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DEVELOPMENT OF FUNCTIONAL IRRIGATION TYPES FOR IMPROVED GLOBAL CROP MODELLING

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Abstract

About 70% of global human water withdrawal from rivers, reservoirs, and aquifers is for irrigation of agricultural land, and about one third of global food production relies on irrigation water. Irrigation systems, however, are usually rather ineffective; much of the withdrawn water is lost before it reaches the plants that require the water for optimal growth. The efficiency of irrigation often is lower than half of the optimum (depending e.g. on climate and irrigation system), such that the accuracy of modelled efficiency may have strong effects on the simulated water cycle and the distribution, seasonal phenology, and productivity (yields) of crop types. Therefore, it is crucial to estimate irrigation efficiencies as detailed as possible in any (large-scale) irrigation assessment.

In this study, generic irrigation functional types (IFTs) have been developed for a better representation of irrigation in the dynamic global vegetation and water balance model including managed land, LPJmL (Bondeau et al., 2006). LPJ is a model of intermediate complexity, representing the intra- and interannual dynamics of terrestrial vegetation (both natural and agricultural) and the associated biophysical and biogeochemical processes (e.g. carbon and water fluxes). Irrigation of agricultural vegetation is one important option of land and water management in this model. The IFTs developed here improve the way in which irrigation efficiencies have been considered in the pilot version of LPJmL. With the introduction of IFTs into LPJmL together with the recently implemented discharge accumulation along a global river topology (Jachner et al., submitted), water flows on agricultural land are represented in a more precise manner.

The present country-scale IFT classification was derived from the dominant irrigation method (surface, sprinkler, or micro-irrigation), irrigation field size, and the associated management system, based on an extensive review of literature and data archives. We determine an overall irrigation project efficiency for each country. This overall efficiency is comprised by a combination of individual (partial) efficiencies that capture water losses a) from the conveyance systems (conveyance efficiency), b) when the irrigation water is brought to the field (field application efficiency), and c) a management factor determined by the irrigation system size, which is a substitute of distribution efficiency (the unequal distribution of irrigation water across the fields). The effectiveness in terms of timeliness of delivery is represented by application of scheduling rules. The dominant irrigation method is used to assign the respective IFT to each country; for a few countries where relevant data were not available, a statistical assignment procedure based on socio-economic and climatic information was employed. The resulting country-scale irrigation efficiencies are tabulated and presented in global maps. Our efficiencies compare well with earlier values that had been derived for larger regions; yet, the present study provides more detailed and consistent estimates of irrigation efficiencies, which owing to their generic nature are suited for application in any large-scale model that represents agricultural water use.

Content

1 Introduction

During the 20th century irrigated agriculture gained an unprecedented importance for global food supply. At the same time, it is one of the principal direct actions disturbing the hydrological cycle and associated ecosystems, thus irrigated agriculture plays a critical role in the modification of evapotranspiration and runoff. It also influences directly and indirectly global environmental change, yet the “issue of interplay among water vapour flows, agricultural food production, and the generation of ecosystem services in terrestrial biomes” has been addressed only recently (Rockström et al., 1999). Although the impacts of irrigation are not yet fully understood, it is already evident that they will gain even more importance in the future, as food security and climate change are major issues of the forthcoming decades, and water withdrawal for irrigation influences both.

Irrigation systems are usually rather ineffective; much of the extracted water is lost – mainly by unproductive evaporation – before it reaches the crops, such that more water has to be withdrawn than is actually needed by the plants. Israelsen first defined irrigation efficiency as “the ratio of irrigation water transpired by the crops of an irrigation farm or project during their growth period, over the water diverted from a river or other natural source into the farm or project canal or canals during the same period of time“ (Israelsen, 1932, in: Wolff & Stein, 1999). The efficiency of irrigation often is lower than half of the optimum required by the crops, such that the accuracy of modelled efficiency is anticipated to have strong effects on the simulated water cycle and the distribution, seasonal phenology, and productivity of crop types. Therefore, it is crucial to estimate irrigation efficiencies as detailed as possible in any (large-scale) irrigation assessment.

In the present study, irrigation functional types (IFTs) are developed for a better representation of irrigation in the dynamic global vegetation and water balance model LPJmL (Sitch et al., 2003; Gerten et al., 2004a; Bondeau et al., 2006). LPJ is a model of intermediate complexity representing large-scale, process-based terrestrial vegetation dynamics (both natural and agricultural vegetation) in a single framework. It is also suitable for the simulation of global ecohydrological processes since terrestrial water and carbon cycles are closely coupled (Gerten et al., 2004a), especially since dicharge accumulation in river systems and water withdrawal from alkes and reservoirs have recently been implemented (Jachner et al., unpublished data). The new “managed land” (mL) model version thus is an enhancement of the earlier LPJ model, which can be used for assessing the role of agriculture and related water and carbon fluxes within the global climate-biosphere system. Irrigation is one option of land management in this model. However, up to now there is only a crude distinction between optimum irrigated and non-irrigated agriculture. Thus, the irrigation efficiency classification and scheduling rules developed here represent an important further development of the LPJmL model, especially since their implementation will help to estimate the volume of water needed to satisfy crop water requirements on irrigated areas with more confidence.

LPJmL uses generic plant functional types (PFTs) that represent natural terrestrial biomes and crop functional types (CFTs) (Bondeau et al., 2006). These functional types are generalised plant prototypes designed to capture the multitude of structures and functions of plants. The country-scale IFTs proposed here follow an analogous principle, that means they capture key functions of irrigation systems derived from a classification of the features of the variety of individual irrigation systems. They represent combinations of irrigation methods and of irrigation scheme sizes, derived from extensive analysis of literature and databases (see Annex A). Their sample areas can cover some hundreds to several thousands of hectares. While the distribution of PFTs and CFTs depends on climatic limits, IFTs are however bound to nation states, as socio-economic and political reasons are usually decisive for irrigation method choices within administrative units. Due to the often poor data availability, a scale below country level is not applicable within this framework and an IFT is assigned to each country where irrigated agriculture takes place.

Several models other than LPJmL compute global irrigation (e.g. Cai & Rosegrant, 2002; Döll & Siebert, 2002; Siebert et al., 2005). For their modelling of water requirements, Döll & Siebert (2002) calculate net irrigation requirements due to climate and cropping patterns on a 0.5° resolution. They further distinguish gross irrigation requirements, based on regional project irrigation efficiency estimates aggregated to several geographic regions. The spatial resolution and geographic differentiation of these efficiencies will be enhanced here. Cai & Rosegrant (2002) used a partially different approach, with river basins as reference areas. Their gross irrigation water demand follows the approach of effective efficiency (or basin efficiency) instead of project efficiency. Basin efficiencies are calculated as the ratio of the theoretical net irrigation water demand and recorded total irrigation water depletion estimates. A similar approach was used by Seckler et al. (1998). They estimated effective efficiencies on a national scale. The effective efficiency is based on total water withdrawal per gross irrigated area, area equipped for irrigation, cropping intensity and estimated crop water requirements. These approaches of irrigation efficiency use estimated evaporation rates and recorded water discharge, and it is not intended to couple them with socio-economic factors. The here proposed generic IFTs adopt a different strategy, as they are based on technical and managerial equipment. Hence their values can potentially be adapted to changing socio-economic circumstances. Hence, the IFTs are less dependent on input data.

The structure of this report is as follows:
Chapter 2 gives an introduction into the dilemma between human water needs and the ecological consequences of human water withdrawal.
Chapter 3 presents the fundamentals of irrigation: Basic technical information about irrigation methods, water conveyance, scheduling and management are provided in the first section. Major sources of water losses and other problems are then explained. These two sections form the basis for the later determination of irrigation efficiencies.
The current implementation of irrigation in LPJmL and its potential starting points for improvement are presented in chapter 4.
In the main part (chapter 5), IFTs and their attributes are developed. The classification into IFTs follows the dominant method of irrigation water application, as these determine most efficiency potentials and possible scheduling approaches. In addition, information about the size of irrigation systems is incorporated. Hence, as a first step all countries where irrigated areas have been reported, are assigned an IFT. Then irrigation efficiencies are defined. As there is a lack of data on the geographical distribution of irrigation techniques (Boucher et al., 2004), for countries where data about the actual application methods are not available, conclusions have been drawn about the most likely prevalent irrigation techniques. The distribution of prevailing IFTs and the assigned project efficiencies are represented in various maps; in an additional map the reliability of this information is assessed. A validation of IFTs has not yet taken place because this requires implementation of IFTs in LPJmL. In a next step, scheduling rules are proposed for each IFT to deal with the effect of different timeliness of delivery. Also considered in the scheduling rules is paddy rice, which is a cultivar with different irrigation rules.
Finally (chapter 6) the results and restrictions of the approach are diuscussed.

2 Importance of irrigation for food production

Water is vital for every living organism. It is one of the key determinants of photosynthesis and a major driving force in the global energy balance. However, although water is abundant on the “blue planet” Earth, most of it is saltwater or frozen freshwater and not available for anthropogenic usage. Actually, less than 1 % of the global water resources are freshwater (Townsend et al., 2000) and approximately one third of the global runoff is directly accessible (Vörösmarty & Sahagian, 2000). The limited availability of water creates a dilemma with restricted scope for denouement, especially in view of the ever-increasing human population (Vörösmarty et al., 2000).

Water is a renewable resource. It is never really lost but continuously transformed into different aggregate states and redistributed in time. Precipitation reaching the earth surface is portioned into interception, percolation, and (sub)surface runoff. Water infiltrating into the soil adds to soil moisture or groundwater and by this means to evaporation and plant transpiration. Thus rainfall is divided into water vapour flows and liquid water flows. Falkenmark (2003) and Rockström et al. (1999) refer to green, blue and white water (Figure 1). Green water is the soil moisture, which returns to the atmosphere via plant transpiration, i.e. the fraction of water used for biomass production. White water is the soil moisture and interception loss that is evaporated without contributing to biomass production. It is sometimes regarded as “unproductive” green water. Blue water comprises the total runoff formed by surface runoff and groundwater recharge.

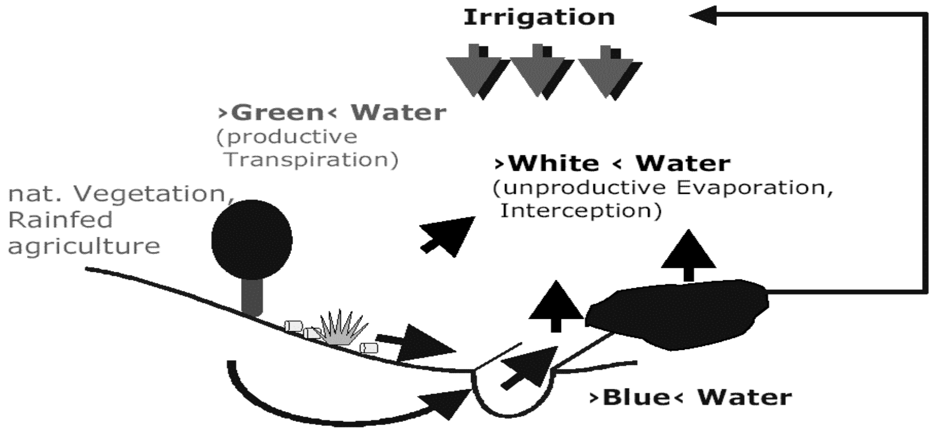

Figure 1 Partitioning of water flows into green, blue, and white (Gerten 2006, pers. comm.)

Usually, when freshwater resources are assessed, green water is ignored, perhaps because it is invisible in contrast to flowing water streams and springs. This “water blindness” has recently been addressed by Falkenmark (2003). Yet, when water scarcity is the issue, it is still only about blue water in most if not all water resources assessments.

