
Sectoral scope	Agricultural sector 40 crop activities 16 livestock, sugar, fruit and vegetables and fish activities
Methodology	Bio-economic framework Food module based on IMPACT Water module based on water balances at the river basin level
Software	GAMS

The food demand and supply module of WATERSIM is based on the IMPACT model (Rosegrant et al. 2008). Food production is function of productivity growth and area expansion:

- Productivity growth is modelled as a function of the exploitable yield gap (De Fraiture and Wichelns 2010). The estimates of maximum attainable yields are from the Global Agro Ecological Zones (GAEZ) methodology (Fischer et al. 2002, Bruinsma 2003), which uses physical and crop management factors to establish maximum levels of productivity on a grid-cell basis.
- The potential for crop area expansion is determined using GAEZ land suitability classes, assuming that expansion is limited to lands in classes 'suitable' and 'very suitable' for agriculture (De Fraiture and Wichelns 2010).

The water supply and demand module is based on water balances at the river basin level (or sub-basin level), based on the water accounting concepts developed by Molden (1997):

- Water demand for human purposes, besides environmental and in-stream purposes, is derived from four sectors (agriculture, domestic sector, industry and livestock). At sub-basin level, water availability is simulated using a water balance approach, considering internally generated runoff, inflow from other units, groundwater contributions existing infrastructure and management practices (De Fraiture 2007).
- Supply is matched to demand adopting an optimization approach, based on a traditional reservoir operation model (described in Cai and Rosegrant 2002) with the objective to maximize the ratio of depletive supply over demand.

- Sub-basins are connected in such a way that outflow from upstream becomes inflow into the lower sub-basin. When water supply falls short of demand, the shortages are distributed over months, sectors and crops using an optimization model and allocation rules. For most countries practice shows that the industrial and domestic sectors take preference over agriculture.

The allocation of irrigation water to crops is based on the profitability of the crop, sensitivity to water stress and net irrigation demand. Higher priority is given to crops with higher profitability, higher drought sensitivity and higher irrigation water requirements (De Fraiture 2007).

Water shortages lead to reductions in productivity and smaller harvested areas (De Fraiture et al 2011). Data are derived from the IWMI Water and Climate Atlas (http://www.iwmi.cgiar.org/WAtlas/), Mitchell et al. (2004) and AQUASTAT database (http://www.fao.org/nr/water/aquastat/main/indexesp.stm). Runoff is computed using the global hydrologic model WaterGap (Alcamo et al. 1997).

The model computes total food production, the area under rainfed and irrigated conditions, water diversions to agriculture and crop water consumption at the basin and national scales (De Fraiture 2007).

Feedback mechanisms between the water and food modules are an important feature of the WATERSIM model. For example, water shortage may lead to a reduction in food production. But this in turn leads to higher food prices, inducing a higher production in the next season and thus partly offsetting food shortage. Another example: higher food demand lead to higher water demand. But increased water demand may provide an incentive to improve water use efficiency (if feasible), thus offsetting part of the increased demand (De Fraiture et al. 2007).

The basic assumption in the food module is that each year the world market for agricultural commodities clears. The water module is based on a water balance approach, i.e. inflow equals outflow plus change in basin storage. Both modules are connected through two variables: (1) agricultural area, which determines food supply and water demand; (2) crop price which determines food demand and crop profitability which in turn affects water allocation. In a first step, the food module estimates food production (area and yield) as a function of socio-economic driving forces. Then, the water module calculates irrigation water supply and, when water availability limits agricultural production, the model accounts for the effects of water stress through a reduction factor for area and yields, in both irrigated and rain fed agriculture. Updated areas and yields are then fed back into the food module and the market equilibrium recalculated. The model iterates between the water and food modules until market equilibrium and water balance is reached (De Fraiture 2007).

3.2.3. Water modelling in GLOBIOM

The Global Biomass Optimization Model (GLOBIOM) is a mathematical programming-based global recursive dynamic partial equilibrium model integrating the agricultural, bio-energy, and forestry sectors[6] (Sauer et al. 2010).

The general concept and structure of GLOBIOM is similar to the US Agricultural Sector and Mitigation of Greenhouse Gas (ASMGHG) model (Schneider et al. 2007).

Table 3. Main characteristics of the GLOBIOM modelling system

Approach	Global recursive-dynamic partial equilibrium agricultural model
Responsibility	International Institute for Applied Systems Analysis (IIASA)
Spatial scope	Global coverage 28 world regions for commodity markets geo-spatially explicit simulation units (SimU) for supply depiction
Temporal scope	Medium and long-term projections, with annual time steps Base year: 2000 Last year: 2030
Sectoral scope	Agricultural and forest sectors 40 crop activities 16 livestock, sugar, fruit and vegetables and fish activities
Methodology	Bio-economic framework Food module based on IMPACT Water module based on water balances at the river basin level
Software	GAMS

The objective function of GLOBIOM simulates the global agricultural and forest market equilibrium by maximizing economic surplus over all included regions and commodities subject to restrictions on resource endowments, technologies, and policies (Schneider et al. 2011).

GLOBIOM is a bottom-up model with a detailed representation of the supply side. The model explicitly depicts factor endowments in each region for (a) agricultural, forest, and other natural lands and (b) land suitable for irrigation.

Irrigation water supply is depicted as constant elasticity, upward sloped function. The price elasticity of water supply is based on estimations by Darwin et al. (1995) and equals 0.3 for all regions (Schneider et al. 2011).

[6] Data, concept and mathematical structure of this model are described in Havlík et al. (2011) and at www.globiom.org.

Crop production parameters are obtained from international sources and through linkage to biophysical models:

- The average yield level for each crop in each country is taken from FAOSTAT (FAO 2007a). For 17 crops - representing nearly 80% of harvested area in 2007 as reported by FAO - fertilization and irrigation management specific yields are simulated with the biophysical model EPIC (Environmental Policy/Integrated Climate) (Williams 1995) at the level of SimUs.
- These yields are calibrated such that the area weighted average yield aggregated over all observed management options in a country equals the reported yield from FAO.
- Four management systems are considered (irrigated, high input–rain-fed, low input–rain-fed, and subsistence management systems) corresponding to the International Food and Policy Research Institute (IFPRI) crop distribution data classification (You and Wood, 2006).
- The costs and technical restrictions for five irrigation systems are derived from a variety of sources (Sauer et al. 2010).
- Production costs are compiled from an internal database at IIASA's Forestry Program (Schneider et al. 2011).

For each SimU, GLOBIOM computes irrigation water consumption, accounting for the beneficial water use by the crops and the application efficiency of the particular irrigation system. However, GLOBIOM does not compute gross water use in terms of actual water withdrawals from surface waters or groundwater. Hence, the model does not take into account the efficiency of water delivery from source to field, which would account for return flows and water potentially available for reuse (Sauer et al. 2010).

The model portrays four major types of irrigation systems: surface systems including basin and furrow irrigation, localized drip, and sprinkler irrigation. The suitability of these systems depends on various factors, which influence crop suitability, water demand, energy requirement, labour intensity, and overall cost, and thus affect motivation-based decision making that aims at individual as well as societal welfare maximization (Sauer et al. 2010).

For each irrigation method, biophysical and technical suitability are evaluated to exclude inappropriate system applications. Not all crop types may be irrigated by all irrigation systems. Among the biophysical determinants of irrigation system choice, the slope, soil, and crop types are directly taken into account (Sauer et al. 2010).

Consumptive irrigation water requirements by irrigation system are calculated as beneficial-use crop irrigation demands divided by the specific field application efficiency. The application efficiency varies by region and is determined by considering regional climatic factors and indicators of sociodemographic development (Sauer et al. 2010).

Unlike for land resources, irrigation water availability is not defined at SimU level. Instead, irrigation water use is constrained through an artificial supply function, representing the relative water scarcity through its increasing marginal cost (Sauer et al. 2010). The upper limit on irrigation water availability is computed by considering the sustainably exploitable internal renewable water amount, and water demands from other sectors (domestic, industry, livestock, and submitted environmental flow).

The model chooses the extent of a particular irrigation system considering irrigation cost per spatial unit for all appropriate combinations of regional geographic background, crop type, and irrigation system (Sauer et al. 2010).

This modelling approach is very data intensive and relies in a number of simplifications:

- Energy use is computed as a function of irrigated area, water application, pressure requirement, and total irrigation time (Buchanan and Cross 2002). A simplified irrigation scheduling is used to consistently represent these interdependencies.
- Labour requirement is the number of irrigation events times the estimated work hours per event. To depict variations in labour intensity by crop type, crop-specific cost data is used (Sauer et al. 2010).
- Irrigation costs include capital costs and costs for operation and maintenance (O&M). Operation costs are composed of pressure-related energy costs in terms of energy prices by source.
- Average capital and maintenance costs per year for each irrigation method are estimated. However, these costs are to be globally identical despite the fact that they may substantially differ across regions.

3.3. Other modelling tools assessing agricultural water use

Because their simulation of water use in agriculture at the EU or global level, two hydrological models have also been analysed: WaterGAP and LISFLOOD.

The global water model WaterGAP (Water – Global Assessment and Prognosis) has been developed since 1996 at the Center for Environmental Systems Research at the University of Kassel.

Since 2003, further model development is done both in Kassel and at the University of Frankfurt. WaterGAP is an integrated environmental model, combining socio-economic drivers and climate change in a single integrated framework, developed to model water availability, use and quality on a global level (Döll et al. 2003). The aim of the model is to provide a basis: (1) to compare and assess current water resources and water use in different parts of the world, and (2) to provide an integrated long-term perspective of the impacts of global change on the water sector.

WaterGAP comprises two main components, a Global Hydrology Model and a Global Water Use Model: the Global Hydrology Model simulates the behaviour of the terrestrial water cycle to estimate global water resources and water availability, while the Global Water Use Model computes water use for each economic sector (domestic, industrial, irrigation and livestock sectors). Both water availability and water use computations cover the globe and are performed at a high spatial resolution (grid cells of 0.5° by 0.5°).

The Global Water Use Model comprises sub-models for each of the water use sectors (domestic, industrial, irrigation and livestock). For each sector, water use is computed as a function of 'water-use intensity' multiplied by the most important 'driving forces' of water use (e.g. population, national electricity production, area of irrigated land, number of livestock). Irrigation water requirements are modelled as a function of cell-specific irrigated area, crop and climate, and livestock water use is calculated by multiplying livestock numbers by livestock-specific water use.

The global water use module and the global hydrology module are linked in order to compute water stress indicators and to calculate the reduction of river discharge due to consumptive water use.

WaterGAP has been mainly used for assessing the impact of global environmental developments (for instance climate change) on water availability and water demand and for determining different water-stress conditions of different regions. The model has been used to analyse the impacts of climate change and socio-economic driving forces (derived from the A2 and B2 scenarios of IPCC) on future global water stress (Alcamo et al. 2007). WaterGAP is also used in the OECD *Environmental Outlook to 2030*, which explores possible paths of development of the global environment, and in other global assessments in combination with IMAGE and IMPACT (MEA 2005, UNEP 2007).

On the other hand, LISFLOOD is a GIS-based spatially-distributed hydrological rainfall-runoff model developed at the JRC (De Roo et al. 2000, Van der Knijff et al. 2010). Driven by meteorological data, the model is typically run using a daily time interval to simulate the long-term catchment water balance.

When modelling water supply and water demand, the model output is the daily accumulated amount of surface water and groundwater in millimetres for each grid cell (daily local runoff).

In a recent work, LISFLOOD has been used to assess current water availability versus current water demands from different economic sectors (De Roo et al. 2012).

As LISFLOOD and CAPRI use different spatial and temporal scale, linking together these models would not be easy. Nevertheless, both modelling systems could benefit from exchange of information. LISFLOOD could provide CAPRI with estimates of irrigation water requirements per crop, which are needed to account for irrigation water use. Likewise, CAPRI could provide LISFLOOD with estimates of future cropland allocation, which are needed in LISFLOOD to account for future agricultural water demand.

3.4. Main findings from previous studies

From the analysis of alternative approaches to model food-water relationships, we can conclude that one of the main factors limiting the development of global food-water economic models is the availability of the homogeneous and precise water data. Main findings regarding water data used in agro-economic modelling include:

- Irrigation requirements are usually estimated using well-known procedures and can be obtained at a disaggregated level.
- Apart from irrigation requirements, water data is highly aggregated (country or country-block level).
- Economic data is based on other studies and/or strong assumptions.
- Water costs: Partial equilibrium models based on a system of supply and demand equations do not account for water costs in an explicit way.

The models IMPACT, WATERSIM and GLOBIOM appear as those with a more advanced water depiction. Critical modelling issues include:

- Competition for water between agricultural and non-agricultural sectors is only modelled in a rough way. GLOBIOM does not include water demand by non-agricultural economic sectors and, to capture pressure on water resources, uses a simplified supply function implying increasing water use costs. On the contrary, IMPACT accounts for water demand by major water users and runs a water allocation model. Competition for water across sectors is modelled by applying allocation rules in case of water shortages.
- Modelling of water flows across socioeconomic boundaries is only done by the models IMPACT and WATERSIM. These models include a food module and a water module that are solved in a iterative way, account for water flows across modelling units and use allocation rules in case of water shortages.

4. Promising approaches to include water into the CAPRI model

4.1. Potential of the current CAPRI system to model irrigation water

CAPRI is a partial equilibrium model for the agricultural sector developed for policy impact assessment of the Common Agricultural Policy and trade policies from global to regional scale with a focus on the EU (Britz and Witzke 2011). It is a deterministic comparative partial static equilibrium model, solved by sequential iteration between supply and market modules (Britz 2008):

- Supply module (EU27+Norway+Western Balkans+Turkey): covering about 280 regions (NUTS 2 level) or even up to ten farm types for each region (in total 1900 farm-regional models, EU27).
- Market module: spatial, global multi-commodity model for agricultural products, about 60 products, 77 countries in 40 trade blocks. Based on the Armington approach (Armington 1969), products are differentiated by origin, enabling to capture bilateral trade flows.