10 to 15% of the global freshwater supply is withdrawn for anthropogenic purposes and this share could increase to more than 40% by 2025 (Vörösmarty & Sahagian, 2000). Irrigation consumes 72% of this global water exploitation and even 90% in developing countries (Cai & Rosegrant, 2002). Thus, worldwide around 277 million ha or 18.5% of the cultivated area is irrigated (ICID, 2000; FAOStat, http://faostat. fao.org). The productivity of irrigated areas is considerably higher than that of rainfed areas (usually two- to threefold). Extended irrigation is part of agricultural production intensification and one of the technologies enabling cropland increase and “Green Revolution” production gains (Foley et al., 2005). Irrigated agriculture produces ~40% of global yields (Siebert et al., 2005). However soil moisture, i.e. green water, remains the water source of the majority of crop yields, even in irrigated areas. Thus, the importance of green water will rise in the future, especially since potentials to increase irrigation are limited. The percentage of water available for irrigation is likely to decrease throughout the next decades (Guerra et al. 1998; Wallace & Gregory, 2002).

Water scarcity is a social construct, introduced by Falkenmark (1989), which depends on population figures and water needs. This means water becomes scarce because people use it for food security, cash crops, households and industries, not seldom to a degree that exceeds the renewable resources. Water availability can be measured in persons per flow unit; countries are regarded as water stressed if less than 1700 m³ per capita are annually available. Regions or countries suffer from absolute water scarcity at a value <1000 m³ per capita per year. Currently approximately 7% of the global population are living in area with some form of water stress (Wallace & Gregory, 2002).

In the future, water scarcity will probably be more strongly triggered by population growth than by climate change (Vörösmarty et al., 2000). The regions with the highest need for green water deficiency compensation are mainly the semi-arid tropics and subtropics, which are exactly the regions with the worst undernutrition problems and highest population growth rates already today (Falkenmark, 2003). Where green water availability is restricted due to low precipitation rates, blue water supplies are usually limited as well. But the deficit must be compensated by provision of additional water either by increasing water infiltration into the rooting zone or by conventional irrigation (Falkenmark, 1997). The first approach increases the share of green water directly while the later one is a transformation of blue water into green water decreasing the availability of blue water. In both cases there must be a source for additional water, namely precipitation. The pressure on water resources is predicted to increase until 2025, when approximately 66% of the world population will experience some water stress (Wallace & Gregory, 2002). Around 55% of the population will, according to these estimates, be unable to meet their food requirements and rely on food imports instead. If water use efficiencies of irrigated and rainfed agriculture are not enhanced enormously, additional land will need to be transformed to cropland, at the expense of the area covered by natural terrestrial ecosystems (Falkenmark, 1997; Rockström et al., 1999). Yet, agriculture as the main water consumer is challenged by other users. Urban, domestic, industrial and ecological purposes must be served as well. Also, in addition to the already existing water uses, new forms of land use are developed as well. With regard to climate change, biofuels gain more and more attention and importance. Yet, biomass for energy production requires land and water resources and enters into competition with crop production (Berndes, 2002; Berndes et al., 2003). Overall water for agriculture enters into an economic rivalry with all other potential uses.

Besides, terrestrial and aquatic ecosystems are affected in different ways. Due to the feedback mechanisms between ecosystem dynamics and the variability of water flow patterns, water is required for ecosystem resilience (Rockström et al., 1999). Disturbances of ecosystem water balance can lead to augmented vulnerability. Less water is available for photosynthesis, wildlife support, and habitat maintenance of some natural biomes while additional water is supplied to others. In semi-arid and arid regions where green water scarcity is compensated by irrigation, introduction of new cultivars changes the local and regional biodiversity. Irrigation often comes along with intensified use of fertilisers and pesticides degrading water quality and contributing to an anthropogenic nutrient input in other ecosystems. Salinization, soil degradation and soil erosion are negative side effects of irrigation as well. They cause a loss of arable area of approximately 1.5 million ha per year (Foley et al., 2005). If human-induced nutrient cycle changes and soil degradation are introduced in LPJmL, irrigation must be taken into account as well.

In addition to these direct biosphere modifications, human appropriation of freshwater significantly impacts global climate change as well. Terrestrial ecosystems, independent of any human influence, play a crucial role in portioning precipitation into green, blue and white water (Falkenmark, 2003). Usually, anthropogenic land cover changes result in increased surface runoff and river discharge (Foley et al., 2005), or, in other words, a higher fraction of blue water. However, irrigation increases plant transpiration and therewith green water flows. Earlier LPJ simulations of global green and white water fluxes showed a shift from evaporation to transpiration on cultivated areas (Gerten et al., 2004b).

Additionally, water vapour is “the most important greenhouse gas in the atmosphere” (Boucher et al., 2004). Disturbances of the hydrological cycle are linked with global climate change in this way. Several regional studies indicate an impact of irrigation on regional surface temperature, convection and cloud formation, precipitation, and humidity (Boucher et al., 2004 provide an overview of these studies). A first assessment of the impact of irrigation on global climate is provided by Boucher et al. (ibid). On a global scale, different atmospheric responses to increased agricultural water use are possible as well (Figure 2).

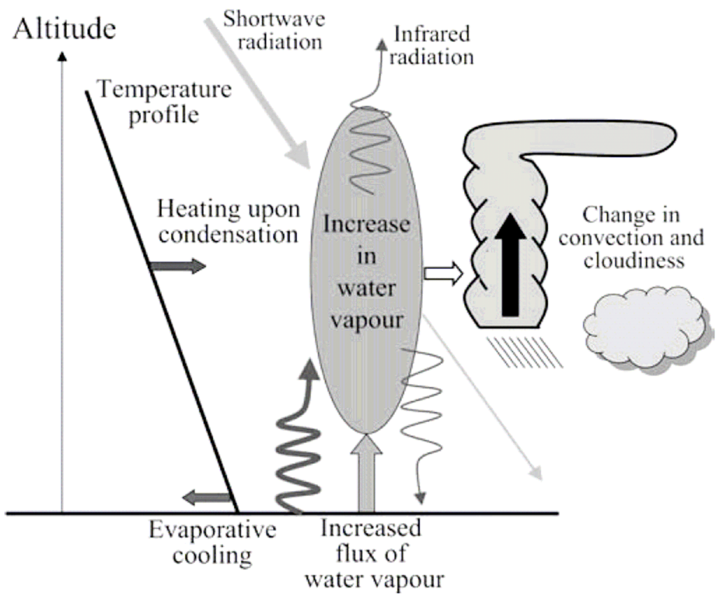

Figure 2 Atmospheric properties and processes potentially induced by irrigation (Boucher et al., 2004)

Boucher et al. (2004) indicate a substantial increase in water vapour content, which was found to be the largest close to the surface. Simultaneously, a significant decrease of the lower troposphere temperature above irrigated continental regions was also found. Combined, these processes cause a large increase in relative humidity. These findings are especially significant in the atmosphere above South Asia, where the majority of the irrigated areas are located. Boucher et al. (2004) conclude that “as a whole these results highlight irrigation as a key climate forcing mechanism among others to understand the inhomogeneous (i.e. regional) pattern of observed temperature changes” (ibid).

In sum, irrigation appears to be influential on different scales and in different Earth system contexts. Hence, it is important to consider effects of irrigation and their global outcomes as precise and process-based as possible, using the best available information. This study contributes to a more sophisticated modelling of irrigation, mainly in terms of efficiency and scheduling, by design of IFTs. Thereby an improvement of blue water representation in LPJmL is proposed. This influences green water flows as well, due to the interdependence within the water cycle. The principles upon which IFTs are developed are presented in the next chapter.

3 Fundamentals of irrigation

This section provides the theoretical background for the development of IFTs described below. The conventional structure of irrigation schemes is explained with their main technical and administrative features and their different possible configurations. The second part of the chapter deals with constraints of water distribution for each of the schemes introduced before. Usually a part of the water which has been withdrawn from a source for irrigational purposes does not reach the plants but is lost on the way. The different features of irrigation systems determine where, and how much, water is lost.

3.1 Structure and functioning of irrigation systems

Existing irrigation systems can be structured according to field application methods, conveyance systems, scheduling methods and management. These aspects of the irrigation scheme determine the overall water use efficiency, i.e. the ratio between water that actually transpires by crops and agricultural water withdrawal. Scheduling provides information regarding the time period within a year when water is made available (accessible to farmers).

Field application method

Basically three types of field application methods can be distinguished: Surface irrigation, sprinkler irrigation and micro- or localised irrigation (Brouwer et al., 1988; Cornish, 1998; Pereira, 1999; Aillery & Gollehon, 2003).

Surface irrigation
Surface irrigation is the most common irrigation method worldwide (Pereira, 1999). All traditional and ancient irrigation systems have been of this type. The term surface irrigation comprises all methods of applying water by gravity flow to the surface of the field (Brouwer et al., 1988). The prevailing techniques are flooding (basin irrigation) and distribution of water via small canals (furrow irrigation) or strips of land (border irrigation).
Basin irrigation is the most common kind of surface irrigation worldwide. Basins are levelled fields surrounded by dykes, which keep the water on the field. This is the favourite method to grow paddy rice[1]. In Southeast Asia basin irrigation is often applied on small terraces on steep slopes. This method can also be applied to other field crops, which are not prone to water logging or wet conditions lasting more than 24 hours.
Furrow irrigation is preferably used to grow crops vulnerable to inundation, broadcast crops, such as cereals, tree crops, and especially row crops such as tobacco. Here ditches are evenly spread on the field to wet the rooting zone of the crops growing between them. For sufficiently high lateral infiltration, water discharge rates must be balanced carefully. To avoid soil erosion, this method is only suitable on gentle slopes.
In border irrigation, water is applied to land strips separated by dikes but open at the downstream end. Inflow rates and duration of application depend on the soils' slopes, which should in general be shallower than in case of furrow irrigation. This irrigation method is best suited for pasture and fodder grass. Because field lengths are usually high, a high degree of mechanization is possible.

Figure 3 Furrow irrigation in North America (Jack Joseph, http://www.lbl.gov/Science-Articles/Archive/EETD-BETR-Krotz.html, 02.08.2006)

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[1] However recent research indicates that it is a misleading but widespread assumption that traditional basin irrigation is the most suitable method to grow rice (Guerra et al., 1998).

Sprinkler irrigation

Sprinkler or spray irrigation is one type of pressurised irrigation. Small droplets of water are sprayed over or under the crop canopy. A wide variety of different sprinkler systems are available from small-scale portable systems (hand-moved sprinklers) to large-scale full-automated stationary systems (Cornish, 1998). This method can be applied to most row, tree, and field crops. The Great Plains in the USA are well known for their large sprinkler irrigated areas (Klohn, 1995).

Figure 4 Sprinkler irrigation in the United States (US Geological Survey, http://ga.water.usgs.gov/edu/irsprayhigh.html, 02.08.2006)

Micro-irrigation

Micro- or localised irrigation or low-flow irrigation systems is another type of pressurised irrigation. Small amounts of water are directly applied to the crop rooting zone via low discharge emitters. Piped distribution systems have already been invented in the late 19th century. Different application technologies are available for localised irrigation such as drip or trickle irrigation, micro-sprinkler or subsurface emitters. Due to its high capital cost, micro-irrigation is commonly only applied to high-value crops such as vegetables and perennial crops, mainly orchards and vineyards. Micro-irrigation is widespread in the Mediterranean area, for example in Malta, Cyprus and Israel (FAO, 1997b).

Figure 5 Micro-irrigation in the United States (Nova Scotia Agriculture and Fisheries, http://ga.water.usgs.gov/edu/irdrip.html, 02.08.2006)

Conveyance system

Unless water is supplied by wells in the field, it needs to be transported from a source to the field. This is usually done in a ramified canal or pipeline system. These conveyance networks allow diverting the command area[2] into distribution units (van den Bosch et al., 1992). The conveyance system comprises those parts of a supply network where the organisational responsibilities include operation and maintenance. These tasks remain within an official organisation whether public, private or economic. The distribution system starts at an outlet where farmers take over responsibility for water distribution to the various fields and for maintenance of the distribution network. Farmers are usually either organised in water user associations or through informal processes.

Surface irrigation

For surface irrigation open and mostly unlined canals are globally prevalent for conveyance. In traditional systems, water discharge within the distribution network and to the field is controlled manually. Modernised and modern systems with some form of automated or semi-automated control are slowly becoming more popular. They enable to control flow rates and application amounts (Pereira, 1999). In these irrigation systems, piped systems are sometimes used. But modernisations only take place to a limited extent and, hence, pipelines for

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[2] A command area is synonymous with the area equipped with an irrigation infrastructure (Burt & Styles, 1999).

surface irrigation are globally rare (Burt & Styles, 1999; Plusquellec, 2002; Aillery & Gollehon, 2003).

Sprinkler and micro-irrigation
For pressurised irrigation closed pipelines are used for conveyance. Therefore discharge control is easier than in the case of surface irrigation (Pereira, 1999). Usually, this requires energy for pumping (Aillery & Gollehon, 2003), except for low-tech sprinklers and localised emitters, which can be operated by gravitation (Cornish, 1998).

Sources of irrigation water

Irrigation water can be taken from different sources: Surface water, groundwater, reused sewage or desalinated seawater and harvested rainwater. The most traditional source is surface water, which is withdrawn from rivers and reservoirs. Groundwater exploitation experienced an exceptional increase in recent decades on global scale, frequently causing regional overexploitation (Vörösmarty & Sahagian, 2000; Plusquellec, 2002). The increasing competition for a scarce resource has led to the development of additional sources of water. Wastewater, although not always treated properly, is increasingly used in agriculture (FAO, 2002).

Water application scheduling

Irrigation scheduling deals with the question of how much water has to be applied when, and how often, to meet the irrigation water need of a crop. The consumptive water use of a crop is its water requirement minus the effective rainfall[3]. This amount has to be acquired from the irrigation system (Brouwer et al., 1989).

To limit or prevent drought-related plant damages and yield losses, it is important to apply the right amount of water at the right time to the crops. In arid and semiarid regions, agricultural production is fully dependent on additional water supply, while temporarily dry periods in other regions can also be by-passed by irrigation elsewhere.

Depending on water supply and economic rational, crops can be *fully irrigated* or *supplementarily irrigated*. In the first case, irrigation schemes are designed to continuously cover the full crop water consumption and avoid predictable water stress. Supplementary irrigation delivers limited additional amounts of water to secure yields during critical stages only (Oweis et al., 1999). It is, however, not always possible to apply water at the exact time and in the precise amount to sustain the highest possible productivity. Conveyance systems have limited discharge capacities. It is not possible to permanently spread water evenly throughout the whole command area. When farmers rely on common water resources, rules must be provided regarding how to distribute the limited supply among them. Therefore irrigation scheduling comprises the issues of timing, flow-rate and duration of application (Snellen, 1996).

Basically, allocation follows one of two contrary principles. Crop-based or on demand water delivery means that farmers receive water whenever they request it. Free cropping is possible, since farmers can decide about their cropping patterns and quickly adapt them to changing external circumstances (Barker & Molle, 2004). For example, where multiple cropping is possible, farmers can cultivate crops with completely different water requirements in the same growing season. In this case the objective is to maximise crop net benefits and land and water resources are allocated accordingly (Smout & Gorantiwar, 2005). In contrast, in water-based or supply-side driven systems, farmers cannot decide when they want to irrigate their fields but receive water as scheduled. Hence fixed cropping is more likely because sowing decisions depend on the water distribution plan (Barker & Molle, 2004; Smout & Gorantiwar, 2005). Crop water requirements must meet the announced or experience-based delivery schedule. Resources are usually allocated to take full advantages of returns to water rather than to land (Barker & Molle, 2004). Often water is allocated on a rotational basis, meaning that farmers or distribution units receive in turn the full canal discharge during a fixed period. Another method is to allow farmers or distribution units to use a fixed share of

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[3] Effective rainfall is the portion of precipitation stored in the rooting zone. Those parts adding to interception, surface runoff and deep percolation cannot be used by plants, hence they are not effective (Brouwer, 1986).

the canal flow (Snellen, 1996). Both ways of fixed distribution can be combined: tertiary canals receive water rotationally while the users below the outlet share these flows on a proportional basis. Rotational irrigation schedules are possible because irrigation does not need to take place on a daily basis. The amount of water, which can be given in one application, the irrigation depth, depends on the soil type, the crop rooting depth and the field size. The necessary irrigation interval depends on the irrigation depth and the climatic conditions (Brouwer et al., 1989).

Surface irrigation

Due to their technical features, it is generally difficult to vary the irrigation depth and frequency of surface irrigation systems regularly. Traditional systems are therefore usually run on a rotational basis since on-demand delivery calls for a well-elaborated management of discharge volumes (Pereira, 1999). Even though the size and frequency of water application should at best follow the crop development, irrigation schedule variations are often unpredictable because they are caused by management failures (Burt & Styles, 1999). In surface systems with a modern or modernised infrastructure, discharge control is easier than in a manually controlled conveyance networks and hence on-demand scheduling would at least be feasible technically (Pereira, 1999).

Paddy rice

Basin irrigation is common for paddy cultivation (Brouwer et al., 1989). Rice grown under traditional practices requires 700-1500 mm per cropping cycle. Water is needed not only to meet evapotranspiration demand during the crop growth season but also for land preparation and seeding before transplantation. Overall the actual amount used by farmers is often several times higher than the requirements (Guerra et al., 1998). Water can be applied on a continuous or rotational basis. In both cases, a water layer has to be established and maintained after transplanting. Therefore the percolation and seepage losses must be offset continuously. Field preparation already starts one or two month before rice transplantation. During this time fields are flooded at least twice (Brouwer et al., 1989).

Sprinkler and micro-irrigation

Pressurised irrigation systems allow for control of discharge rates, durations and frequency and are therefore designed for on-demand supply. Especially micro-irrigation systems distribute small amounts of water on a frequent basis from once or twice a week up to several applications per day (Pereira, 1999).

In the case that the water supply is not sufficient to meet the demand of all crops within a given area during one growing season and additional sources are not at disposal, other distribution rules must be introduced to minimise production losses. Independent of the irrigation method, different approaches are possible:

- The discharge rates can be curtailed for the whole area:
    - Every user has to abandon an equal amount of water.
    - Flow rates are shortened proportionally.

  In this case less than optimal water is spread over the area so that more, or all, farmers or fields get some water (Brouwer et al., 1989). This is also known as protective irrigation with the objective to maximise returns to scarce water resources rather than to available land (Barker & Molle, 2004).

- Irrigation can be reduced to a part of the full command area:
    - Some farmers/fields are favoured by location (head-enders) or social prestige and are served first and the unprivileged (e.g. tail-enders) are simply cut off.
    - Only the crops with the highest economic value get sufficient water to secure maximum productivity.

    In consequence it is possible that some farmers are excluded from irrigation water in shortage periods. Here the aim is to maximise return rates to land rather than to water (Perry & Narayanamurthy, 1998).

The latter principles can be applied on two levels: first by the conveyance system management to select the delivery rates to the tertiary canals, and second by the farmers who decide about the water distribution on their fields.

Irrigation management

In countries where water is legally a private good, farmers who can use their own water source are entirely independent. If several farmers depend on the same source, formal or informal organisations for irrigation management are necessary. The management of an irrigation system is responsible for its operation and maintenance (O&M). Thus scheduling as well as control and repair of infrastructure are part of its assignment.

The typical ways of irrigation management are public managed, mixed managed and farmer managed irrigation systems, depending on the degree of responsibility assumed by either public agencies and/or farmers (Snellen, 1996). Throughout the last two decades farmer organisations, mostly water user associations (WUA), have gained in importance. The turnover of basic irrigation management functions from a public authority to a local or private entity (also named privatisation, disengagement, post-responsibility system, commercialization, and self-management; Vermillion 1997) is widely called irrigation management transfer (IMT) (Barker & Molle, 2004). The extent of management transfer varies. In less developed countries mixed-management of systems is common. These Asian model WUAs (Meinzen-Dick, 1997) are social associations (Plusquellec, 2002) without real power to decide on their own affairs. In Latin America and in industrialised countries WUAs are stronger. The American model is a business association that is able to ensure full cost recovery and reliable serviced. Therefore WUAs must not be o small so that they can hire qualified staff for operation and maintenance instead of relying on cooperation (Burt & Styles, 1999).

The effect of the management system on irrigation efficiency and performance largely depends on socioeconomic factors and is discussed controversially (Plusquelled, 2002; Meinzen-Dicke, 1997, Rice, 1997, Burt & Styles, 1999). For discrimination of IFTs in the present study, more general management factors have been considered (see below). The influence of management on irrigation water loss is explained in the next chapter, as well as the impact of technical features.

3.2 Water losses in different irrigation systems

Considerably more water is withdrawn for irrigation purposes than needed to meet crop water requirements. Globally, the volume divided for agriculture is approximately almost threefold the volume beneficially transpired by crops, i.e. global average irrigation efficiency is 35% only (Wallace & Gregory, 2002). Throughout the whole system from withdrawal to crop transpiration, water is lost for a variety of reasons.

The amount of water lost in these different stages determines the water use efficiency of the system. In order to minimise water loss, the physical infrastructure must be designed in a way that allows to be operated easily and to provide good water delivery service (Burt & Styles, 1999). Besides technical aspects, management is the most crucial factor influencing amount and source of shortfalls (Table 1).

Table 1 Water Losses in irrigation systems

	Field Application Loss	Responsible Process	Conveyance System Loss	Responsible Process	Scheduling Loss	Responsible Process
Surface Irrigation	Over- and underwatering, excessive tailwater runoff, overtopping of bunds, deep percolation; soil evaporation and additional evaporation from surface	Non-uniform water supply & discharge above soil infiltration or storage capacity, lack of maintenance	Evaporation from surface, non-beneficial transpiration of adjacent vegetation, seepage, leakages, overtopping, evaporation from barren land, siltation	Canal length, permeability of construction material, design failures, general canal condition, rotation losses and begin and end of each turn, lack of maintenance	Drainage	Untimely delivery
Sprinkler Irrigation	Air losses (evaporation before reaching the plant), interception, runoff, deep percolation	Wrong pressure, wind, runoff mainly for incanopy-sprinkler, lack of maintenance	Leakages	Design failures, lack of maintenance	Drainage	Untimely delivery
Micro-Irrigation	Soil evaporation, Overwatering	Wrong pressure, lack of maintenance	Leakages	Design failures, lack of maintenance	Drainage	Untimely delivery

Field application losses

Water is lost when spread onto the field. The chosen application technique influences the degree of evaporation, percolation and surface runoff (Molden, 1997) as follows:

Surface irrigation

In surface irrigation systems, percolation losses are inevitable because the part of the field closest to the outlet is always longer in contact with the irrigation water than the opposite end of the field (Brouwer et al., 1989). Water is lost to surface runoff or deep percolation when the soil moisture storage capacity is lower than the amount of discharge brought to the field. The extent of these losses largely depends on the flow rate, land levelling and soil conditions/soil types. The stream size is especially significant in furrow and border irrigation. If water moves too slowly, the percolation rate will be higher close to the outlet resulting in overwatering on the upper end of the field and underwatering on the lower end. If the discharge rate is too high, overtopping might occur, and the risk of erosion is augmented. Bad levelling leads to an increasing non-uniformity in water distribution causing over- and under-irrigation depending on location. Furthermore excessive tailwater runoff is generated where no adequate drainage is provided and inflow rates are not stopped soon enough (Brouwer et al., 1989; Rogers et al., 1997; Pereira, 1999).