The data bases underlying the model exploit wherever possible well-documented, official and harmonised data sources, especially data from EUROSTAT, FAOSTAT and OECD. Specific modules ensure that the data used in CAPRI are mutually compatible and complete in time and space. They cover about 50 agricultural primary and processed products for the EU, from farm type to global scale including input and output coefficients.

The comparative-static structural nature of CAPRI makes this model mainly suited for counterfactual analysis against an existing baseline or reference scenario. The CAPRI baseline depicts the projected agricultural situation in the simulation year under exogenous assumptions and a status-quo policy setting. The baseline used in this study builds upon the medium-term outlook for EU agricultural markets and income for 2020 (European Commission 2010b) and is based on specific assumptions regarding macroeconomic conditions, the agricultural and trade policy environment, the path of technological change and international market developments.

Focusing at the supply module, it consists of independent aggregate non-linear programming models representing the activities captured by the Economic Accounts for Agriculture (EAA). The supply module currently covers all individual Member States of the EU-27 and also Norway, Turkey and the Western Balkans broken down to about 280 administrative regions, in line with the NUTS2 classification of EUROSTAT.

The programming models are a kind of hybrid approach, as they combine a programming approach - based on a Leontief-technology for variable costs covering a low and high yield variant for the different production activities and constraints such as land, feed and crop nutrient requirements - with a partly econometrically estimated non-linear cost function (Jansson and Heckelei 2011) which captures the effects of labour and capital on farmers' decisions. The non-linear cost function allows for perfect calibration of the models and a smooth simulation response rooted in observed behaviour (Britz and Witzke 2011).

The regional supply models include a land supply and demand module for arable and grassland, which are treated as imperfect substitutes. Prices are exogenous in the supply module and provided by the market module. Agricultural policy measures are captured in high detail.

Some key interactions between agriculture and the environment are also modelled in CAPRI such as agricultural NPK balances and GHG emissions from agriculture. Nevertheless, as CAPRI simulates the behaviour of agricultural producers and consumers at the aggregated level (at the NUTS2 level), its capability to model the links between food production and environmental externalities is rather limited; a higher spatial resolution would be desirable to capture environmental effects. That is why most of the environmental indicators in CAPRI are "passive" indicators without any feedback with the supply models. Some of these indicators make part of the post-model analysis and downscaling techniques are used to compute them at a higher spatial scale.

So far, CAPRI does not distinguish between rainfed and irrigated agriculture. Substitution between rainfed and irrigated crops is not modelled. Water availability, which is a real constraint for Mediterranean agriculture, is not taken into account.

Although there was an attempt to include water indicators in CAPRI and crop-specific water balances were included as passive environmental indicators, these water balances rely on out-of-date information and their applicability is very limited.

CAPRI shows, however, a high potential to model water issues. The supply side is based on explicit profit optimisation under constraints, which has advantages when modelling resource constraints or incorporating engineering data or results from bio-physical models.

Thanks to the programming approach of the CAPRI supply module, constraints on irrigable area and water availability can be directly included in the model.

Furthermore, since yields are endogenous in CAPRI, the yield response to water can also be incorporated.

While CAPRI offers high potential to model water issues, it also presents non-negligible limitations. The primal-dual approach used in CAPRI and the lack of differentiation between rainfed and irrigated crops in the CAPRI database complicate the integration of irrigation issues. Actually, the CAPRI database, which includes a large set of historical data, is crucial both for deriving the baseline scenario and for calibrating the model. Since no distinction between rainfed and irrigated agriculture has been made so far in this database, creating this distinction will imply a large bulk of data work.

Hereafter, the potential extensions of CAPRI to model water are briefly discussed. It should be noticed that while most of the environmental indicators in CAPRI are "passive" indicators, irrigation water demand should be treated as endogenous in the model.

4.2. Proposal to include water into the CAPRI model

4.2.1. The step-by-step integration of water issues into CAPRI

In the previous sections we have analysed how water has been modelled in other agro-economic systems and we have assessed the potentiality of the CAPRI model to deal with water. From this analysis, we can conclude that the most promising methodologies to integrate water modelling into the CAPRI system would be:

- Given the activity-based approach of the supply module, irrigation could be modelled by differentiating between rainfed and irrigated activities. Estimating input-output coefficients for rainfed and irrigated activities would be the critical point.
- Similarly, livestock water use could be computed by using livestock-specific coefficients of water use. Water use by head depending on the livestock category and production intensity is available from other studies.
- Since CAPRI models the agricultural sector at the regional level, water use balances should be defined at the regional level. Assuming that sectors other than agriculture are exogenous, the regional water availability for irrigation and livestock purposes could be estimated. While linkages with non-agricultural sectors are included in CAPRI (through the CAPRI regional CGEs), water use is not accounted for in the regional CGEs and, what is more, even if it would be included, it would not be in physical units. Therefore, domestic and industrial water use per region could be taken from other modelling systems (IMPACT or WaterGAP).

- Modelling competition with other sectors for water use as well as interregional water flows in a more accurate way will imply building a new water use module in CAPRI, which would interact with the supply module. The IMPACT water use module could be taken as a proxy.

Obviously, to achieve a high level of complexity and resolution in water modelling will require to work at a high spatial resolution and to account for all components of the water cycle. This is the orientation found in global hydrologic models. However, these models do not represent crop-water linkages in detail and the feedback with agricultural markets and policies is missing.

Since we aim at building a modelling tool able to provide scientific support for the assessment of pressures on water use driven by climate change or by changes in agricultural and water policies, modelling food-water linkages is essential and, therefore, will be the core of the study.

Integrating water issues in CAPRI will involve significant changes both in the CAPRI database and in the supply module. Hence, for building the water module, we will follow a step-by-step approach:

- Phase 1: irrigation sub-module
- Phase 2: water use sub-module

In the first phase, the focus will be on irrigation. A distinction will be made between rainfed and irrigated activities and between rainfed and irrigated land. Irrigation water will be treated as a quasi-fixed production factor, meaning that total availability will be limited, and input-output coefficients will be estimated at the regional level for each rainfed/irrigated activity.

In the second phase, water use balances will be taken into account, and competition between agricultural and non-agricultural water use will be modelled. Four water use sectors will be considered (domestic, industrial, irrigation and livestock) and sectoral water withdrawal and use will be assessed. Total water supply will be taken from official statistics (EUROSTAT, FAOSTAT) and/or other modelling systems (IMPACT) and will be used to estimate water stress indicators. Furthermore, we will investigate the possibility of taking into account interregional water flows when estimating water availability.

4.2.2. Irrigation sub-module

Irrigation water use will be the focus of the first phase of construction of the water module. The main objective will be to include water considerations in the supply module of CAPRI (at the NUTS2 level).

Compared to other agro-economic models with EU coverage, the programming approach of the regional supply models in CAPRI presents advantages to add new activities and constraints:

- Flexibility to incorporate crop-water relationships (input/output coefficients).
- Flexibility to add new land constraints. Regional constraints on irrigable land could be incorporated but, since irrigated land is currently below irrigable land in all EU regions, these constraints would not have any effect.
- Flexibility to enter irrigation water as a quasi-fixed production factor. In Southern EU regions, irrigation water is a limiting factor for agricultural production.
- Flexibility to estimate environmental indicators at the regional level (irrigation intensity, water use intensity, water stress).

The main water issues that need to be incorporated in this module are: regional irrigable and irrigated areas, irrigation shares per crop, irrigation water requirements and use, irrigation efficiencies, yield response to water and irrigation costs.

The critical bottlenecks to build this irrigation module are related to data availability. Although some data on irrigable and irrigated areas is available at the EU-wide regional level, crop-specific irrigated areas are mostly unavailable and data on irrigation water use is rarely found in official statistics. As a result, building an irrigation module in CAPRI will imply complementing EU data sources with water data from national statistics as well as using econometric methods to build a consistent water database.

4.2.3. Water use sub-module

In the second phase, a water balance approach will be envisaged with the aim of extending the water module to non-EU regions and accounting for competition between agricultural and non-agricultural water uses.

To include water considerations in non-EU regions, we could follow a similar approach as the recently developed for the land use module in CAPRI.

To account for water use in other sectors, we could mirror the approach used by the IMPACT model. Taking into account data availability, the water sectors considered in this study will include domestic, industrial, irrigation and livestock. Water use by sector could be computed as a function of water use intensity (e.g.

domestic water use per capita) and the driving forces of water use (e.g. population). The main driving forces of water use are population in the domestic sector, industrial production in the industrial sector, irrigated area and climate in the irrigation sector and the number of livestock in the livestock sector.

For each sector, we will distinguish between water withdrawal, total water use and consumptive water use; the ratio of consumptive water use to water withdrawal is the sectoral water use efficiency. Water withdrawal and use in the main sectors (domestic, industrial, irrigation and livestock) will be simulated following a balance approach and allocation rules to account for competition between users. As data on environmental flows is lacking, some assumption will be needed to account for environmental water demands.

Allocation rules need to be defined. In the IMPACT model, for instance, water demands for the domestic, livestock and industrial sectors are assumed to be met. This, in fact, implies that priority is given to all other sectors than irrigation when allocating water. Therefore, water scarcity will mainly affect the irrigation sector.

In theory, sectoral water withdrawal and use is provided by EUROSTAT at the national level. In practice, few data points are available and, therefore, results from other modelling tools will be used instead. Water stress indicators, such as the water exploitation index, can be calculated.

Future food-water scenarios may imply changes both in water use intensity and the driving forces of water use and, therefore, may imply changes both in irrigation water demand and irrigation water availability.

Water availability could be estimated taking into account interregional water flows. An iterative procedure could be used to ensure that agricultural water use does not exceed potential water availability. Basically, a similar methodology that the one implemented in the IMPACT model, could be developed to build the water module in CAPRI.

5. The irrigation sub-module

5.1. Water in the supply module of CAPRI

Irrigation water use, so far not covered in CAPRI, is the focus of the first phase of construction of the water module. This phase aims at including water considerations in the supply module of CAPRI (at the NUTS2 level), which will imply:

- To make a distinction between irrigable land (land equipped for irrigation) and non-irrigable land.
- To make a distinction between rainfed area and irrigated area for all potential irrigable activities in the model.
- To enter crop-specific irrigation water use as a specific input and to estimate irrigation costs.
- To estimate input-output coefficients for rainfed and irrigated activities.
- To model regional irrigation water as a quasi-fixed input.
- To model water policy measures such as irrigation water prices at the regional level.

We first need to distinguish irrigable and non-irrigable activities. In principle, irrigable activities are those for which an irrigated area has been reported in official statistics in at least one MS. Whereas non-irrigable activities will be handled in the supply module just as before, irrigable activities are split into a rainfed and irrigated variant. If an activity is not irrigated in a particular region, only the rainfed variant exists in the data base and model. Potential irrigable activities are shown in Table 4.

According to Wriedt et al. (2008), there are regions with a considerable share of grassland irrigation. However, these authors do not include grassland irrigation in their European Irrigation Map and recognize that there is currently no statistical data available at European level on grassland irrigation. As there is no mention to grassland irrigation in the Farm Structure Survey, which is the main EU-wide harmonized database on irrigation areas, including grassland irrigation in CAPRI will not be straightforward. If irrigation statistics improve in the near future, it would be desirable to also account for grassland irrigation.

Table 4. Potential irrigable activities

Group	Activity	Code
Cereals	Soft wheat	SWHE
	Durum wheat	DWHE
	Rye and Meslin	RYEM
	Barley	BARL
	Oats	OATS
	Grain Maize	MAIZ
	Paddy rice	PARI
Oilseeds	Rape	RAPE
	Sunflower	SUNF
	Soya	SOYA
Other arable crops	Pulses	PULS
	Potatoes	POTA
	Sugar Beet	SUGB
	Flax and hemp	TEXT
	Tobacco	TOBA
Vegetables and Permanent crops	Tomatoes	TOMA
	Other Vegetables	OVEG
	Apples Pears and Peaches	APPL
	Other Fruits	OFRU
	Citrus Fruits	CITR
	Table Grapes	TAGR
	Olives for oil	OLIV
	Table Olives	TABO
	Wine	TWIN
	Nurseries	NURS
	Flowers	FLOW
Fodder activities	Fodder maize	MAIF
	Fodder root crops	ROOF

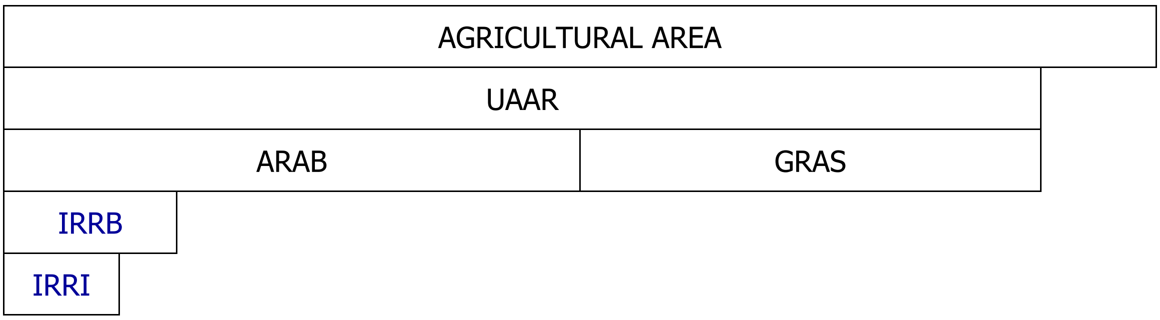
Table 5 illustrates the activity-based approach followed in the CAPRI supply module. For irrigable activities, input/output coefficients need to be specified both for the rainfed and the irrigated variants (the new components added in the irrigation module are highlighted in blue).