In basin irrigation, infiltration above the point of saturation is unavoidable (Burt & Styles, 1999). A thin water layer remains on the soil surface and losses due to percolation must be refilled continuously. Additionally, evaporation from the water surface is inevitable. Keeping dams in good conditions is particularly important in these cases, to prevent spillovers and bund breaks between fields. In case of paddy irrigation, additional water is needed for land preparation and plant protection. This water cannot be used for crop transpiration but it is necessary for this rice-growing method (Bruinsma, 2003).

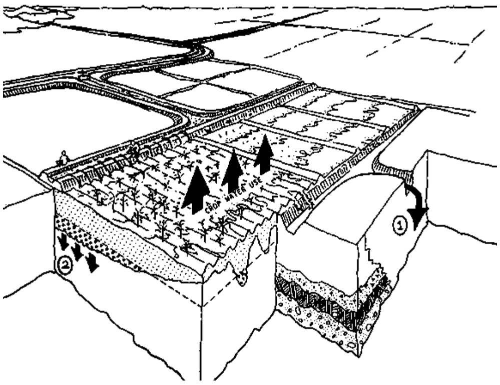
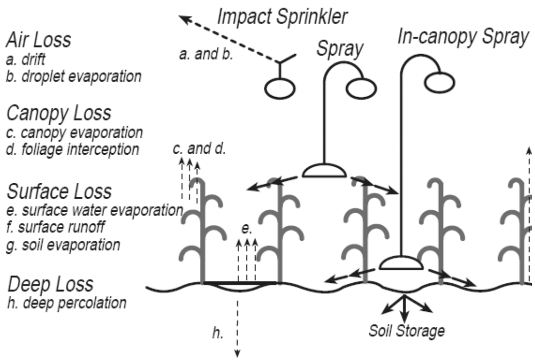


Figure 6 Surface irrigation: irrigation water losses in the field (Brouwer et al., 1989)

1. Surface runoff, whereby water ends up in the drain
2. Deep percolation to soils layers below the rooting zone

Sprinkler Irrigation
Water pressure and wind influence the distribution uniformity where sprinkler irrigation is used. With above-canopy sprinkling evaporation losses can be significant. “Throwing fine particles of water through hot air is about the best way to maximise evaporation losses.” (Seckler, 1996). Also interception losses can be high in these systems. However, this is partly counterbalanced by reduced transpiration from the wetted leaves (Rogers et al., 1997). In contrast, in-canopy sprinklers struggle less with interception. Soil evaporation only occurs early in the season before the plant cover is closed. But the runoff can be up to 60% on sloping grounds (ibid).
Suboptimal irrigation can also be a consequence of poor water pressure control. Water is discharged non-uniformly either close to the nozzle or at the field margins (Brouwer et al., 1989). In both cases, over- and underirrigation take place on different parts of the field and thus percolation losses might occur.

Figure 7 Sprinkler irrigation: irrigation water losses and storage locations (Rogers et al., 1997)



Micro-irrigation
Micro-irrigation is a method that reduces the risk of loosing water during application (Molden, 1997). Yet these systems should be designed and managed to fulfil crop water requirements and not to save water (Pereira, 1999). In contrast to surface runoff, soil evaporation cannot be suppressed totally but is reduced significantly (Keller & Seckler, 2004). Flow rates are important for both pressurised systems since they determine the system pressure. Wrong pressure is the main source of over- and underirrgation. In case of overirrigation, percolation losses are possible (Brouwer et al., 1989; Pereira, 1999). In general, pressurised systems must be properly operated according to their design rules and the equipment quality must be controlled regularly to be efficient (Pereira, 1999).

Conveyance system

Additional water is lost during the transport to the field. Losses in the conveyance and distribution system occur because of evaporation from open waters, non-beneficial transpiration of vegetation on the canal banks, seepage, leakages, overtopping, evaporation from barren land, and pollution (Fairweather et al., 2004; Seckler, 1996).

Surface Irrigation

The extent of water losses in open networks depends mainly on canal length, permeability of the building material and general canal conditions. Thereby no significant differences are apparent between lined (with concrete, bricks, or membranes) and unlined canals. Bos & Nugteren (1990) assume that linings are applied where otherwise substantial seepage losses would be inevitable. On the other hand, lined canals do not show constantly low seepage rates throughout their operating life. Small cracks in the concrete are already sufficient to reduce its barrier effect considerably (Plusquellec, 2002). Overall these losses are higher in large schemes because of the longer canals and higher on sandy soils because of the higher permeability (Brouwer et al., 1989).

In general, rotational schedules for surface irrigation show higher losses than schemes with continuous flow due to higher losses at the beginning and end of each flooding. These losses exceed the losses via percolation gained through occasional instead of permanent wetting. A frequent design failure augments water wastage because it enforces full supply in the main canal: the scheme canals can only be operated at maximum flow conditions because diversions and outlets are not supplied at lower water levels (Plusquellec, 2002).

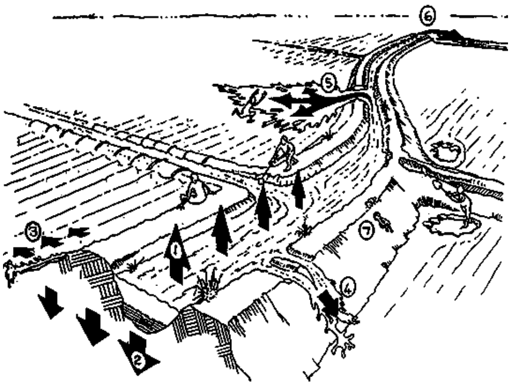


Figure 8 Surface irrigation: irrigation water losses in the conveyance system (Brouwer et al., 1989)

1. Evaporation from the water surface
2. Deep percolation to soil layers underneath the canals
3. Seepage through the bunds of the canals
4. Overtopping the bunds
5. Bund breaks
6. Runoff in the drain
7. Rat holes in the canal bunds

Sprinkler and Micro-irrigation

Adequately maintained pipeline networks in pressurised systems are protected from most problems occurring in open canal networks. Very little water is lost in their conveyance systems (for sprinkler irrigation, see McLean, 2000). The prevention of water waste is actually one of the main reasons for micro-irrigation in arid regions.

All kinds of losses reduce the efficiency of an irrigation project, although some of this water, mainly percolation and runoff, might be reused downstream in a river basin. A quantified assignment of losses to different technical features is, however, not possible. The irrigation efficiency estimations in chapter 5.2 are based on general quantifications of the unavoidable and frequent losses presented above.

Irrigation scheduling

Untimely delivery is one of the results of scheduling and adjustment failures and thus related to management (Svendsen & Rosegrant, 1994). This is a problem in rotational systems especially. Unreliable or inadequate schedules are the main problems in system operation. These problems are passed to the distribution system. This system can only work effectively if water is properly supplied through its conveyance system (Burt & Styles, 1999). Only if on-site storage capacities exist, scheduling failures can be balanced.

If water is delivered at a time when the farmer can make little use of it, it is drained without benefit (Fairweather et al., 2004). The same happens when water is supplied to parts of an irrigation scheme not under cultivation. This problem occurs especially where drainage water is reused (Seckler, 1996). Unreliable and inadequate deliveries are frequently amplified by infrastructure damages and design failures.

Irrigation management

Lack of maintenance is thus a second major cause for water losses. Irrigation schemes require recurring rehabilitation to protect their canal network and water control infrastructures from deterioration before their life expectancy has passed. The canal network must be kept in good condition to prevent leakages, erosion, siltation, weed growing and corrosion and to repair illegal manipulations of canal structures. Regular inspections are necessary to detect the beginning of structural decay before they become a major problem. (van den Bosch et al., 1992; van den Bosch et al., 1993). Bad maintenance can increase the water losses to more than 50% of the discharged volume (Brouwer et al., 1989). In large-scale schemes the need and the effort for maintenance is higher than in small systems.

The complexity of irrigation management is related to the size of an irrigation project. The larger a project, the more difficult it becomes to operate it effectively with a high degree of adequacy, equity, reliability and flexibility at the same time. In the predominating traditional surface irrigation systems management is a major cause for low efficiencies. In command areas of more than 10.000 ha the conveyance efficiency suffers from this management challenges and design failures. In these systems it is complicated to control the supply to remote parts of the system. Communication often suffers due to a lack of communication networks (Burt & Styles, 1999). If water is abundant, operators often prefer to provide more water than necessary and to spill unused water to ensure that tail-enders receive a satisfactory discharge as well (Burt & Styles, 1999; Bos & Nugteren, 1990). Smaller systems, especially those with less than 1000 ha, often have operational problems due to a lack of proficient staff.

In pressurised and in modernised surface irrigation systems modern hardware enhances the systems ability to cope with its inherent complexity. Automated or semi-automated control makes scheduling and discharge control easier, because discipline and cooperation become less of a requirement. Yet, modernisation is lagging behind in most countries with traditional surface irrigation and therefore inappropriate hardware or inappropriate use of hardware are prevalent (Burt & Styles, 1999).

However, quantification of irrigation losses due to management failures is difficult. In contrast to unavoidable losses related to the application method, such as over-irrigation close to the outlet of a furrow irrigated field, management is extremely variable. Therefore only the more likely failures of large scales are directly considered in the efficiency calculations proposed here.

4 Improvements of irrigation modelling in LPJmL

In this study, an improvement for the implementation of irrigation in LPJmL is proposed. The current irrigation implementation is described below and potential improvements are pointed out.

The LPJmL model

The LPJ dynamic global vegetation and water balance model (Sitch et al., 2003) has recently been enhanced to simulate not only potentially natural vegetation but also agricultural vegetation (Bondeau et al., 2006). This new model version "LPJ managed Land" (LPJmL) thus represents the global biosphere under human influence, with a spatial resolution of 0.5 degree. In LPJmL generic crop functional types (CFTs) have been introduced to simulate transient impacts of expanding (or declining) global agricultural areas on the terrestrial carbon and water cycles. Compatible to PFTs (plant functional types) for potential natural vegetation, CFTs are generalised and climatically adapted plant prototypes. One purpose of LPJmL is to address nonlinear biophysical and biogeochemical features of continuing large-scale replacement of natural vegetation by agroecosystems, under CO_2 increase and climate change. In addition, land management is to be represented in the model, including irrigation, fertilisation, residue treatment and multiple cropping.

The robust, process-based representation of the coupled CO_2 and H_2O exchanges in LPJ is maintained in LPJmL. For example, transpiration and photosynthesis rates are coupled for both PFTs and CFTs. Transpiration is the lesser of atmosphere-controlled demand (D) or transpirational supply (S) (Gerten et al., 2004a). The photosynthesis rate is directly related to the potential canopy conductance g_{pot}. The actual canopy conductance falls below g_{pot} if $S<D$. Therefore the increasing water stress limits the photosynthesis rate, and thus the biomass production and eventually the yield, as well as the transpiration rate.

Irrigation, hence, affects crop yields directly because it means absence of water stress during the growing season. Water availability as limiting factor is thus excluded, such that photosynthesis, yields and transpiration increase up to their potential value.

Irrigation module and potential improvements

The current LPJ irrigation module assumes optimum irrigation with respect to timeliness and adequacy of delivery. Constraints of application systems, losses or delays are not included (Figure 9). A priority list, indicating which CFTs are irrigated before others, is applied globally.

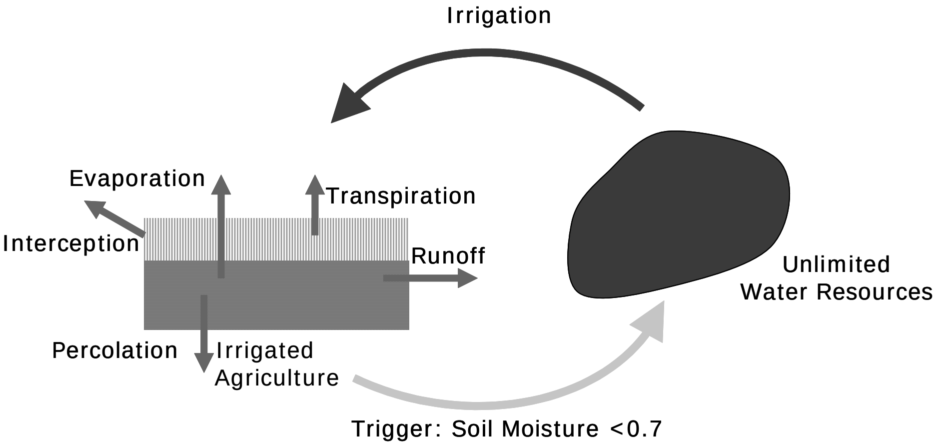


Figure 9 Current implementation of irrigation in LPJmL

In LPJmL the irrigated agricultural fraction of each 0.5°grid cell is determined with data on global areas equipped for irrigation in 1995 (Döll & Siebert, 1999) (Figure 10). The priority list specifies a likely order for CFT irrigation. This list complies with some European agricultural practices but is applied globally (Bondeau et al., 2006). To improve regional differences in cropping patterns new priority lists should be included (suggestions see below).

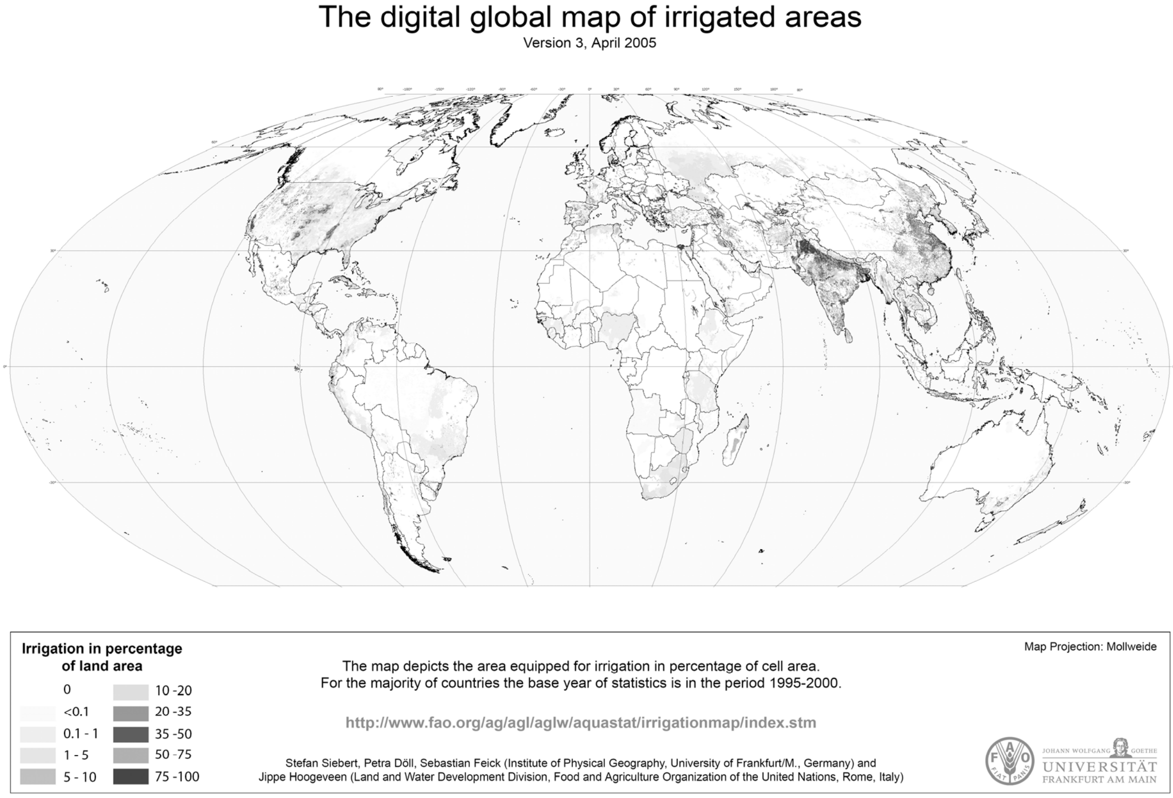


Figure 10 Digital global map of irrigated areas (update from Siebert et al., 2005)

Currently, CFTs are limited to major crop types and some important irrigated crops are not included: cotton, sugar cane, and fruits and vegetables. Irrigation water is supplied on a daily basis, as soon as the upper soil layer water content is too low to maintain a supply–demand ratio of 0.7. This means that irrigation scheduling in LPJ follows an on-demand crop-based approach with optimum adequacy, flexibility and reliability of supply. This is suitable for pressurised systems. For surface irrigation the scheduling rules should be adjusted to a rotational principle.

As another simplification of the current irrigation module, the irrigation period is not restricted at times of severe blue water shortages. That means, irrigation water supply is not constrained by actual renewable resources, although the annual irrigation consumption is subtracted from runoff (Bondeau et al., 2006).

But blue water constraints are especially important because they limit the amount of water that can be brought to the fields. In LPJ, irrigation water supply is limited by precipitation as source of renewable resources throughout a basin. Thus the comparison of amounts of irrigation water with the available blue water in each grid cell contributes to a better assessment of irrigation limitations. This information is provided by a new river routing module, which is currently under construction (Jachner et al., unpublished data). The module allows for lateral redistribution of the computed runoff among grid cells. River basins with main rivers and tributaries are implemented. Volumes of natural available water can now be estimated within the boundaries of each river basin. LPJ will be enabled to quantify the actually needed water supply to meet crop water consumption when irrigation losses are additionally taken into account. But even with this advancement, some sources of irrigation water will not be taken into account, such as groundwater extraction, water transfer between river basins

by transfer schemes or even by ships, seawater desalination and sewage treatment.
Furthermore, full irrigation for all crops and efficient irrigation is assumed for all irrigated areas in the current irrigation module (Bondeau et al., 2006). Water is distributed uniformly to all irrigated areas ensuring optimum equity. Irrigation losses due to conveyance systems, application method or management failures have not been taken into account, which should lead to a pronounced overestimation of irrigation. Currently, first model runs are executed with gross water requirements based on regional efficiency factors proposed by Döll & Siebert (2002). By use of national irrigation efficiencies, as developed in this study, variations in blue water discharge and in irrigation productivity could be computed. They are caused by water scarcity, regional and basin related discrepancies in water distribution or influence of irrigation method. The available runoff computed by river routing can be combined with the new irrigation efficiencies. Water losses, occuring while water is transported from the river takeoff to the plant, reduce the amount of water available for within in each grid cell. A part of these losses evaporates while another part adds to the computed river downstream (Figure 11). The proposed changes for scheduling and efficiency estimation are parameterised in the IFTs.

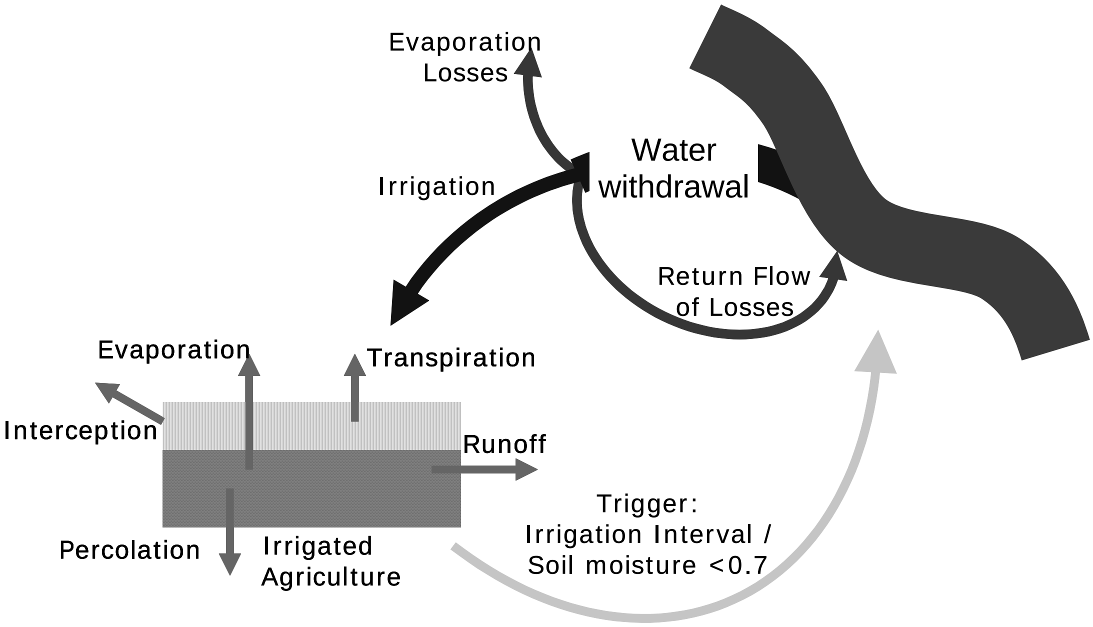


Figure 11 Optimal irrigation implementation of IFTs in LPJmL

The area equipped for irrigation evolved over time. It should be noted, that there is no direct relation between the area equipped for irrigation within a country and its classification as a particular IFT. In order to determine the irrigation development since 1901, it has been assumed in the model that in 1901 rice was the single irrigated CFT. From 1902 on, a linear increase is presumed until 1995 (Bondeau et al., 2006). Additional data (https://faostat.fao.org) specify the annual irrigated areas on a country level since 1961. This information is used to adapt the linear growth rates to the actual ones for the according time period. Global data about the development of national irrigated areas before the 1960s are not available. Hence changing the current approach for the period of 1901 to 1960 does not contribute to a refinement of irrigation expansion over time.
The assignment to an IFT and thus irrigation efficiency and scheduling can change over time as well. Therefore some conclusions with regards to the application of IFTs over time will be drawn in chapter 5.4 below.

5 Irrigation functional types

IFTs are introduced for a better representation of irrigation as one form of land use in LPJmL. An IFT must therefore cover the principal features of an irrigation system. Amount and timing of water availability influence the water stress experienced by crops. Hence water use efficiency and scheduling are the most important parameters of each IFT. In this chapter their dimension is determined for each IFT. The irrigation efficiency is a combination of three partial efficiencies. The irrigation method determines two of them: field application efficiency and conveyance efficiency due to a linkage between application and conveyance method. As third parameter, a management factor, is introduced instead of the distribution efficiency. The management factor is related to the IFT scale component.

In addition, scheduling guidelines for LPJ are developed to estimate the timeliness of delivery.

Irrigation efficiency and scheduling are both parameters of outstanding importance and are both determined by irrigation method and in case of efficiency also by scale. Therefore the method and the scale are the key elements used for discrimination of IFTs. The identification of types is based on empirical data about irrigation methods on a national scale. This is due to a severe lack of global data below this aggregation level. Each country where irrigated agriculture takes place is assigned a certain type. Thus, the same irrigation efficiency is applied to all areas equipped for irrigation in a country. Since irrigation methods change over time, some rules are proposed how these changes can be taken into account.

As result, a global map of irrigation efficiencies provides an overview of how much blue water reaches the fields in irrigated agriculture in different regions of the world. The quality of the IFT assignment and of the resulting global map is assessed as well.