Table 5. Input-output coefficients for CAPRI activities

SWHE [Soft wheat production activity]		Description	Unit
Outputs			
SWHE	3068.63	Soft wheat yield	kg/ha
STRA	2454.90	Straw yield	kg/ha
Inputs			
NITF	73.65	Organic and anorganic N applied	kg/ha
PHOF	31.95	Organic and anorganic P applied	kg/ha
POTF	62.60	Organic and anorganic K applied	kg/ha
WIRR		Irrigation water	m3/ha
SEED	4.47	Seed input	const Euro 1995/ha
PLAP	4.34	Plant protection products	const Euro 1995/ha
REPA	11.59	Repair costs	const Euro 1995/ha
ENER	52.78	Energy costs	const Euro 1995/ha
WATR		Water costs	const Euro 1995/ha
INPO	15.80	Other inputs	const Euro 1995/ha
Income indicators			
TOOU	397.33	Value of total outputs	Euro/ha
TOIN	154.85	Value of total inputs	Euro/ha
GVAP	242.47	Gross value added at producer prices	Euro/ha
PRME	145.14	CAP premiums	Euro/ha
MGVA	387.61	Gross value added at producer prices plus premiums	Euro/ha
Activity level and data relating to CAP			
LEVL	1299.16	Hectares cropped	1000 ha
ILEV		Irrigated activity level	1000 ha
HSTY	2.29	Historic yield used to define CAP premiums	t/ha
SETR	6.90	Set aside rate	%

To account for irrigation in the land balances, we include a distinction between rainfed and irrigated areas. For regions with irrigation (ri), arable land will be split into irrigable land and rainfed land (non-irrigable land).

Figure 1. Land balances in CAPRI



The irrigable area (IRRB) is the area equipped for irrigation and, therefore, is the maximum area that can be irrigated. Total irrigated area in a particular year (IRRI) is usually lower than total irrigable area, due to increasing marginal costs, water scarcity, etc.

At the regional level (or even at the farm level), total water availability for irrigation purposes is limited. This will be expressed in the water supply balance, indicating that total water use by crops cannot exceed potential water availability.

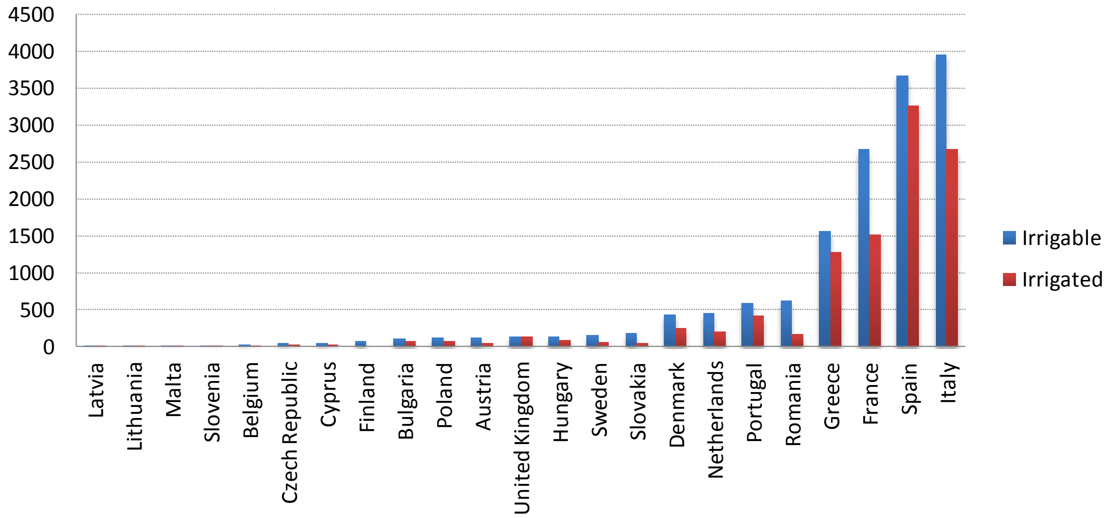
In the next sections, we will detail the steps that could be followed to integrate irrigation in the supply module of CAPRI.

5.2. Irrigable and irrigated areas

Data on area equipped for irrigation (irrigable area) and area irrigated at least once a year (irrigated area) are available in EUROSTAT, as they are regularly assessed in the Farm Structure Survey (FSS) and reported at MS and NUTS2 levels.

Data on area equipped for irrigation (irrigable area) and area irrigated at least once a year (irrigated area) are available in EUROSTAT, as they are regularly collected with the Farm Structure Survey (FSS) and reported by EUROSTAT at MS and NUTS2 levels. The total irrigable area in EU27 was around 15 million hectares in 2007 (16 million hectares in 2003) or 9% of total utilized agricultural area, while the total irrigated area was 10.3 million hectares in 2007 (10.8 million hectares in 2003). As shown in Figure 2, irrigation is mainly relevant in the Mediterranean.

Figure 2. Irrigable and irrigated areas in 2007 (in 1000 ha)

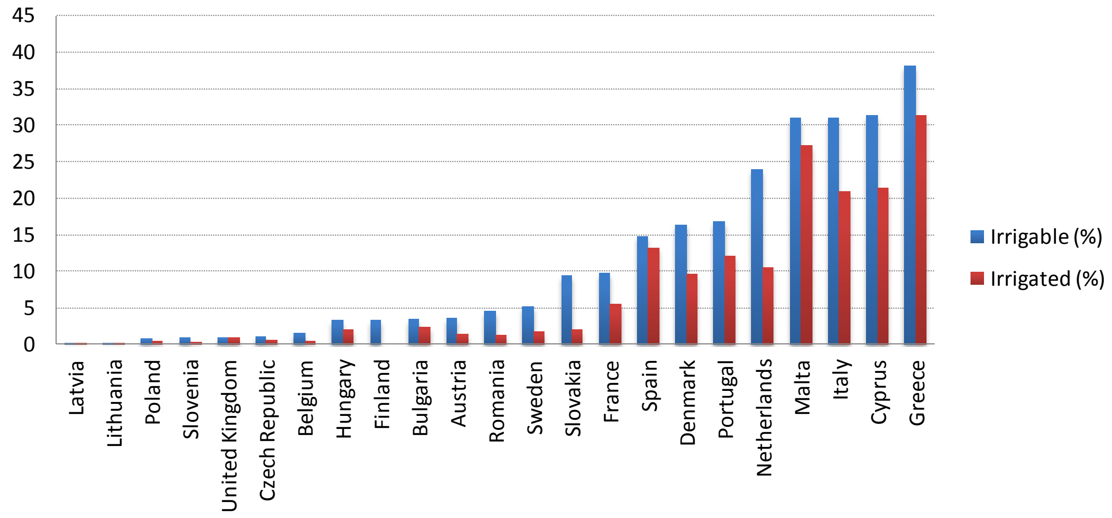


Source: Data from EUROSTAT (no data for Germany, Estonia and Ireland)

Although irrigable area represents less than 9% of total utilized agricultural area at the EU level, the share of irrigable area in total UAA is higher than 30% in four

Mediterranean countries (Greece, Cyprus, Italy and Malta) and shares at the regional level are even higher in some cases.

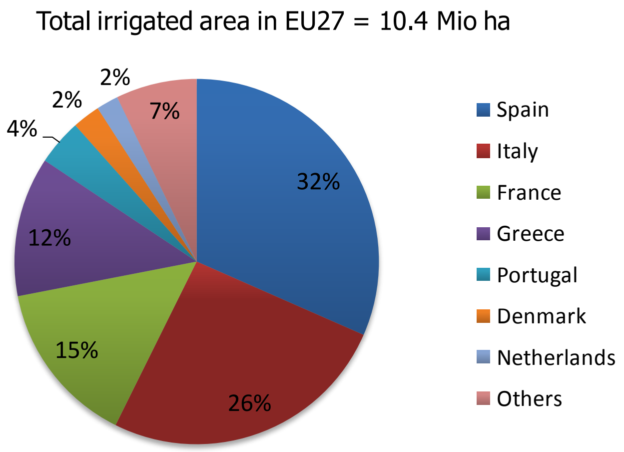
Figure 3. Irrigable and irrigated areas in 2007 (percentage share of UAAR)



Source: Data from EUROSTAT (no data for Germany, Estonia and Ireland)

With regard to actual irrigated area, Spain represents almost one third of total EU irrigations and only four countries (Spain, Italy, France and Greece) account for 85% of total irrigated area within the EU.

Figure 4. Share of irrigated area in EU27 total (2007)



Source: Data from EUROSTAT

This study is based on irrigation data from 2000, 2003, 2005 and 2007. The following table shows the availability of data on irrigation areas. Data at NUTS 2 level is incomplete.

Table 6. Data on irrigation area

Variable	Source	Unit	Temporal coverage	Spatial coverage	Spatial resolution
Total irrigable area	EUROSTAT (FSS)	ha	2000, 2003, 2005, and 2007	EU27, Norway, Switzerland and Croatia	NUTS 0 and 2
Total irrigated area	EUROSTAT (FSS)	ha	2000, 2003, 2005, and 2007	EU27, Norway, Switzerland and Croatia	NUTS 0 and 2
Irrigated area by irrigation method	EUROSTAT (FSS)	ha	2003		NUTS 0 and 2
Irrigated area per crop	EUROSTAT (FSS)	ha	2000, 2003, 2005, and 2007	EU27, Norway, Switzerland and Croatia	NUTS 0 and 2

Crop-specific irrigated area is only provided for 10 selected crops (durum wheat, maize, potatoes, sugar beet, soya, sunflower, fodder plants, vines, fruit and berry orchards and citrus fruit). The number of crops will be higher once the FSS data for 2010 will be available. Additional national statistics could be used to fill some gaps in the EUROSTAT data.

The main variables on irrigation areas included in the irrigation module are presented in Table 7.

Table 7. Main variables on irrigation areas

Topic	Variable	Unit	Code
Irrigation area	Total irrigable area	1000 ha	IRRB
	Total irrigated area	1000 ha	IRRI
	Crop-specific irrigated area	1000 ha	ILEV
Irrigation method	Surface irrigation	1000 ha	IMSUR
	Sprinkler irrigation	1000 ha	IMSPR
	Drop irrigation	1000 ha	IMDRO
	All irrigation methods	1000 ha	IMALL

So far, CAPRI distinguishes arable and grassland and comprises thus two land balances:

$$LEVL_{r,"arab"} = \sum_{arab} LEVL_{r,arab}$$

$$LEVL_{r,"gras"} = LEVL_{r,"grae"} + LEVL_{r,"grae"}$$

Both land balances might become slack if marginal returns to land drops to zero. For arable land, idling land not in set-aside (activity FALL) is a further explicit activity. For the grassland, the model distinguishes two types with different yields

(GRAE: grassland extensive, GRAI: grassland intensive) so that idling grassland can be expressed of an average lower production intensity of grassland by changing the mix between the two intensities (Britz and Witzke 2011).

Land available to agriculture is a function of returns to land and substitution between arable land and grassland is possible:

$$\overline{LEVL}_{r,"uaar"} = LEVL_{r,"\mathrm{arab}"} + LEVL_{r,"\mathrm{gras}"}$$

To account for irrigation, we split arable land into irrigable land and rainfed land. Irrigable land is the land equipped for irrigation and is then the maximum area which can be irrigated in a particular region at a given time.

Hence, for each region with irrigation (*ri*) we define a new constraint for irrigable land, indicating that total irrigated area in the region cannot exceed total irrigable land:

$$LEVL_{ri,"irri"} \leq \overline{LEVL}_{ri,"irrb"}$$

Total irrigated area is defined as the sum over irrigated activities ($wact$):

$$\sum_{wact} LEVL_{ri,"wact"} = LEVL_{ri,"irri"}$$

While data on total irrigable and irrigated area per region is provided by EUROSTAT, crop-specific irrigated area is only provided for a selected group of crops. Ex-post data on crop-specific irrigated areas will then be estimated so as to match the official statistics. This will be done through a joint estimation procedure for irrigated areas, crop yields and water use, which will be detailed further on.

A survey of irrigation methods was included in the FSS in 2003, reporting the area covered by specific irrigation methods (surface irrigation, sprinkler irrigation and drop irrigation). For 2003, EUROSTAT provides data on irrigation methods at the NUTS2 level. In the testing case study, we assume that the share of each irrigation method in the CAPRI base year (2003-2005) matches the EUROSTAT figures.

The share of irrigation methods will be mainly used to compute irrigation efficiencies.

5.3. Irrigation water availability

EUROSTAT (through the OECD-EUROSTAT Joint Questionnaire on Inland Waters) provides country-level statistics on water availability and water use for the EU-27, Norway, Switzerland, Croatia and Turkey. Sectoral water abstraction and use are reported for the agricultural, domestic, manufacturing, mining and electricity production sectors.

In some irrigated regions, water availability is a major constraint for agricultural production. The volume of water available for irrigation depends on the total exploitable water resources of the region but also on water needs in other sectors and the efficiency of water use.

To compute irrigation water availability, we assume that water is allocated first to the domestic sector, then to the livestock and industrial sectors and finally to the irrigation sector. Therefore, irrigation water potential availability (or maximum water withdrawal) equals total water supply minus estimated water withdrawal over all other sectors.

Since data on water availability and water use is available only at the national level in EU-wide statistical sources, these datasets will be complemented with national statistics whenever possible.

WATERGAP has estimated water availability as well as potential consumption rates for the year 2020 (Flörke and Alcamo 2004). In the testing case study, we will assume that potential irrigation water availability for the CAPRI baseline matches WATERGAP results.

Water availability constraints will be entered at regional level to express that total water withdrawal for irrigation purposes ($IRWW$) cannot exceed potential irrigation water availability ($IRWA$):

$$IRWW_{ri} \leq IRWA_{ri}$$

5.4. Irrigation water use

5.4.1. Crop-specific water balance

Irrigation water use is included as a crop specific input. As it is not reported in official statistics, estimated values will be used instead.

Theoretical crop water requirements can be derived from crop-specific water balances at the regional level. Crop water requirement *(CWR)* is defined as the total amount of water needed for a crop under optimum growth conditions and without water- and nutrient-stress. Climate and crop type are the main factors determining the crop water requirement, which is normally expressed in mm/day or mm/period.

Various modelling tools have been developed to estimate crop water requirement and the "crop yield response to water". A widespread approach are the FAO guidelines (Doorembos and Kassam 1979), which estimate the crop water requirement *(CWR)* as the potential crop evapotranspiration *(EPOT)*, avoiding the problem of clearly defining optimum growth conditions. This approach, based on the quantification of the cumulative crop evapotranspiration during the crop growing season, has been recently updated in the AquaCrop model (Raes et al. 2009).

Potential evapotranspiration *(EPOT)* refers to the maximum evapotranspiration over the growing period of the crop under optimum growth conditions (conditions where water, nutrients and pests and diseases do not limit crop growth).

In turn, actual evapotranspiration *(EACT)* refers to the actual level of evapotranspiration, given the available soil water.

Under non water-limited conditions, actual evapotranspiration *(EACT)* equals potential evapotranspiration *(EPOT)* and the potential crop yield *(YPOT)* will be reached.

However, under water-limited conditions, actual evapotranspiration *(EACT)* will fall below potential evapotranspiration *(EPOT)* and water stress will adversely affect crop growth. As a result, the actual crop yield *(YACT)* will be lower than the potential crop yield *(YPOT)*. Knowing the potential crop yield per region will allow to define the actual yield as a function of the potential yield and to define the technology variants for the irrigated activities in a way consistent with crop-water relationships.

Several approaches could be envisaged to estimate crop-water relationships. Because of its simplicity and robustness, the AquaCrop model could be chosen to estimate crop water requirements, potential yields (non water-limited conditions) and rainfed yields (standard rainfed conditions). An alternative option would be to use data from other biophysical modelling tools (the LISFLOOD model developed at JRC-IES, for instance).

Table 8. Estimated data on crop-specific water balances

Variable	Calculation method	Unit	Temporal coverage	Spatial coverage	Spatial resolution
Effective precipitation	AquaCrop	mm	MT average	EU27, NO, TUR and WB	NUTS 2
Crop specific potential evapotranspiration	AquaCrop	mm	MT average	EU27, NO, TUR and WB	NUTS 2
Potential crop yield	AquaCrop	t/ha	MT average	EU27, NO, TUR and WB	NUTS 2
Rainfed crop yield	AquaCrop	t/ha	MT average	EU27, NO, TUR and WB	NUTS 2

5.4.2. Irrigation water requirements

Once the crop water requirement has been estimated, we will calculate net irrigation requirement *(CNIR)* as the volume of water needed to compensate for the deficit of water over the growing period of the crop.

Net irrigation requirement *(CNIR)* is commonly determined as the difference between CWR (i.e. potential crop evapotranspiration) and the actual crop evapotranspiration under rainfed conditions or effective precipitation (PEFF). It is expressed in millimetres per year or in m3/ha per year (1 mm = 10 m3/ha).

$$CNIR_{ri,wact} = EPOT_{ri,wact} - PEFF_{ri,wact}$$

Net irrigation requirement is then the total volume of water needed by a certain crop in addition to the rainfall for achieving the potential yield. In the absence of irrigation, the maximum yield under rainfed conditions is determined by the amount of rainfall and its distribution over the growing season. This water-limited yield is equal to the potential yield in the case of sufficient rainfall, and is lower than the potential yield in the case of water deficit.

Data on crop irrigation water requirements or irrigation water use are usually not available in official statistics. Therefore, the first step to compute irrigation water use will be to estimate net irrigation requirements per crop and per region.

The main variables used to model crop-water relationships in CAPRI are presented in Table 9.

Table 9. Main variables for crop-water linkages

Topic	Variable	Unit	Code
Irrigation water	Effective precipitation	mm	PEFF
	Reference evapotranspiration	mm	EREF
	Potential evapotranspiration	mm	EPOT
	Actual evapotranspiration	mm	EACT
	Crop water requirement	mm	CWR
	Crop net irrigation requirement	mm	CNIR
	Crop gross irrigation requirement	m3/ha	CGIR
	Water application efficiency	%	IRWAE
	Water transport efficiency	%	IRWTE
	Water use efficiency	%	IRWUE
	Crop actual irrigation water use	m3/ha	CAWU
Crop yield	Potential yield	kg/ha	YPOT
	Actual yield	kg/ha	YACT
	Rainfed yield	kg/ha	YNOI

5.4.3. Irrigation efficiency

FAO (2001) defines irrigation efficiency as the percentage of the irrigation water consumed by crops to the water diverted from the source of supply. It distinguishes between conveyance efficiency, which represents the efficiency of water transport in canals, and the field application efficiency, which represents the efficiency of water application in the field.

In this report, the term water application efficiency *(IRWAE)* indicates the ratio of the volume of irrigation water evapotranspirated by the crop to the volume of water applied to the crop. Water transport efficiency *(IRWTE)* is the ratio of water used to water withdrawn.

Water application efficiency depends on the irrigation method and management practices. Based on the regional net irrigation requirement per crop, we estimate regional gross irrigation requirements ($CGIR$) by division with the regional water application efficiency ($IRWAE$):

$$CGIR_{ri,wact} = \frac{CNIR_{ri,wact}}{IRWAE_{ri,wact}}$$

According to Brouwer et al. (1989), indicative field application efficiencies range from 0.60, 0.75 and 0.90 for surface irrigation, sprinkler irrigation, and drip irrigation, respectively. Using the indicative values for each irrigation method and the estimated area share by irrigation method, we compute the regional application efficiency per activity.

The transport efficiency mainly depends on irrigation infrastructure and water management of the canals, the soil type or permeability of the canal banks and the condition of the canals. Data on irrigation efficiency are usually not easily available. Therefore, we consider the range 0.60-0.95 given by Brouwer et al. (1989).

Taken into account the irrigation water use efficiency, the potential water abstraction can be estimated:

$$CPWW_{ri,wact} = \frac{CGIR_{ri,wact}}{IRWTE_{ri}} = \frac{CNIR_{ri,wact}}{IRWAE_{ri,wact} \times IRWTE_{ri}}$$

The term "irrigation efficiency" does not automatically imply a waste of water. Part of the unused water may flow back to a water source and be used again downstream. Irrigation efficiency at the river basin level or the regional level is usually higher than at the field level (because of reuse of return flows at the aggregate level).

5.4.4. Regional irrigation water use

Once the per hectare irrigation water requirements are calculated, these are multiplied by the crop-specific irrigated to give the total irrigation water requirements per NUTS-2 region.

Both net irrigation requirement and gross irrigation requirement are theoretical irrigation water needs. Compared to CGIR, actual irrigation water use may be lower (water scarcity, decreasing marginal returns) or higher (non optimal irrigation scheduling, salt leaching factor, etc.).

Since data on irrigation water use per crop and per region is not reported in official statistics, the actual irrigation water use per crop (CAWU) will be estimated for each irrigated region based on theoretical crop water requirements, rainfed and irrigated shares and crop yields.

Regional irrigation water use *(IRWU)* will be computed by summation over all irrigated crops.

$$IRWU_{ri} = \sum_{wact} CAWU_{ri,wact} \times LEVL_{ri,wact}$$

Irrigation water withdrawal is the volume of water extracted from any source (rivers, lakes, aquifers, non-conventional sources) for irrigation purposes, and usually exceeds the consumption of water because of water lost in the distribution network.

$$IRWW_{ri} = \frac{IRWU_{ri}}{IRWTE_{ri}}$$

5.5. Yield response to water

When crop water requirements are fully met by available supply *(EACT = EPOT)*, no water stress will take place and the potential yield will be attained *(YACT = YPOT)*. Potential yield (YPOT) is the yield linked to potential evapotranspiration (EPOT) and is the maximum yield achievable in a given climate under ideal, constraint-free conditions (i.e. assuming perfect management of water and fertilizer and control of pests and diseases).

When water supply is insufficient to fulfil crop water requirements *(EACT < EPOT)*, a water deficit will take place, often called crop water stress, adversely affecting crop growth and ultimately crop yield. As a result, the actual crop yield will not reach the potential yield *(YACT < YPOT)*.

The effect of water stress on growth and yield depends on the crop species on the one hand and the magnitude and the time of occurrence of water deficit on the other. Crops vary in their response to water stress. According to FAO (2009), in some crops a water deficit induces an increase in water productivity (i.e. sorghum) whereas for other crops water productivity decreases with increase in water deficit (i.e. maize).

Furthermore, the yield response to water deficit may vary among varieties of the same crop. In general, high producing varieties are also the "most sensitive in their response to water, fertilizer and other agronomic inputs.

Also, when water deficit occurs during a particular part of the total growing period of a crop, the yield response to water deficit can vary greatly depending on how sensitive the crop is at that growth period. In general, crops are more sensitive to water deficit during emergence, flowering and early yield formation.

Finally, the response of yield to water cannot be considered in isolation from all the other agronomic factors, such as fertilizers, plant density and crop protection, because these factors also determine the extent to which actual yield *(YACT)* approaches maximum yield *(YPOT)*.

The "crop yield response to water" procedure developed at the FAO (Doorembos and Kassam 1979) is a widely applied approach for estimating crop yields. The actual crop yield can be quantified by relating the relative yield loss to relative reduction in evapotranspiration using the following equation:

$$1 - \frac{YACT}{YPOT} = Ky\ (1 - \frac{EACT}{EPOT})$$

The yield response to water is quantified through the yield response factor *(Ky)* which relates relative yield decrease to relative evapotranspiration deficit. The yield response factor is derived for each crop based on the assumption that the relationship between relative yield and relative evapotranspiration is linear.

Table 10. Yield response factor for selected crops (Ky)

Crop	Ky	Crop	Ky
Alfalfa	0.7 - 1.1	Potato	1.1
Banana	1.2 - 1.35	Safflower	0.8
Bean	1.15	Sorghum	0.9
Cabbage	0.95	Soybean	0.85
Citrus	0.8 - 1.1	Sugar beet	0.7-1.1
Cotton	0.85	Sugarcane	1.2
Grape	0.85	Sunflower	0.95
Groundnut	0.7	Tobacco	0.9
Maize	1.25	Tomato	1.05
Onion	1.1	Water melon	1.1
Pea	1.15	Wheat (winter)	1.0
Pepper	1.1	Wheat (spring)	1.15

Source: AquaCrop

The "crop yield response to water" is updated recently in the Aquastat model (Raes et al., 2009). AquaCrop is a water-driven simulation model that requires a relatively low number of parameters and input data to simulate the yield response to water of most of the major field and vegetable crops cultivated worldwide.

The AquaCrop model could be use to compare the potential against actual yields in the EU at the regional level. Another possibility would be to include yields coming from other biophysical models which simulate the response of crop yield to water. This would be particularly helpful to estimate the impacts of climate change on crop yields when simulating climate change scenarios.

5.6. Estimation of input-output coefficients for irrigated activities

5.6.1. Irrigation costs

Regarding irrigation costs, EU-wide statistics seem to be lacking. Water is included as a cost item in the European Farm Accounting Data Network (FADN), but this cost component only includes the cost of connection to a water delivery system and the consumption of water. Water application costs as well as irrigation investment costs are not reported separately in FADN. The cost of using irrigation equipment is recorded under "current upkeep of machinery and equipment", "motor fuels and lubricants" and "electricity". As regards capital cost, it is recorded under “investment” and “depreciation”.

As production costs given by FADN are not broken down to the level of agricultural activities, CAPRI uses an econometric procedure to allocate farm input costs to particular agricultural activities. In spite of the difficulties to individualize irrigation costs, FADN data will be used as much as possible to keep consistency with the input allocation model in CAPRI. Nevertheless, as available data on irrigation costs is really limited, additional data from national statistics should ideally be used to fill the gaps in EU-wide statistics.

Through the input allocation process, inputs as feed, NPK fertilizer, energy or plant protection costs are allocated to individual production activities in CAPRI. Several sources are combined in a statistical approach which ensures consistency to the Economic Accounts of Agriculture or other statistics on feed and fertilizer use, inter alia: (a) econometric estimates based on single farm data from the European Farm Accounting Data Network, (b) engineering information (e.g. requirement function for animals or nutrient contents of crops), (c) standard gross margins.

The initial estimates for the input allocation based on FADN data was carried out in the framework of the first CAPRI research project and cannot be updated in an automated way. Separating irrigation from those cost components where it is currently “hidden” will imply, apart from the difficulties related to the particular allocation rules to use, to thoroughly reorganise the input allocation procedure.

Therefore, integrating irrigation water in the supply module of CAPRI will require a thorough revision of the input allocation procedure. Besides, as available data on irrigation costs is really limited, additional data from national statistics should ideally be used to fill the gaps in EU-wide statistics.

5.6.2. Irrigation shares, irrigation requirements and crop yields

EUROSTAT (FSS) provides data on agricultural area and crop areas for 46 crop types. Irrigation data are reported as total area equipped for irrigation (irrigable area) and total area irrigated at least once a year (actual irrigated area). In addition to regional totals, crop-specific irrigated areas are also reported, but only for 10 selected crops (durum wheat, vines, maize, potatoes, sugar beet, soya, sunflower, fodder plants, fruit and berry orchards and citrus fruits). Additional national statistics could be used to fill some gaps in the Eurostat data.

The distinction between rainfed and irrigated activities requires splitting the total crop area in each region into rainfed area and irrigated area. Given the lack of data on crop-specific irrigated areas, an estimation procedure could be used to estimate irrigation shares.

With the aim of taking advantage of all the information available, a joint estimation procedure for irrigated shares, rainfed and irrigated crop yields and irrigation water use is suggested. This also ensures that irrigated areas, crop yields and water use will be consistent with regional figures.

Since the irrigation module is under development and, therefore, no data on irrigation is yet included in the CAPRI database, we will take the CAPRI database as the starting point, that is, as the "official set of regional data". Once the irrigation module will be integrated in CAPRI, ideally this estimation procedure will be integrated in the data module.