5.1 Discrimination of IFTs

For identification of the IFTs’ main characteristics, two sources of empirical data were used. First, information about the irrigation method is available for 134 countries, covering 96% of all areas equipped for irrigation. For these countries information about the fraction of irrigated area equipped with each method was available. However it is not possible to disclose in which areas which methods are dominant within each country. The data are mainly based on ‘FAO Irrigation in Figure’ statistics, yet for some countries additional sources are added (ICID, 2001; Veneman et al., 2004; Insitute for European Environmental Policy, 2000; Australian Bureau of Statistics, 2005; Secretaria General Tecnica, 2005). This data material is statistically analysed to identify the most common distribution patterns of irrigation methods. In some countries, the complete irrigated area might be equipped with the same method. Yet, a variety of mixtures of methods is imaginable.

The globally predominant patterns of irrigation basically form the foundation of IFTs. A further specification is then done by consideration of the scale of irrigated areas.

The second criterion for IFT discrimination is the size of irrigation systems. Based on an improved global map of irrigated areas (Siebert et al., 2005), it is estimated if the majority of command areas within a country are large- or small-scale.

For those countries where national data about irrigation methods are not available, the type of irrigation is assessed to be the same as in countries with similar socio-economic and climatic conditions. Therefore, proxy data are collected of the countries with known distributions of irrigation methods: income per capita, rural population and precipitation during the vegetation period, among others. Those countries belonging to the same IFT are compared in order to identify significant attributes, which characterise the respective country groups.

Discrimination by irrigation method

Four dominant patterns of irrigation have been identified (see also chapter 3.1):

- surface irrigation,
- sprinkler irrigation,
- a combination of surface and sprinkler irrigation,
- micro-irrigation.

In the majority of the countries, one irrigation technique is used on the majority of fields, while the other methods are applied to a considerably lesser extent or only for research purposes. An almost equal distribution among all methods is not common. This conclusion is the result of a cluster analyses conducted with the available data, as described in the following.

For a first overview of the dominant patterns of irrigation methods, only 33 countries have been taken into consideration. These are the countries with the largest irrigated areas. Together in these countries approximately 80% of the global areas under irrigation are situated. They belong to the group of 134 countries with known fractions of irrigation methods. For this group of countries, several k-means cluster analyses were conducted[4]. A value-triple was used for each country, consisting of the fraction of each irrigation method (surface, sprinkler, and micro-irrigation). The purpose of the cluster analyses was the identification of patterns of distribution of irrigation methods within countries. A k-means analysis allows for predetermination of the numbers of clusters. For this sample size, runs with three to six clusters were chosen. The restriction was selected because the objective was the identification of a limited numbers of clusters.

This first analysis indicated that in most countries one irrigation method is prevalent (Figure 12). Therewith it is inadequate to create IFTs representing distinct mixtures of all three irrigation methods. On most irrigated areas in the absolute majority of countries, surface irrigation is applied. Only few countries are almost completely equipped with sprinkler irrigation. Considerably more countries, but still few compared to the surface irrigation dominated ones, are characterised by a standoff between surface and sprinkler irrigation. In those countries with the largest irrigated areas worldwide, micro-irrigation is widely negligible.

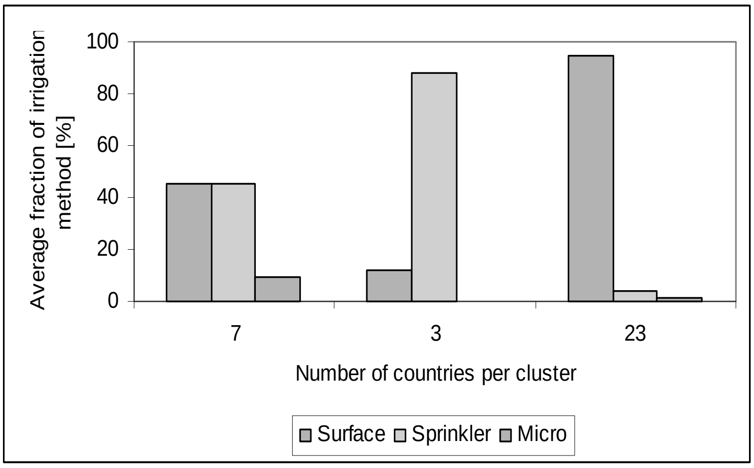


Figure 12 Distribution of irrigation methods within clusters for a cluster analysis with 3 centres

In a second step, all other countries for which data were easily available were taken into account as well. The examination of the patterns of irrigation methods of these countries largely confirmed the results of above analysis. However, some countries with small irrigated areas (and small country size) did not fit into the three categories. Micro-irrigation is dominant in these countries. Therefore a fourth type was added.

For each type, the average fractions of each method were calculated. The ranges of values of the dominant or two main methods are used to assign thresholds for discrimination to each IFT (Figure 13).

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[4] The cluster analysis used the algorithm of Hartigan and Wong (1979).

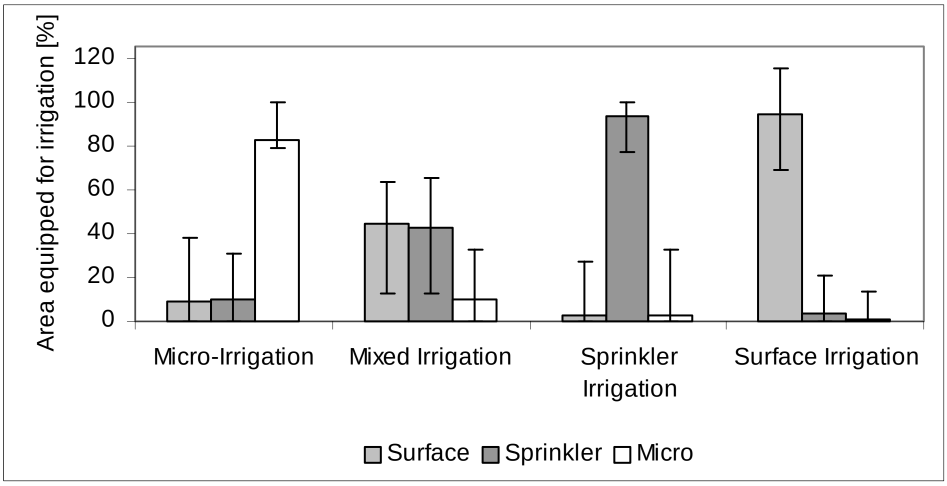
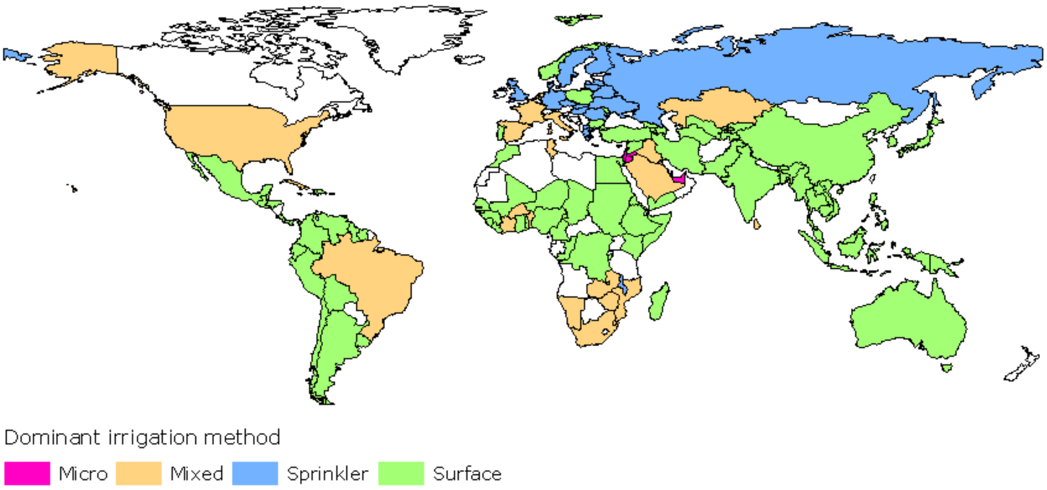


Figure 13 Average fraction of areas equipped with each irrigation method per IFT. Average values are calculated based on country data. The error bars show the minimum and maximum coverage rates of each method.

Based on the empirical data, the following thresholds are defined for each IFT:

- surface irrigation	>66% of the command area is equipped for surface irrigation
- sprinkler irrigation	>66% of the command area is equipped for sprinkler irrigation
- mixed irrigation	33-66% are equipped for surface irrigation & 33-66% is equipped for sprinkler irrigation with <50% equipped for micro-irrigation
- micro-irrigation	>50% of the area is equipped for micro-irrigation

For surface, sprinkler and micro-irrigation types it is assumed that the complete area is irrigated with the respective method, which is a realistic assumption because the methods are predominant in the respective countries. For mixed irrigation, a 50:50 distribution of sprinkler and surface irrigation is assumed; the global distribution of these IFTs is presented in Map 1.



Map 1 Distribution of IFTs among countries with available data

Spatial allocation of methods in mixed IFTs

For mixed IFT the parameters of sprinkler and surface IFTs should be applied to the respective area according to the spatial distribution. A priority list is developed for the spatial allocation of both methods.

Rice and managed grassland are always assigned to surface irrigation. Paddy, and therewith basin irrigation, is the dominant cultivation method for rice (Guerra et al., 1998).

Managed grassland currently includes the economically most valuable crops, namely fruits and vegetables and cotton. Including this CFT would mean that only grassland gets irrigated by sprinklers, due to the importance of managed grasslands with regard to the overall irrigated area. Thus the economically least valuable crop would be irrigated with the more investment intensive method, which is highly uneconomical. Hence grassland is excluded from the priority list.

For the other CFTs, it is assumed that those crops where yield increases due to irrigation are the largest are irrigated by the more expensive sprinklers since higher investments should be counterbalanced by higher yields. LPJmL assumes perfect management without nutrient limitation. Thus increased crop yields in LPJmL are only related to improved water supply. Therefore, rises in yields of irrigated crops compared to rainfed yields are calculated, based on the harvested dry mass in LPJ of 1995. Average values of yields are computed based on grid cells and not on national averages. Thus countries with larger irrigated areas are rated higher. The output per cropped irrigated area [t DM/ha] is approximately two to threefold for all irrigated CFTs compared to rainfed cultivation. The yield increases are compared for countries with mixed irrigation and globally (Table 2).

Table 2 Increase in yields due to irrigation in countries of mixed IFT. Own calculation, based on data provided by Christoph Müller (pers. comm.).

CFT	Average increase of yields in countries with mixed irrigation [% of rainfed yields]
Groundnuts	295,41
Maize	306,83
Pulses	324,00
Rapeseed	264,77
Soybean	303,66
Sunflower	397,06
Temperate Cereals	287,08
Temperate Roots & Tuber	357,47
Tropical Cereals	274,74
Tropical Roots & Tuber	322,94

The irrigated fraction of the CFT with the highest yield increase is the first crop stand assigned to sprinkler irrigation, then the irrigated fraction of that CFT with the second highest yield increase, and so on, until half of the total area under irrigation is allocated. Surface irrigation is assigned to rice, managed grassland and the residual CFTs. The average irrigated fraction of CFTs is determined in chapter 5.4.

Under consideration of the increases in yield, the following priority list for sprinkler application should be established: 1 sunflower; 2 temperate roots and tubers; 3 pulses; 4 tropical roots and tuber; 5 maize; 6 soybean; 7 groundnuts; 8 temperate cereals; 9 tropical cereals; 10 rapeseed; 11 managed grassland; 12 rice.