For each irrigated region, the variables in the estimation will be:

- Rainfed and irrigated area per crop
- Rainfed and irrigated yield per crop
- Irrigation water use per crop
- Share of irrigation method per crop

The estimation procedure will yield the most probable values for these variables for the CAPRI base year (2003-2005), so that the following conditions are respected:

- The total irrigated area at the NUTS2 level matches the statistical data reported by EUROSTAT (Farm Structure Survey for 2003)
- The weighted average of rainfed and irrigated yields equals the regional crop yields in the CAPRI base year
- The total irrigation water use at the NUTS2 level matches the statistical data on irrigation water use reported by EUROSTAT;

and based on minimization of deviations from given information:

- the reported irrigation shares at the NUTS2 level for 10 selected crops,
- the area covered by each irrigation method,
- the rainfed yield implicit in the yield response to water function
- the actual water use per crop implicit in the yield response to water function

Through this estimation procedure, estimated input-output coefficients for rainfed and irrigated activities will be consistent with the average regional values found in the CAPRI database for the base year situation. Ideally, the estimation procedure should be updated with each new release of the CAPRI base year. However, updating of the water database will depend on availability of updated EUROSTAT data. In this respect, it is important to keep in mind that irrigation data is not published annually and the last available year, even if incomplete, is 2007.

The CAPRI baseline should be recalibrated to take into account the likely development of irrigated shares and water use efficiency in the irrigation sector. In a first moment, however, as no time series are available for irrigation data, a very simplified method based on expert knowledge will be used.

6. The water use sub-module

6.1. Introduction

To account for water supply and demand, a water balance approach is suggested. For EU regions, a more detailed representation will be possible in the supply module of CAPRI. For non-EU regions, stylized water supply and demand functions could be used instead.

In a further step, the linkage to a water use model could be envisaged.

6.2. Water balance approach in the CAPRI supply module

6.2.1. Accounting for water supply and demand

For a given water availability, the water use sub-module computes water withdrawal and use in the domestic, industrial, irrigation and livestock sectors.

While water abstraction is the quantity of water taken from any water source, water use is the part of the abstracted water reaching the end user and water consumption is the part of the water actually consumed[7]. The ratio of consumptive use to water abstraction is called water use efficiency.

6.2.2. Water availability

The OECD/Eurostat Joint Questionnaire on Inland Waters defines climatic water balances at the regional level, whose main components are precipitation, actual evapotranspiration, internal flow, actual external inflow and total outflow (Table 10).

Table 11. Data on water availability

Variable	Source	Unit	Temporal coverage	Spatial coverage	Spatial resolution
Precipitation	EUROSTAT	Million m3	1990-2007	EU27, NO, TUR and WB	NUTS 0
Actual evapotranspiration	EUROSTAT	Million m3	1990-2007	EU27, NO, TUR and WB	NUTS 0
Internal Flow	EUROSTAT	Million m3	1990-2007	EU27, NO, TUR and WB	NUTS 0
Actual external inflow	EUROSTAT	Million m3	1990-2007	EU27, NO, TUR and WB	NUTS 0
Total actual outflow	EUROSTAT	Million m3	1990-2007	EU27, NO, TUR and WB	NUTS 0
Actual outflow into the sea	EUROSTAT	Million m3	1990-2007	EU27, NO, TUR and WB	NUTS 0
Actual outflow into neighbouring territories	EUROSTAT	Million m3	1990-2007	EU27, NO, TUR and WB	NUTS 0
Total fresh water resources	EUROSTAT	Million m3	1990-2007	EU27, NO, TUR and WB	NUTS 0

[7] The difference between total use and consumptive use is the return flow, the part of the water that returns to either the surface water or the groundwater.

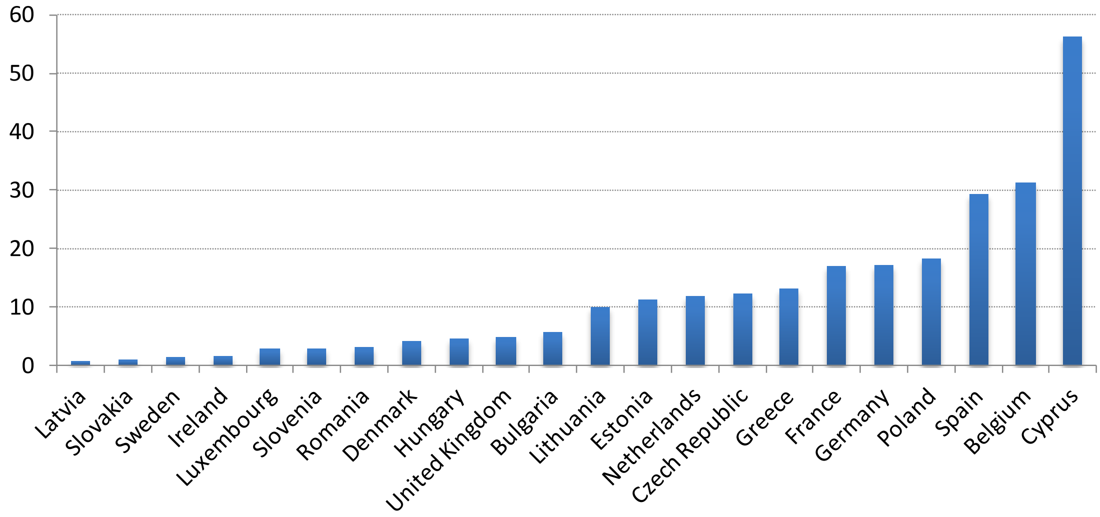
These regional water balances allow estimating the total freshwater resources. Ideally, this estimation could be done at the regional level, but data is only available at the national level so far. Although the time series at the national level are incomplete, the long-term annual average is provided for most countries.

Table 12. Water balance in 1000 Mio m3 per year (long term annual average)

	Precipitation	Evapotrans-piration	Internal flow	External inflow	Outflow	Freshwater resources
Belgium	28.9	16.56	12.33	7.61	15.34	19.93
Bulgaria	68.6	50.51	18.09	89.14	108.54	107.23
Czech Republic	54.7	39.42	15.24	0.74	15.98	15.98
Denmark	38.5	22.15	16.34	*0.00*	1.94	16.34
Germany	307.0	190.00	117.00	75.00	182.00	188.00
Estonia	29.0	:	:	:	12.35	12.35
Ireland	80.0	32.50	47.50	:	:	47.50
Greece	115.0	55.00	60.00	12.00	:	72.00
Spain	346.5	235.39	111.13	0.00	111.13	111.13
France	485.7	310.39	175.29	11.00	168.00	186.29
Italy	296.0	129.00	167.00	8.00	155.00	175.00
Cyprus	3.1	2.75	0.33	0.00	0.08	0.33
Latvia	42.7	25.80	16.90	16.83	32.90	33.73
Lithuania	44.0	28.50	15.51	8.99	25.90	24.50
Luxembourg	2.0	1.13	0.91	0.74	1.60	1.64
Hungary	55.7	48.17	7.53	108.90	115.66	116.43
Malta	:	:	:	:	:	:
Netherlands	29.8	21.29	8.48	81.20	86.30	89.68
Austria	98.0	43.00	55.00	29.00	84.00	84.00
Poland	193.1	138.30	54.80	8.30	63.10	63.10
Portugal	82.2	43.57	38.59	35.00	34.00	73.59
Romania	154.0	114.59	39.42	186.32	245.62	225.74
Slovenia	31.7	13.15	18.60	13.50	32.27	32.09
Slovakia	37.4	24.28	13.07	67.25	81.68	80.33
Finland	222.0	115.00	107.00	3.20	110.00	110.00
Sweden	313.9	141.15	172.71	11.83	194.63	183.36
United Kingdom	283.7	111.20	172.50	2.84	175.34	175.34
Iceland	200.0	30.00	170.00	-	170.00	170.00
Norway	470.7	112.00	377.29	12.15	389.44	389.44
Switzerland	61.6	21.60	40.71	12.80	53.50	53.51
Croatia	63.1	40.13	23.01	:	:	:
FYR of Macedonia	19.5	:	:	1.01	6.32	:
Turkey	501.0	273.60	227.40	6.90	178.00	234.30

Human activities also greatly affect the individual components of the hydrological cycle, mainly through water abstraction from ground and surface water sources. An approximation to the degree of anthropogenic influence in the water cycle is the water stress indicator. Figure 5 shows the big discrepancies in water stress across EU. While some countries exploit more than 30% (Cyprus, Belgium) of total freshwater resources, in other countries the share of water withdrawal on total freshwater resources is less than 5% (Latvia, Sweden).

Figure 5. Water stress in 2009 (% of freshwater abstraction on total freshwater resources)



The main variables considered in CAPRI are shown in Table 13. These variables allow for computing a regional water balance and will be mainly used to compute water indicators.

Table 13. Water availability components

Topic	Variable	Unit	Code
Water availability	Precipitation	Mio m3	WAPR
	Actual evapotranspiration	Mio m3	WAEA
	Internal Flow	Mio m3	WAFI
	Actual external inflow	Mio m3	WAIN
	Total actual outflow	Mio m3	WAOU
	Total fresh water resources	Mio m3	TFWR

Total freshwater resources are an indicator of water availability and will be used to compute potential water supply. Data at the national level will be complemented with national statistics whenever possible to compute climatic water balances at the regional level.

6.2.3. Regional water withdrawal and use

6.2.3.1. Introduction

Data on water abstraction and use are collected regularly by Eurostat via the OECD/Eurostat Joint Questionnaire on Inland Waters. These data include annual water abstraction data per sector at national level. Sectors considered include agriculture, domestic sector, manufacturing sector, mining sector, construction and electricity production. Agriculture encloses irrigation, forestry and fisheries, although data for irrigation is also found in some cases. No indication about water use in the livestock sector is given.

Table 13 shows the main variables on water use balances in EUROSTAT. However, the datasets are very incomplete and, for some countries, only the data on total abstraction is reported.

Table 14. Data on water use balance

Variable	Source	Unit	Temporal coverage	Spatial coverage	Spatial resolution
Total gross abstraction of freshwater	EUROSTAT	Million m3	1990-2009	EU27, NO, TUR and WB	NUTS 0
Returned water (before or without use)	EUROSTAT	Million m3	1990-2009	EU27, NO, TUR and WB	NUTS 0
Total net fresh water abstraction	EUROSTAT	Million m3	1990-2009	EU27, NO, TUR and WB	NUTS 0
Desalinated water	EUROSTAT	Million m3	1990-2009	EU27, NO, TUR and WB	NUTS 0
Reused water	EUROSTAT	Million m3	1990-2009	EU27, NO, TUR and WB	NUTS 0
Imports of water	EUROSTAT	Million m3	1990-2009	EU27, NO, TUR and WB	NUTS 0
Exports of water	EUROSTAT	Million m3	1990-2009	EU27, NO, TUR and WB	NUTS 0
Total water available for use within the territory	EUROSTAT	Million m3	1990-2009	EU27, NO, TUR and WB	NUTS 0
Losses during transport, total	EUROSTAT	Million m3	1990-2009	EU27, NO, TUR and WB	NUTS 0
Total water available for end users within the territory	EUROSTAT	Million m3	1990-2009	EU27, NO, TUR and WB	NUTS 0
Total waste water generated	EUROSTAT	Million m3	1990-2009	EU27, NO, TUR and WB	NUTS 0
Waste water discharged to inland waters	EUROSTAT	Million m3	1990-2009	EU27, NO, TUR and WB	NUTS 0
Waste water discharged to marine waters	EUROSTAT	Million m3	1990-2009	EU27, NO, TUR and WB	NUTS 0
Reused water	EUROSTAT	Million m3	1990-2009	EU27, NO, TUR and WB	NUTS 0
Discharges of used water	EUROSTAT	Million m3	1990-2009	EU27, NO, TUR and WB	NUTS 0
Consumptive water use	EUROSTAT	Million m3	1990-2009	EU27, NO, TUR and WB	NUTS 0
Total water consumption	EUROSTAT	Million m3	1990-2009	EU27, NO, TUR and WB	NUTS 0

Although data on sectoral water use is theoretically reported for all sectors (Table 14), in fact very few data points are available. In most cases, only total supply and supply to agriculture are reported. In general, data on water abstractions for irrigation purposes is very incomplete and often based on estimates (metering devices are absent in most irrigation systems).

Table 15. Data on sectoral water supply

Variable	Source	Unit	Temporal coverage	Spatial coverage	Spatial resolution
Total supply	EUROSTAT	Million m3	1990-2009	EU27, NO, TUR and WB	NUTS 0
Supply to agriculture, forestry, fishing (total)	EUROSTAT	Million m3	1990-2009	EU27, NO, TUR and WB	NUTS 0
Supply to mining and quarrying	EUROSTAT	Million m3	1990-2009	EU27, NO, TUR and WB	NUTS 0
Supply to manufacturing industries (Total)	EUROSTAT	Million m3	1990-2009	EU27, NO, TUR and WB	NUTS 0
Supply to the production and distribution of electricity (Total)	EUROSTAT	Million m3	1990-2009	EU27, NO, TUR and WB	NUTS 0
Supply to all industrial activities	EUROSTAT	Million m3	1990-2009	EU27, NO, TUR and WB	NUTS 0
Supply to construction	EUROSTAT	Million m3	1990-2009	EU27, NO, TUR and WB	NUTS 0
Supply to the domestic sector (Total)	EUROSTAT	Million m3	1990-2009	EU27, NO, TUR and WB	NUTS 0

In CAPRI, we have retained four sectors: domestic, industrial, irrigation and livestock. Table 15 shows the main components of the water use sub-module. In principle, in-situ water use will not be taken into account, as no statistical information is available.

In all sectors, sectoral water use is computed as a function of water use intensity and driving forces or water use. Both the water use intensity and the driving forces may change in future scenarios. For instance, a future scenario may imply a reduction/increase of water available for irrigation. Improvements in water use efficiency are taken into account by a sector-specific technological change factor.

Table 16. Water abstraction and use components

Topic	Variable	Unit	Code
Total water abstraction/use	Total water withdrawal	Mio m3/year	TOWW
	Total water use	Mio m3/year	TOWU
	Total water consumption	Mio m3/year	TOWC
Domestic sector	Domestic water withdrawal	Mio m3/year	DOWW
	Domestic water use	Mio m3/year	DOWU
	Domestic water consumption	Mio m3/year	DOWC
	Water use efficiency in the domestic sector	%	DOWUE
	Water use intensity in the domestic sector	m3/capita.year	DOWUI
Industrial sector	Industrial water withdrawal	Mio m3/year	INWW
	Industrial water use	Mio m3/year	INWU
	Industrial water consumption	Mio m3/year	INWC
	Water use efficiency in the industrial sector	%	INWUE
	Water use intensity in the industrial sector	m3/GVA.year	INWUI
Irrigation sector	Irrigation water withdrawal	Mio m3/year	IRWW
	Irrigation water use	Mio m3/year	IRWU
	Irrigation water consumption	Mio m3/year	IRWC
	Water use efficiency in the irrigation sector	%	IRWUE
	Water use intensity in the irrigation sector	m3/capita.year	IRWUI
Livestock sector	Livestock water withdrawal	Mio m3/year	LVWW
	Livestock water use	Mio m3/year	LVWU
	Livestock water consumption	Mio m3/year	LVWC
	Water use efficiency in the livestock sector	%	LVWUE
	Water use intensity in the livestock sector	m3/capita.year	LVWUI

6.2.3.2. Water use in the domestic sector

Water in the domestic sector accounts for the annual withdrawals and use of water by the domestic sector (households and small businesses) at country level.

Total water use in the domestic sector (*DOWU*) is calculated as the water use intensity (*DOWUI*, measured in cubic meters per capita per year) multiplied by the regional population (*POP*). Country-wide values can be allocated to regions based on population density.

$$DOWU_r = \ DOWUI_r \times POP_r$$

Over time, water use intensity may change depending on income growth and technological changes. For European countries, it has been observed that water use intensity first increases as income per capita increases but then tend to stabilize or even decline (Kuznets curve).

The relationship between water use intensity and income is derived for each country as a function of gross domestic product (GDP) and water price ($WPRI$). A technological change factor (TCH) is entered to account for the fact that improving technology leads to improvements in water use efficiency.

$$DOWUI_r = f(GDP_r, WPRI_r) \times TCH_r$$

Domestic water withdrawal ($DOWW$) accounts for losses in the distribution systems. As in all other sectors, we distinguish transport efficiency ($DOWTE$) and application efficiency.

$$DOWW_r = \frac{DOWU_r}{DOWTE_r} = \frac{DOWC_r}{DOWUE_r}$$

EU-wide estimations on domestic water use are available from WaterGAP (Florke and Alcamo 2004).

6.2.3.3. Industrial water use

It is assumed that the industrial sector includes the manufacturing, the mining, the construction and the energy production sectors. Water use in the manufacturing sector is mainly driven by the GVA in this sector. In the energy sector, the main driver of water use is electricity consumption.

Industrial water use is calculated as water use intensity times the main driver of water use. A technological change factor is also included to account for water use efficiency improvements.

$$INWU_r = \sum_i INWUI_{r,i} \times GVA_{r,i} \times TCH_{r,i}$$

The industrial water withdrawal is obtained by division by the water transport efficiency.

$$INWW_r = \frac{INWU_r}{INWTE_r} = \frac{INWC_r}{INWUE_r}$$

EU-wide estimations on industrial water use are also available from WaterGAP (Florke and Alcamo 2004).

6.2.3.4. *Irrigation water use*

As in other user sectors, we distinguish between water consumption, water use and water withdrawal.

Irrigation water withdrawal refers to the total volume of water that is withdrawn from its source for irrigation purposes. In turn, irrigation water used is the volume of water used for irrigation, that is, once the transportation losses have been discounted. Finally, water consumption refers to the volume of water evapotranspirated by crops.

$$IRWU_{ri} = \frac{IRWC_{ri}}{IRWAE_{ri}}$$

$$IRWW_{ri} = \frac{IRWU_{ri}}{IRWTE_{ri}} = \frac{IRWC_{ri}}{IRWUE_{ri}}$$

Irrigation water use is computed in the supply module of CAPRI:

$$IRWU_{ri} = \sum_{wact} CAWU_{ri,wact} \times LEVL_{ri,wact}$$

6.2.3.5. *Livestock water use*

There is no database available reporting livestock water use. To compute water use in the livestock sector, we will use livestock-specific water use intensities and multiply them by the number of livestock of each category given by CAPRI.

$$LVWU_{r} = \sum_{aact} LVWUI_{r,aact} \times LEVL_{r,aact}$$

Livestock-specific water use intensities refer to water use coefficients by animal type, and will be taken from other studies (Mc Nitt 1983, van der Leeden 1990).

6.2.4. Balancing supply and demand for water

The total water supply by region can be estimated from regional water balances and historic data. We could assume that domestic water demand is satisfied first, then industrial and livestock water demand and, finally, irrigation water demand. The approach used by the IMPACT model is similar to this one.

Assuming that domestic and industrial water demands are exogenous, potential agricultural water supply can be obtained as total water supply minus demand on the domestic and industrial sectors.

Livestock water requirements are assumed to be always met. Irrigation being the last-priority water user, total water available for irrigation will be limited. In most regions, irrigation water demand will be lower than water availability but, in some regions, irrigation water demand will reach potential water availability and, therefore, water will be a limiting factor.

This approach allows accounting for competition between agricultural and non-agricultural water use. An increase in water demand by other economic sectors (following a high population or GDP growth) will be translated in a higher pressure on agricultural water use. In addition, the effects of climate change on agricultural water demand and supply could be also taken into account.

6.3. Water balance approach in the CAPRI global market model

6.3.1. Crop-water linkages at the global level

While the detailed supply models for EU regions present great advantages for integrating water considerations, the CAPRI market module faces similar limitations than other multi-commodity models to deal with crop-water relationships.

To date, only the IMPACT model enables analysing linkages between food and water at the global level. The IMPACT food module integrates irrigation water in the behavioural functions. Above all domestic crop production is determined by area and yield response functions and both area and yield are function of irrigation water applied. To account for competition between agricultural and non-agricultural water uses, the food module is linked to a water allocation module.

In the following it is suggested to incorporate water in the supply behavioral functions of CAPRI as well as to investigate the possibility to link CAPRI to a water allocation model.

6.3.2. Water supply and demand system

Contrary to the IMPACT framework, the current CAPRI market model drives supply quantities by behavioural equations that do not distinguish between an area and a yield response.

However, in the context of the GLUES project, it is envisaged to introduce explicit land allocation in the global market model of CAPRI. One medium term goal of the initiative is to improve the interaction with plant growth models world-wide. Equally, the project aims to develop an approach to model agricultural land use change which is as far as possible empirically based and allows taking, if possible, differences in agricultural land quality into account.

A similar approach could be envisaged to integrate water allocation in the CAPRI market module.

In the current implementation of the land allocation system, land supply and demand are function of the land price. Integration of land demand consists in treating land as a net put in the normalized quadratic profit function of CAPRI. Hence, land demand from agriculture reacts to changes in the land price and output quantities depend on land prices. In order to parameterize the function, information about yield and supply elasticities is used. Land supply is integrated through a land supply curve with exogenous given elasticities.

Adopting a similar approach, we could integrate water allocation in the market module of CAPRI. Irrigation water could be incorporated in the normalized quadratic profit function of CAPRI. Assuming that irrigation water demand depends on water price, we could account for changes in irrigation water use. A specific assumption on the relation between yield and water use will be needed. Data requirements will include:

1. Data on total irrigation water use for countries / country blocks.
2. Supply elasticities for irrigation water.

Water supply could be integrated through a water supply curve with exogenous given elasticities.

Information needed to parameterize the demand and supply functions could be borrowed from other models and studies, such as the IMPACT and WATERGAP models.

6.3.3. Link to a water allocation model

A further development of the CAPRI water module could be achieved by linking CAPRI to a water allocation module. This approach, already used by the IMPACT model, will enable to improve the representation of global water balances in CAPRI, taking into account sectoral water competition and interregional water flows.

The implementation of this approach will noticeably raise the computational requirements to run the CAPRI system. Therefore, the pros and cons of the approach should be carefully balanced prior to its adoption.

6.4. Water indicators

So far, CAPRI does not distinguish between rainfed and irrigated agriculture and does not include indicators on water availability and use.

There has been a previous attempt to include water indicators in CAPRI. Crop-specific water balances were included in a previous project at a high spatial scale. As these water balances, which have not been updated recently, were included as passive indicators, their applicability in the framework of the new water module remains unclear.

Within the water module, a number of water indicators could be estimated, including:

- Share of irrigable area on total utilized agricultural area
- Share of irrigated area on total utilized agricultural area
- Crop-specific water deficit/surplus by region
- Share of irrigation water consumption on total water consumption
- Share of irrigation water use on total water use
- Share of irrigation water withdrawal on total water withdrawal
- Share of livestock water consumption on total water consumption
- Share of livestock water use on total water use
- Share of livestock water withdrawal on total water withdrawal
- Water exploitation index

7. Case study for the irrigation sub-module

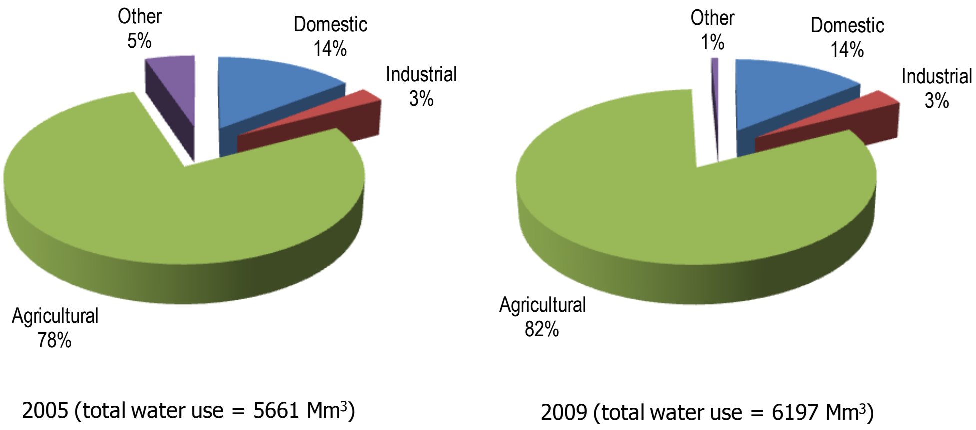
7.1. Choice of test regions

The approach has been applied to a specific case study in order to test its feasibility. Two NUTS2 regions have been selected: one with high share of irrigation (e.g. Andalucía) and one with a likely increasing need for irrigation in the future (Midi-Pyrenees).

Differentiation between rainfed and irrigated cultivation has been considered for the main irrigated activities in these regions: wheat, sunflower, maize, rice, potato, tomato, other vegetables, olive groves, citrus fruit and other fruits. Ex-post data on rainfed and irrigated areas and yields come from EUROSTAT as well as national statistics. Data on water use and irrigation projections to 2020 are derived from other studies (Junta de Andalucía 2011). Data and model structure for all other NUTS 2 regions remain unchanged.

As shown in Figure 6, agriculture is the major water user in Andalucía, accounting for about 78% of total water use in 2005 and reaching 82% in 2009.

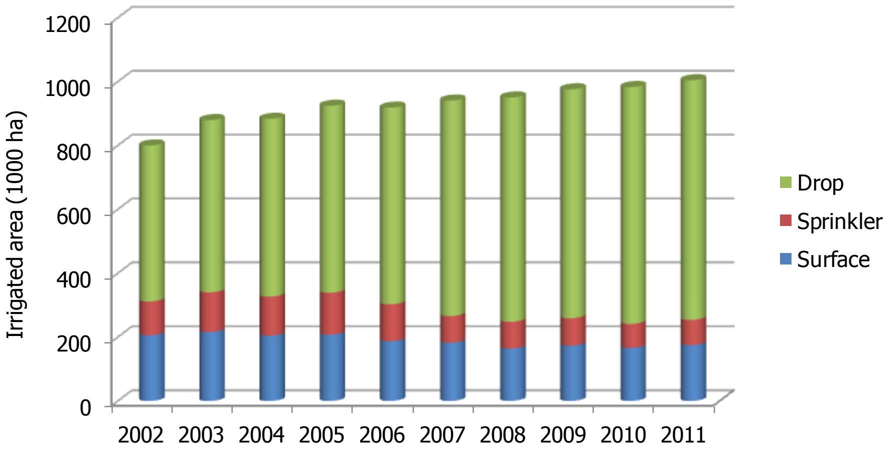
Figure 6. Total water use in Andalucía and sectoral distribution



Source: Own elaboration based on data from the Andalusian Water Agency (www.juntadeandalucia.es).

The increasing share of agricultural water use is mainly due to the gradual expansion of the irrigated area (in particular, to the irrigation of formerly dry land crops such as olive), while the average water application rate is decreasing. The declining trend in water use per hectare can be explained both for the increase in low water intensity crops and for the fast adoption of drop irrigation, replacing surface irrigation (see Figure 7).

Figure 7. Recent evolution of irrigated area in Andalucia



Source: Own elaboration based on data from MAPA 2011.

7.2. Definition of crop activities in the irrigation sub-module

Crop activities in the supply module of CAPRI have been separated into non-irrigable and irrigable. In principle, irrigable activities are those for which an irrigated area has been reported in official statistics in at least one MS. Nevertheless, since EUROSTAT only provides irrigated areas for a selected group of crops, we decided to consider as irrigable those activities which are being effectively irrigated in at least one of the selected regions.

No change has been entered in CAPRI for non-irrigable activities: they will be handled in the supply module just as before. On the contrary, irrigable activities will be split into two separated activities: rainfed and irrigated. To keep consistence with the general CAPRI framework, this separation between rainfed and irrigated production methods is done for all regions in the supply module, meaning that when an activity is not irrigated in a particular region, only the rainfed variant exists.