Assignment of countries without information about irrigation methods

For the missing 40 countries or 4% of the global irrigated area where no data about the irrigation method is available, a decision tree was developed[5]. Some rules were derived from FAO guidelines for the choice of an appropriate irrigation method (Brouwer et al., 1989). They are used to identify decisive climatic and socio-economic conditions. Proxies were selected which represent these conditions and which are available for almost all countries simultaneously. The proxies are temperature and precipitation, water withdrawal, income categories, and different population indicators (rural population, employment in agriculture of

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[5] Some statistical methods for classification, especially multiple regressions and discriminant analysis have been discarded as not feasible. The purpose of the decision mechanism is the assignment of a nominal value (IFT) based on metric information. A multiple regression is an appropriate tool if dependent and independent variables are both metric. A discriminant analysis can be used in the present case. However this requires a linear or non-linear normal distribution of the independent variables (Backhaus et al., 1996). The chosen proxies do not comply with this precondition.

total population, employment in agriculture of rural population). Some variables with theoretical explanatory value had to be excluded because missing data outweigh the existing data, for example rural population living below the poverty line. After selection, the potential correlations between proxy values in countries with known irrigation methods and the IFT affiliation are examined.

Average temperature and precipitation (during the vegetation period and annual averages) are used as proxies for water availability and the need for irrigation. Sprinkler irrigation only occurs in countries with an average temperature <15°C and a precipitation level <120 mm per month throughout the same period. Micro-irrigation is also concentrated in the same temperature range but with a lower precipitation threshold of 70 mm. However, countries with surface and mixed irrigation are also located in this value range. Hence an exact classification is not possible. If average temperatures exceed 20°C, only surface and mixed irrigation occurs. While the latter is more concentrated in a precipitation range of 50 to 150 mm, surface irrigation is more frequently used where precipitation is higher. But this is no rigorous threshold as surface irrigation is also used at low precipitation rates (Figures 14, 15).

These results are coherent with the expected ones. Firstly, sprinkler and micro-irrigation are more appropriate in areas with low water availability, while surface irrigation is more common where water is abundant. Secondly, where full irrigation is needed the low flexibility of surface irrigation is sufficient, but where irrigation is only supplementary, sprinkler and micro-irrigation are more suitable.

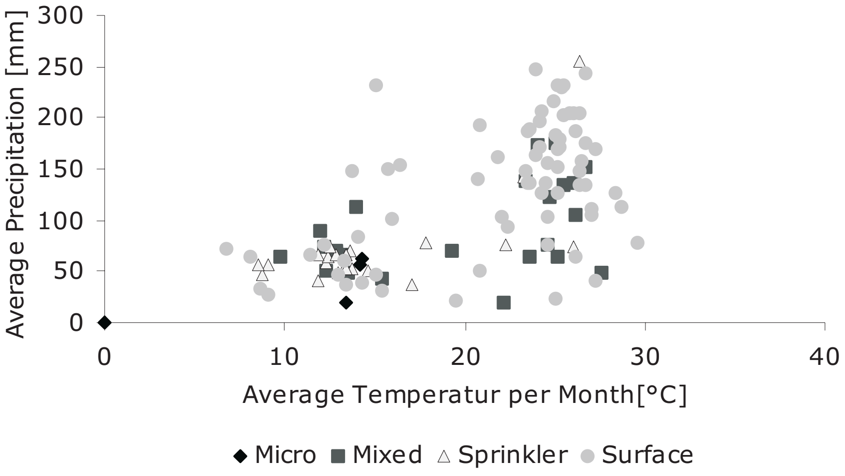

Figure 14 Average monthly temperature and precipitation

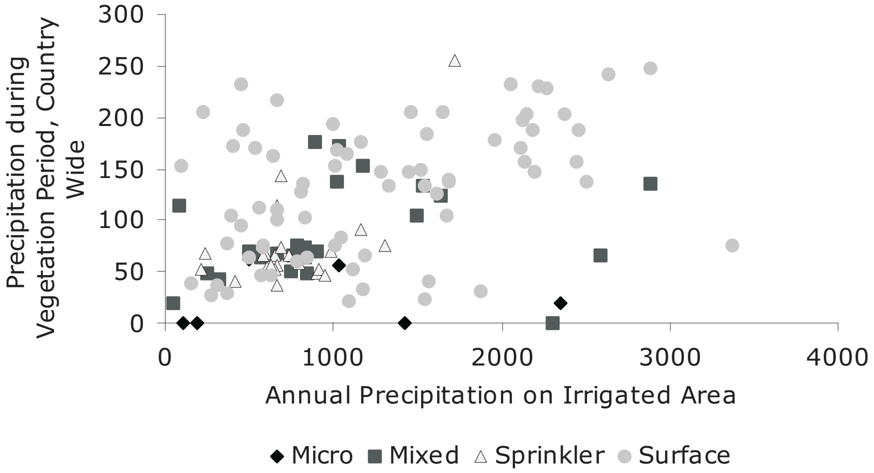

Figure 15 Precipitation on irrigated areas and during the vegetation period

As socio-economic factors labour force and capital to meet investment requirements are represented by per capita income and population figures. There is a clear relation between irrigation methods and per capita income[6] for all IFTs except mixed irrigation type (Table 3).

Table 3 Number of countries per irrigation method per World Bank income category in absolute figures.

	Surface	Mixed	Sprinkler	Micro	total
Low income	36	6	/ *	/	42
Lower middle income	24	8	4	1	37
Upper middle income	12	3	8	5	28
High income	5	9	7	4	25
total	77	26	19	10	132

* Sprinkler irrigation is actually dominant in Malawi, a low income country. However Malawi's values for all parameters are extremely different from all other sprinkler irrigating countries but fit excellent into the surface irrigation profile. Therefore Malawi is excluded from the sample analysis.

In low income and lower middle income economies surface irrigation is prevalent. Capital intensive pressurised methods are mainly used in countries with higher income. These findings confirm the assumed rules of choosing an appropriate irrigation method with regards to capital and labour input requirements. Mixed irrigation does not follow income categories. Mixed irrigation takes place where surface irrigation is replaced by sprinklers over time or new command areas are directly equipped with pressurised systems. A potential explanation for the missing relation is the involvement of donor agencies in irrigation development or financial and technical support of political supportive countries.

The percentage of rural population is also closely related to the aspect of labour input. Sprinkler irrigation is never prevalent in countries with more than 50% of rural population. This irrigation type is restricted to countries in which agriculture is not a main source of employment in total (<7%) and less than one quarter of the rural population earn their income in this sector. Micro-irrigation is similar with regards to an economically active population but where rural population might exceed urban population.

For surface and especially for mixed irrigation such a distinction is less obvious. Both occur in countries with little rural population as well as in rural societies. In the case of mixed irrigation, a part of the sample is similar to sprinkler irrigation while the rest remains within the same range than surface irrigation (Figures 16 & 17).

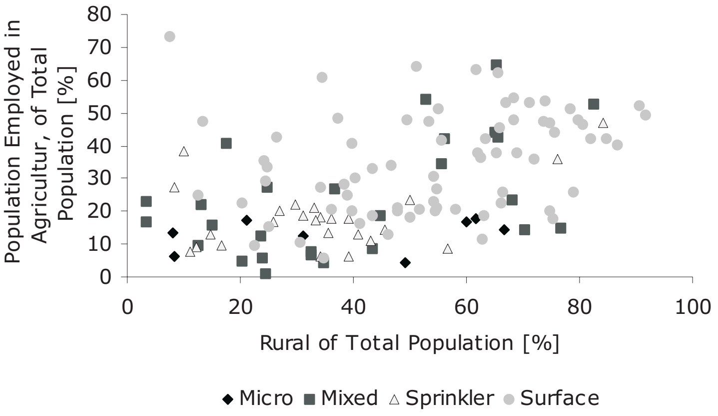

Figure 16 Rural population

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[6] Income is classified according to the World Bank analytical income categories: "Economies are divided according to 2004 GNI per capita, calculated using the World Bank Atlas method. The groups are: low income, $825 or less; lower middle income, $826 - $3,255; upper middle income, $3,256 - $10,065; and high income, $10,066 or more." (http://web.worldbank.org/WBSITE/EXTERNAL/DATASTATISTICS/0,,contentMDK:20420458~menuPK:64133156~pagePK:64133150~piPK:64133175~theSitePK:239419,00.html, 19.06.2006)

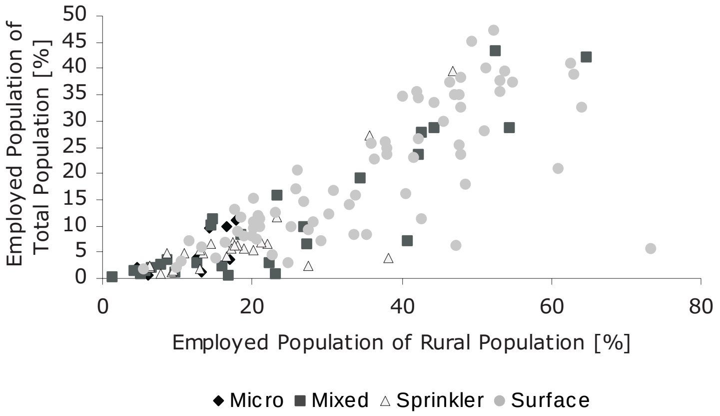
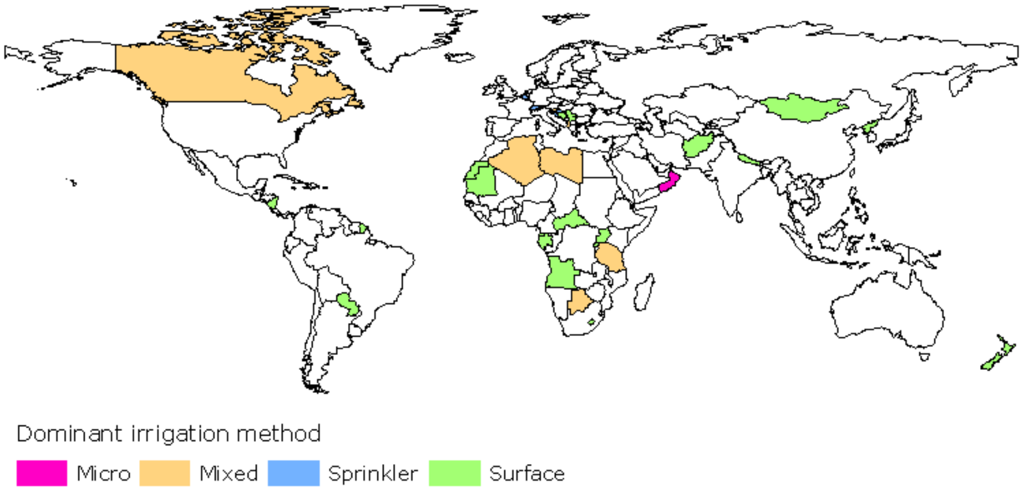


Figure 17 Employment in agriculture

Overall, surface irrigation shows a tendency to be economically more dependent on agricultural employment than pressurised systems. These findings correspond with the labour and capital input requirements of the various irrigation methods. Construction and O&M of surface irrigation systems is labour intensive. Thus low capital investment is needed when it is manually executed. Pressurised systems are technology based and therefore rely on capital investment especially in the case of large-scale irrigation. Construction and O&M are less labour intensive but the needed energy supply increases operation costs.