Table 17. Irrigable activities split into rainfed and irrigated variants

Activity	Average activity	Rainfed activity	Irrigated activity
Soft wheat	SWHE	SWHE0	SWHE1
Durum wheat	DWHE	DWHE0	DWHE1
Barley	BARL	BARL0	BARL1
Grain Maize	MAIZ	MAIZ0	MAIZ1
Paddy rice	PARI	PARI0	PARI1
Rape	RAPE	RAPE0	RAPE1
Sunflower	SUNF	SUNF0	SUNF1
Soya	SOYA	SOYA0	SOYA1
Potatoes	POTA	POTA0	POTA1
Sugar Beet	SUGB	SUGB0	SUGB1
Flax and hemp	TEXT	TEXT0	TEXT1
Tobacco	TOBA	TOBA0	TOBA1
Tomatoes	TOMA	TOMA0	TOMA1
Other Vegetables	OVEG	OVEG0	OVEG1
Apples Pears and Peaches	APPL	APPL0	APPL1
Other Fruits	OFRU	OFRU0	OFRU1
Citrus Fruits	CITR	CITR0	CITR1
Table Grapes	TAGR	TAGR0	TAGR1
Olives for oil	OLIV	OLIV0	OLIV1
Table Olives	TABO	TABO0	TABO1
Wine	TWIN	TWIN0	TWIN1
Nurseries	NURS	NURS0	NURS1
Flowers	FLOW	FLOW0	FLOW1
Fodder maize	MAIF	MAIF0	MAIF1
Fodder root crops	ROOF	ROOF0	ROOF1

Data for total irrigable and irrigated land are taken from official data sources. Table 18 displays the share of irrigable and irrigated areas in the base year (average 2003-2005) and in the last data year available (2007).

Table 18. Share of irrigable and irrigated areas in the test regions (EUROSTAT, FSS)

	Irrigable area (%)		Irrigated area (%)	
	BAS	2007	BAS	2007
ES000000	15.18	14.75	13.60	13.12
ES610000	19.18	19.22	18.14	18.01
FR000000	9.80	9.72	6.56	5.50
FR620000	15.46	15.42	11.45	9.09

For each irrigable activity, rainfed and irrigated areas have been estimated based on EUROSTAT data (FSS), when available, and other national data sources. EUROSTAT data on crop-specific irrigated areas is not available for all regions/years. In particular, for the Andalucía region no data on crop-specific irrigated areas is reported in EUROSTAT for 2003, 2005 and 2007 (Table 19). For the Midi-Pyrenees region, only 2003 data is available.

Table 19. Irrigated share per crop in the base year 2003-2005 (EUROSTAT, FSS)

	ES000000	ES610000	FR000000	FR620000
DWHE	7.31	--	15.05	0.98
MAIZ	100.00	--	43.36	78.88
SUNF	12.18	--	2.08	1.26
SOYA	13.53	--	69.11	85.32
POTA	40.18	--	36.15	20.74
SUGB	82.75	--	12.65	--
APPL	25.87	--	71.18	76.83
OFRU	25.87	--	71.18	76.83
CITR	88.95	--	100.00	--
TAGR	21.08	--	3.45	2.98
TWIN	21.08	--	3.45	2.98

Technology variants, as they are defined in the supply module of CAPRI, apply both for rainfed and irrigated activities.

7.3. Input-output coefficients for rainfed and irrigated activities

In order to keep consistency with the current CAPRI database, for each irrigable crop, rainfed and irrigated variants have been defined so as to match the "average" crop activity. That is, not only the sum of rainfed and irrigated areas will give the total crop area, but also yields and input costs for the "average" activity will be recovered as a weighted average over irrigation methods.

Because lack of accurate data, a rough procedure has been used in this case study to allocate inputs to rainfed and irrigated variants. Accounting for irrigation costs will imply a re-estimation of input costs in CAPRI, a task that is well beyond the framework of this research project. Meanwhile, irrigation costs are computed as a share of general costs.

Irrigation water use has been included as a specific input. Crop-specific water use is commonly estimated from site specific crop irrigation requirements and climatic data. Since no data on net irrigation requirements has been received by the contractor so far, data coming from a regional study has been used as an alternative for testing purposes in the Andalucía region. In contrast, no data has been found for the Midi-Pyrenees region.

Water use efficiency has been computed based on the share of irrigation methods in the region. Indicative water application efficiencies of 0.60, 0.75 and 0.90 has been used for surface irrigation, sprinkler irrigation and drip irrigation (see Brower et al. 1989).

Table 20. Share of irrigation methods in the test regions (FSS, 2003) and irrigation efficiency

Irrigation method	Andalucía	Midi-Pyrenees
Surface irrigation (%)	31.02	3.45
Sprinkler irrigation (%)	6.27	95.06
Drop irrigation (%)	62.73	9.61
Water application efficiency	0.86	0.82

A big inconsistency exists between the share of irrigation methods according to FSS data and regional statistics for Andalucía. Further work will be needed to improve the estimates on irrigation efficiency.

Regarding water transport efficiency, data is not easily available. For testing purposes, we will consider an average value of 0.80 (see Brower et al. 1989).

Technology variants for irrigated activities are entered in the same way as previously for the "average" activities in the supply model. Estimating crop-water relationships could facilitate further improvements on the way technology variants are defined.

7.4. Reference run

Once the irrigated activities have been defined and the associated input-output coefficients have been added to the CAPRI database, a new CAPRI baseline has been calibrated. The resulting baseline scenario represents the continuation of current policies and the most probable technology development until 2020. It is to a larger extend based on existing medium term outlooks for agricultural markets, but incorporates for the test regions an estimate about the development of irrigations.

For the time being, changes have been only entered in CAPMOD. In a further step, water data should ideally be incorporated in COCO and CAPREG and trends on water supply and demand should be estimated in CAPTRD.

Water considerations mainly affect the supply module in CAPRI. In CAPMOD, irrigable activities are split into rainfed and irrigated variants before solving the regional supply models and are aggregated again in the reporting part in order to allow for model comparison.

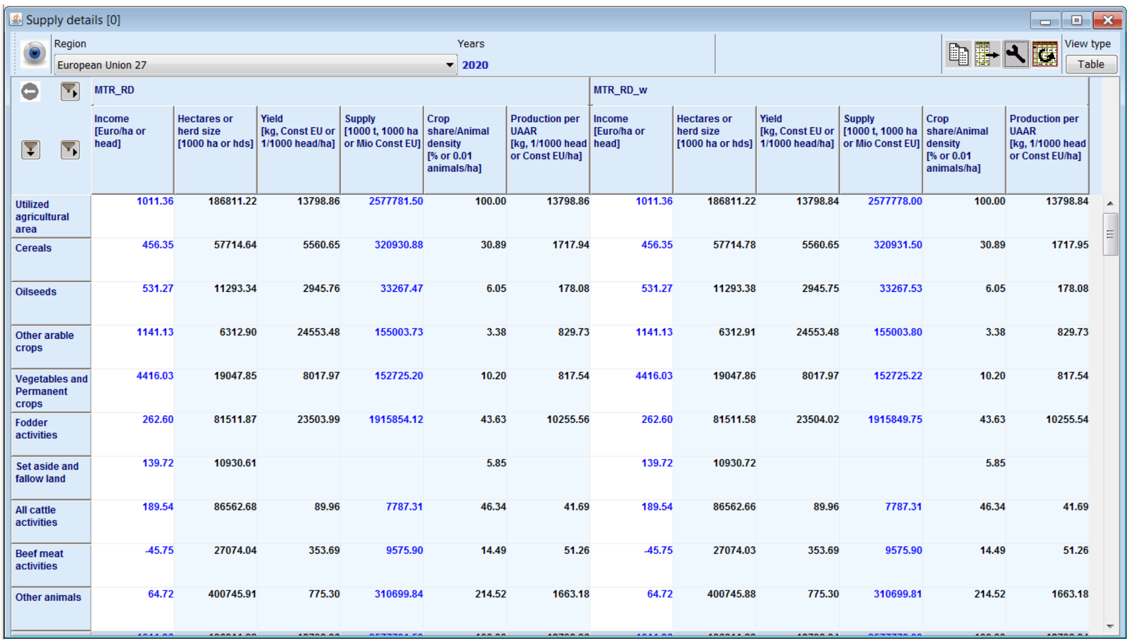
The reference run has shown the feasibility of the proposed approach. With irrigated activities, CAPRI calibrates to the same calibration point than without the irrigation module, as shown in tables 21 and 22.

Table 21. Welfare overview for the baseline scenario (without and with the irrigation module)

Region: European Union 27 — Years: 2020 — View type: Table

	MTR_RD	MTR_RD_w
Total [Mio Euro]	7813335.00	7813335.00
Money metric [Mio Euro]	7691838.00	7691838.00
Agricultural income [Mio Euro]	180970.61	180970.61
Premiums [Mio Euro]	50865.20	50865.20
EAA Output [Mio Euro]	406668.56	406668.56
Output crops [Mio Euro]	214814.66	214814.69
Output animals [Mio Euro]	232994.53	232994.52
EAA Input [Mio Euro]	276565.09	276565.09
Crop specific Input [Mio Euro]	68788.63	68788.65
Animal specific Input [Mio Euro]	128599.03	128599.01
Other Input [Mio Euro]	79177.41	79177.45
Profit of dairies [Mio Euro]	27719.44	27719.44
Profit of other processing [Mio Euro]	-42663.67	-42663.70
Tariff revenues [Mio Euro]	7139.61	7139.61
Tariff rate quota rents [Mio Euro]	678.65	678.65
Tax payers cost, total [Mio Euro]	51669.11	51669.11
Cost EU [Mio Euro]	47120.25	30909.94
Cost EU under Pillar I [Mio Euro]	43003.42	28180.44
Cost EU under Pillar II [Mio Euro]	4118.05	2733.06
Cost national budget [Mio Euro]	4550.15	3145.96

Table 22. Supply results for the baseline scenario (without and with the irrigation module)



Supply details [0]

Region: European Union 27 — Years: 2020 — View type: Table

MTR_RD

	Income [Euro/ha or head]	Hectares or herd size [1000 ha or hds]	Yield [kg, Const EU or 1/1000 head/ha]	Supply [1000 t, 1000 ha or Mio Const EU]	Crop share/Animal density [% or 0.01 animals/ha]	Production per UAAR [kg, 1/1000 head or Const EU/ha]
Utilized agricultural area	1011.36	186811.22	13798.86	2577781.50	100.00	13798.86
Cereals	456.35	57714.64	5560.65	320930.88	30.89	1717.94
Oilseeds	531.27	11293.34	2945.76	33267.47	6.05	178.08
Other arable crops	1141.13	6312.90	24553.48	155003.73	3.38	829.73
Vegetables and Permanent crops	4416.03	19047.85	8017.97	152725.20	10.20	817.54
Fodder activities	262.60	81511.87	23503.99	1915854.12	43.63	10255.56
Set aside and fallow land	139.72	10930.61			5.85	
All cattle activities	189.54	86562.68	89.96	7787.31	46.34	41.69
Beef meat activities	-45.75	27074.04	353.69	9575.90	14.49	51.26
Other animals	64.72	400745.91	775.30	310699.84	214.52	1663.18

MTR_RD_w

	Income [Euro/ha or head]	Hectares or herd size [1000 ha or hds]	Yield [kg, Const EU or 1/1000 head/ha]	Supply [1000 t, 1000 ha or Mio Const EU]	Crop share/Animal density [% or 0.01 animals/ha]	Production per UAAR [kg, 1/1000 head or Const EU/ha]
Utilized agricultural area	1011.36	186811.22	13798.84	2577778.00	100.00	13798.84
Cereals	456.35	57714.78	5560.65	320931.50	30.89	1717.95
Oilseeds	531.27	11293.38	2945.75	33267.53	6.05	178.08
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Vegetables and Permanent crops	4416.03	19047.86	8017.97	152725.22	10.20	817.54
Fodder activities	262.60	81511.58	23504.02	1915849.75	43.63	10255.54
Set aside and fallow land	139.72	10930.72			5.85	
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Beef meat activities	-45.75	27074.03	353.69	9575.90	14.49	51.26
Other animals	64.72	400745.88	775.30	310699.81	214.52	1663.18

Tables 23 and 24 compare results for the CAPRI baseline with and without the irrigation module, with a special focus on rainfed and irrigated areas.

Table 23. Rainfed and irrigated areas in the Andalusian region (1000 ha)

	Baseline	Baseline (with irrigation module)		
		Average	Rainfed	Irrigated
Utilized agricultural area	5469.3	5469.3	4468.9	1000.4
Cereals	680.3	680.3	592.4	87.9
Oilseeds	172.0	172.0	152.2	19.8
Other arable crops	190.3	190.3	190.3	0.0
Vegetables and Permanent crops	1972.5	1972.5	1079.9	892.7
Soft wheat	96.6	96.6	88.8	7.7
Durum wheat	318.7	318.7	293.2	25.5
Barley	113.6	113.6	113.6	
Grain Maize	27.8	27.8		27.8
Paddy rice	26.9	26.9		26.9
Rape	1.3	1.3	1.3	
Sunflower	165.0	165.0	145.2	19.8
Soya	0.9	0.9	0.9	
Potatoes	8.3	8.3		8.3
Sugar Beet	13.1	13.1	13.1	
Tobacco	0.5	0.5	0.5	
Tomatoes	8.7	8.7		8.7
Other Vegetables	21.8	21.8		21.8
Apples Pears and Peaches	25.7	25.7	10.3	15.4

Other Fruits	199.5	199.5		199.5
Citrus Fruits	84.6	84.6		84.6
Table Grapes	1.4	1.4	1.4	
Olives for oil	1476.6	1476.6	959.8	516.8
Table Olives	107.3	107.3	69.7	37.5
Wine	27.1	27.1	27.1	

Source: Own elaboration from CAPRI-Water results

Table 24. Rainfed and irrigated areas in the Midi-Pyrenees region (1000 ha)

	Baseline	Baseline (with irrigation module)		
		Average	Rainfed	Irrigated
Utilized agricultural area	2469.7	2469.7	2290.3	179.4
Cereals	644.7	644.7	516.6	128.1
Oilseeds	260.4	260.4	218.4	42.0
Other arable crops	9.8	9.8	9.8	0.0
Vegetables and Permanent crops	202.2	202.2	192.9	9.2
Soft wheat	185.0	185.0	185.0	
Durum wheat	179.4	179.4	175.8	3.6
Barley	70.6	70.6	70.6	
Grain Maize	157.7	157.7	33.1	124.6
Rape	19.1	19.1	19.1	
Sunflower	190.1	190.1	186.3	3.8
Soya	45.0	45.0	6.8	38.2
Potatoes	0.4	0.4	0.3	0.1
Sugar Beet	0.0	0.0	0.0	
Tobacco	0.4	0.4		
Tomatoes	0.4	0.4	0.4	
Other Vegetables	22.2	22.2	22.2	
Apples Pears and Peaches	4.1	4.1	1.0	3.2
Other Fruits	7.8	7.8	1.8	6.0
Citrus Fruits	0.1	0.1	0.1	
Table Grapes	1.2	1.2	1.2	
Wine	32.6	32.6	32.6	

Source: Own elaboration from CAPRI-Water results

The irrigation sub-module has been built in such a way that baseline results will be similar to the previous CAPRI baseline without endogenous water considerations.

Even if splitting irrigable activities into two separate activities will almost duplicate the number of endogenous crop activities in the supply module, this approach shows great advantages. First, it is fully consistent with the current CAPRI framework, meaning that the water module could be further developed step by step without interfering with the CAPRI master version. Second, it is fully modular in the way that CAPRI could be applied both with and without the water module.

7.5. Testing policy scenarios

Water policy scenarios like the Water Framework Directive could be modelled in CAPRI once the irrigation module will be fully operational. The irrigation module will also enable CAPRI to simulate the potential impact of climate change and water availability on agricultural production at the regional level.

To illustrate the potentiality of the approach, water policy scenarios, consisting in introducing irrigation water prices, are compared to the baseline situation. In this first testing application of the module, the counterfactual water pricing scenario differs from the baseline only in the irrigation water price, ranging between 0.2 to 0.4 Euros per cubic meter.

Tables 25 and 26 display the impact of irrigation water pricing on irrigated areas and water use. As expected, total irrigated land decreases as the water price increases. This effect is more acute in the Midi-Pyrenees region.

Table 25. Impacts of water prices on irrigated areas and water use (Andalucía)

	Baseline scenario	Irrigation water price scenario		
		0.2 €/m3	0.3 €/m3	0.4 €/m3
Irrigated area (1000 ha)				
Cereals	87.87	71.69	63.13	54.55
Oilseeds	19.81	14.74	11.9	9.15
Fruits and vegetables	338.33	328.34	321.91	315.05
Olive groves	554.34	551.89	548.81	545.22
Total irrigated land	1000.35	966.66	945.75	923.97
Utilized agricultural area (1000 ha)	5469.25	5469.25	5461.8	5452.23
Irrigation share (%)	18.29	17.67	17.32	16.95
Water use (Mio m3)	3633.93	3383.99	3246.2	3105.48

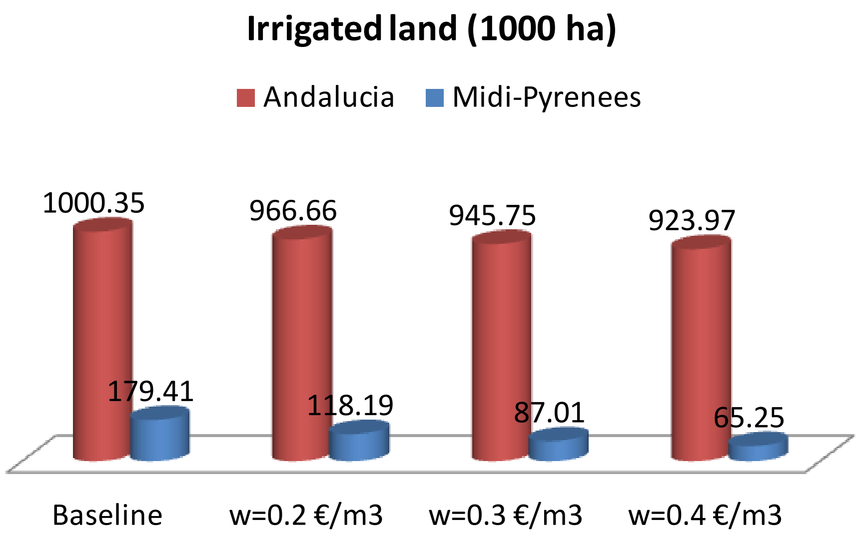
Source: Own elaboration from CAPRI-Water results

Table 26. Impacts of water prices on irrigated areas and water use (Midi-Pyrenees)

	Baseline scenario	Irrigation water price scenario 0.2 €/m3	0.3 €/m3	0.4 €/m3
Irrigated area (1000 ha)				
Cereals	128.14	72.66	44.46	25.84
Oilseeds	42.03	36.31	33.34	30.21
Fruits and vegetables	9.24	9.22	9.21	9.2
Olive groves				
Total irrigated land	179.41	118.19	87.01	65.25
Utilized agricultural area (1000 ha)	2469.73	2469.73	2469.73	2469.73
Irrigation share (%)	7.26	4.79	3.52	2.64
Water use (Mio m3)	963.93	562.57	358.65	240.48

Source: Own elaboration from CAPRI-Water results

Figure 8. Regional irrigated land under alternative water pricing scenarios

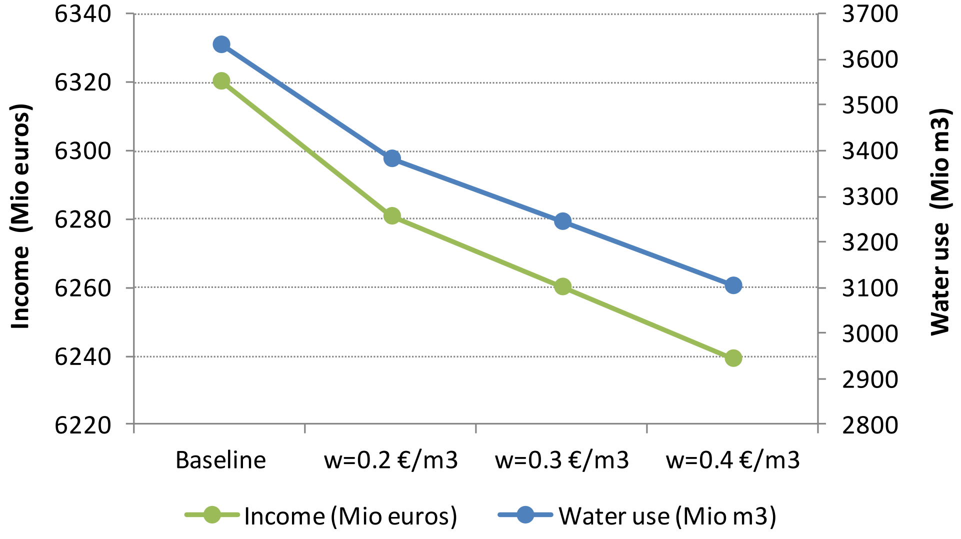


Source: Own elaboration from CAPRI-Water results

Figure 8 displays changes in irrigated land in both regions as a result of increasing water prices.

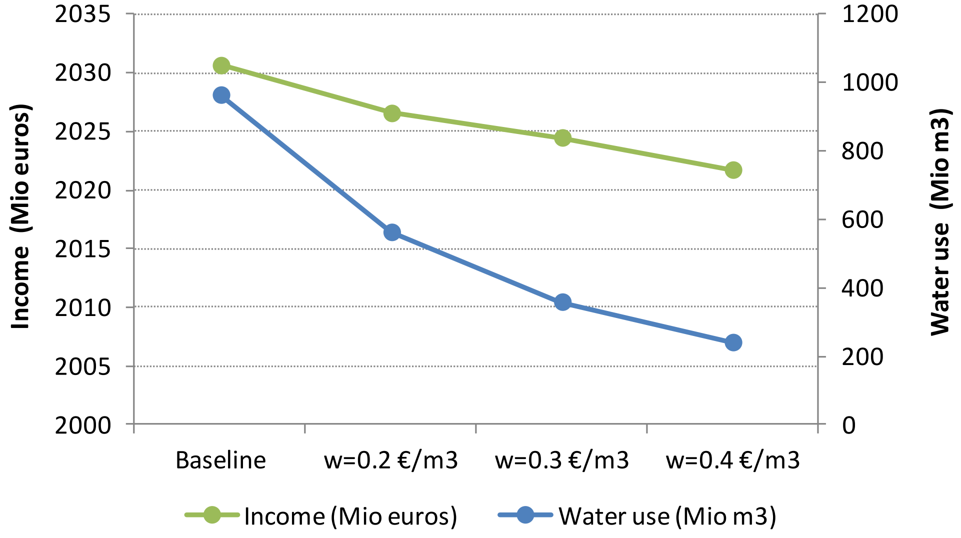
Figures 9 and 10 show the simulated impacts on regional agricultural income and total irrigation water use. Because of decreasing supply for irrigated crops, producer prices increase as the water price increases. However, in our case study for one European region, that effect is minor, mainly because we simulated a water price increase in only one European region. Consequently, impacts in demand are also not significant. Only for paddy rice a clear price effect is observed.

Figure 9. Agricultural income and irrigation water use under alternative water pricing scenarios (Andalucía)



Source: Own elaboration

Figure 10. Agricultural income and irrigation water use under alternative water pricing scenarios (Midi-Pyrenees)



Source: Own elaboration

These results are very preliminary as the water module is still under development. Nonetheless, they already illustrate the potentiality of the approach to analyse agrifood and water policies in a joint framework. In contrast with most commonly used approaches, feedback through market prices is taken into account.

8. Concluding remarks and further steps

Incorporating water issues in EU-wide agro-economic models is crucial to analyse future agricultural policies in a context of climate change and increasing pressure on water resources.

The development of the CAPRI water module will enable to provide scientific assessment on agricultural water use within the EU and to analyse agricultural pressures on water resources at the regional level:

- In the irrigated regions, the impacts on irrigation water demand of alternative agricultural and water policies could be evaluated. Even if the approach does not account for the heterogeneity of climate and water conditions inside each region, it will give an indication on the futures changes in water use following changes in agricultural and water policies.
- In all regions, crop-specific water balances could be combined with NPK balances to evaluate impacts of water leaching on pollution. Also, the results from CAPRI could serve as input into biophysical models to derive future irrigation water demand at a higher spatial resolution.

Nevertheless, for the water module to become operational, several steps are still required:

1. Re-estimation of input costs to differentiate irrigation costs (water, electricity, etc.) from other input costs.
2. Estimation of crop net irrigation requirements at the EU regional level, as well as water-limited and non-water-limited crop yields. The AquaCrop model is a good alternative to compute irrigation requirements as well as potential yields. Furthermore, AquaCrop calculates both water use and leaching with and without irrigation.
3. In irrigated regions, estimation of input-output coefficients for rainfed and irrigated activities for all irrigated activities within the EU. For this step to be undertaken, the two previous steps have to be accomplished.
4. Estimation of water availability and sectoral water use at the regional level. Results from other studies could be used instead.
5. Integration of the water database into the CAPRI database.

A limiting factor for the development of the water module is the lack of homogeneous and accurate data at EU-wide level for a good number of relevant variables such as irrigation costs, irrigation water use, irrigation efficiency, crop-specific irrigated areas, crop yields under rainfed and irrigated conditions, etc. In some cases, input from other biophysical models could be used as an alternative option.

Furthermore, the lack of adequate data to calibrate the model limits its applicability to simulate policy regulatory constraints on irrigation. For instance, since data on irrigation methods is very limited, policy measures related to irrigation equipment can only be modelled in a rough way.

Also, data on irrigation costs needs to be improved if adoption of irrigation in rainfed regions is to be modelled. Although substitution between rainfed and irrigated crops will be possible, methodological problems could arise to calibrate irrigation costs in newly irrigated regions. Assuming that a rainfed crop will be irrigated (at least partially) in the simulation year, a cost transfer approach could be used to estimate irrigation costs in the baseline for this crop.

Other limitation of the approach refers to its potentiality to simulate climate change scenarios. Because of the missing link with climatic data, climate change scenarios will imply higher/lower irrigation requirements or higher/lower irrigation water availability, both entered as exogenous changes.

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Title: Exploring the feasibility of integrating water issues into the CAPRI model

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Abstract
Although numerous modelling efforts have integrated food and water considerations at the farm or river basin level, very few agro-economic models are able to jointly assess water and food policies at the global level. The present report explores the feasibility of integrating water considerations into the CAPRI model.
First, a literature review of modelling approaches integrating food and water issues has been conducted. Three agro-economic models, IMPACT, WATERSIM and GLOBIOM, have been analysed in detail. In addition, biophysical and hydrological models estimating agricultural water use have also been studied, in particular the global hydrological model WATERGAP and the LISFLOOD model.
Thanks to the programming approach of its supply module, CAPRI shows a high potentiality to integrate environmental indicators as well as to enter new resource constraints (land potentially irrigated, irrigation water) and input-output relationships. At least in theory, the activity-based approach of the regional programming model in CAPRI allows differentiating between rainfed and irrigated activities.
The suggested approach to include water into the CAPRI model involves creating an irrigation module and a water use module. The development of the CAPRI water module will enable to provide scientific assessment on agricultural water use within the EU and to analyze agricultural pressures on water resources.
The feasibility of the approach has been tested in a pilot case study including two NUTS 2 regions (Andalucia in Spain and Midi-Pyrenees in France). Preliminary results are presented, highlighting the interrelations between water and agricultural developments in Europe.
As a next step, it is foreseen to further develop the CAPRI water module to account for competition between agricultural and non-agricultural water use. This will imply building a water use sub-module to compute water use balances.

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