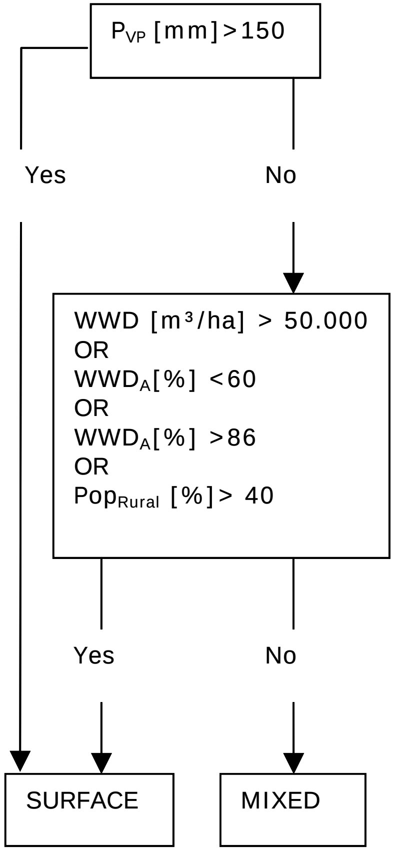
Income categories have the highest explanatory value. For each income category a customised decision structure has been developed (Figure 18). Finally this structure is applied to the countries with missing irrigation information, so that the remaining 4% of the global irrigated area are classified as well. The results of the assignment are presented in map 2. The complete global distribution of irrigation methods in presented in map 3.



Map 2 Distribution of IFTs among countries with assigned IFTs

P_{VP}	Average monthly precipitation during vegetation period [mm]
P_T	Total annual Precipitation [mm]
T_{VP}	Average monthly temperature during vegetation period [°C]
WWD	Agricultural water withdrawal per area equipped for irrigation [m³/ha]
WWD_A	Agricultural water withdrawal of total water withdrawal [%]
Pop_{Rural}	Rural population of total population [%]
Pop_{RA}	population economically active in agriculture of rural population [%]
Pop_{TA}	population economically active in agriculture of total population [%]

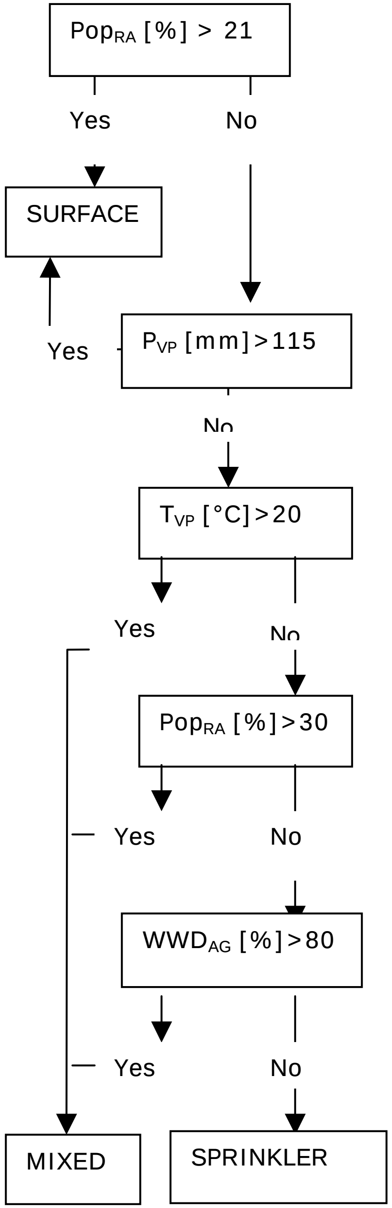
Low Income Countries



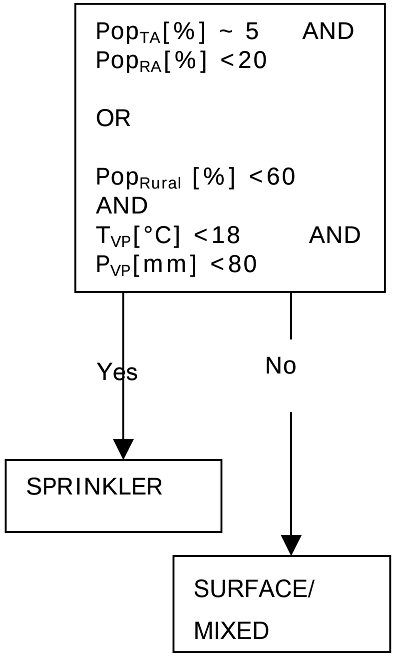
Regional Exception for Lower Middle Income Countries:

Africa → MIXED

Lower Middle Income Countries



Upper Middle Income Countries



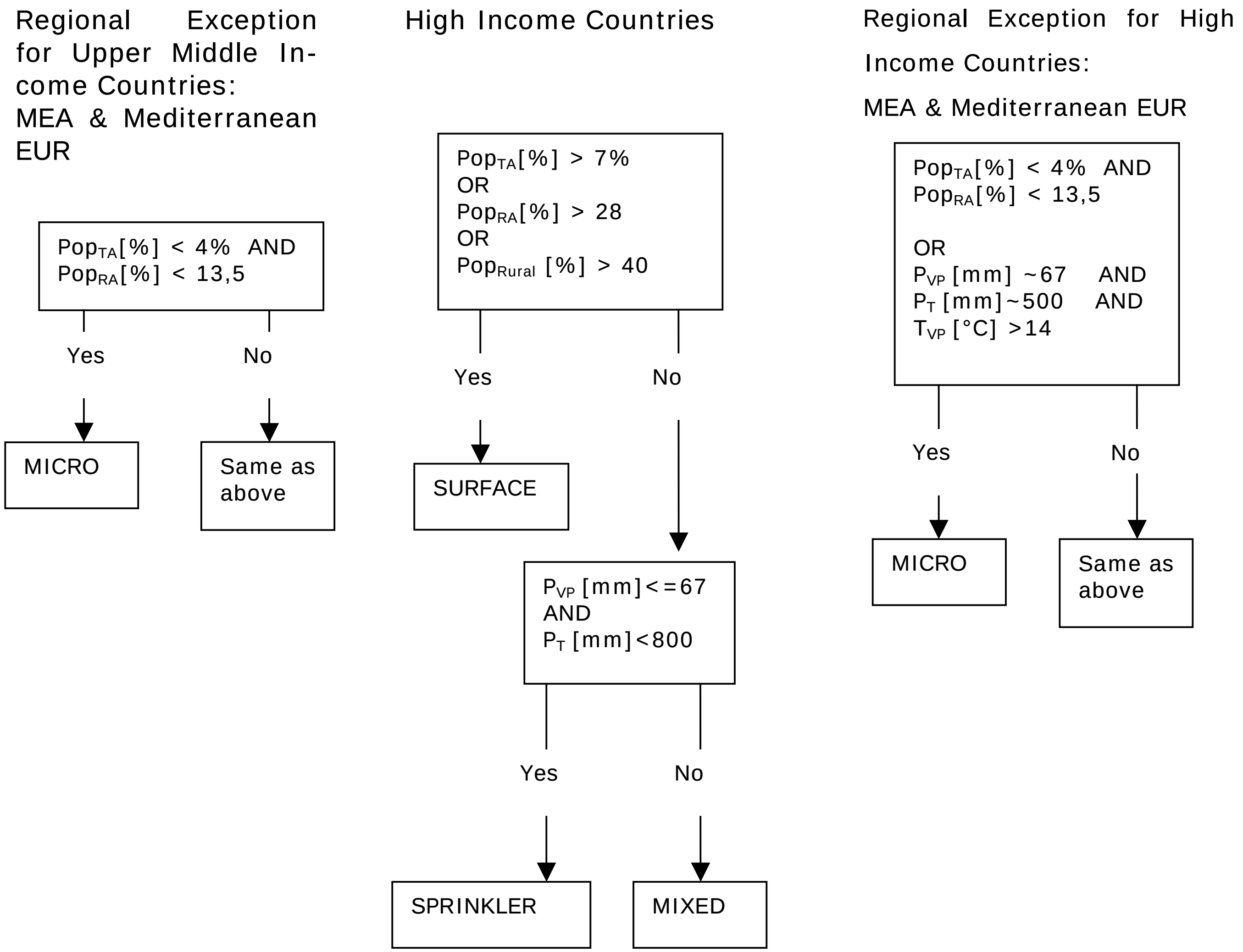
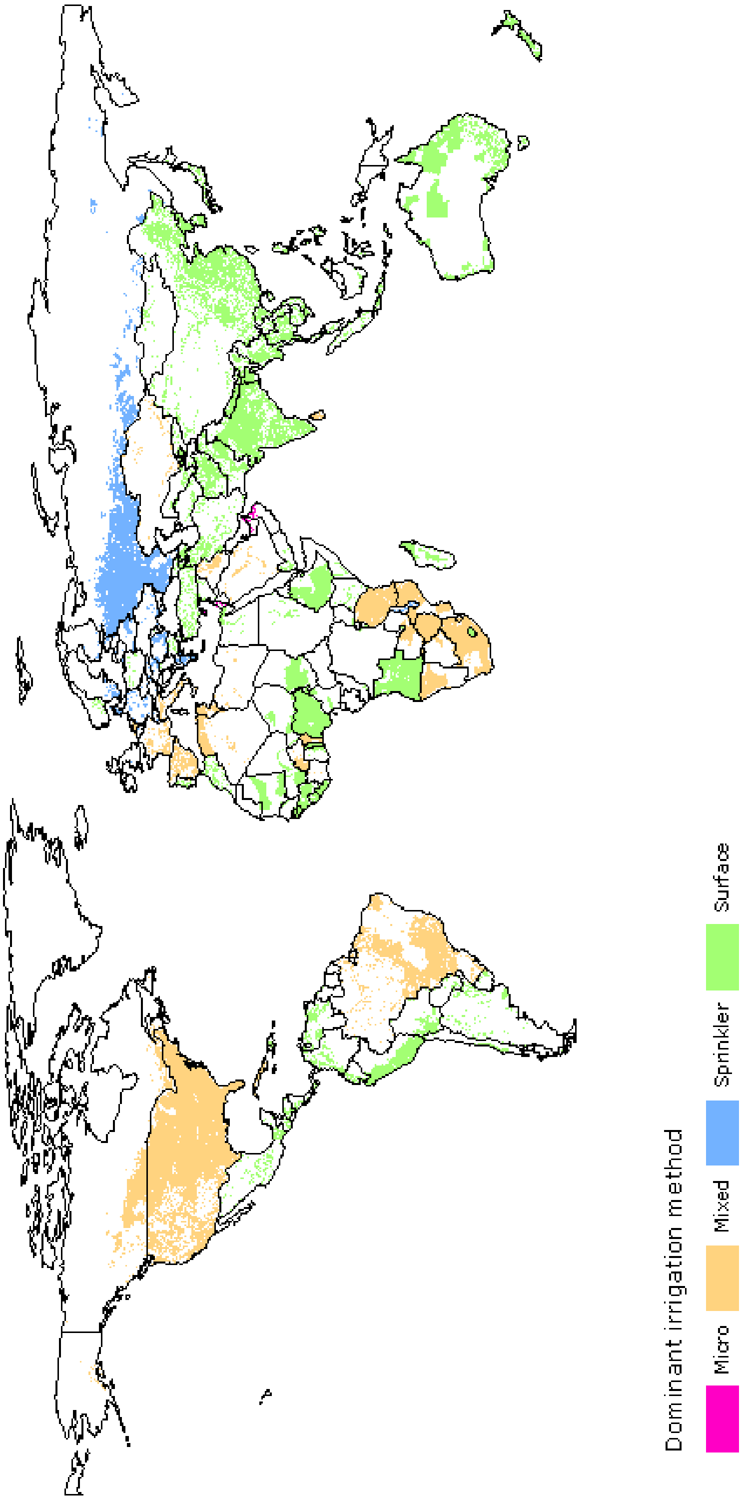


Figure 18 Decision structure for assignement of IFTs to countries without information about irrigation methods



Map 3 Global map of dominant irrigation methods. Only areas which are at least partially equipped for irrigation are represented.

Discrimination by scale

Areas equipped with irrigation infrastructure are distinguished into large (>=10,000 ha) and small-scale (< 10,000 ha) command areas. For each country, the ratio of large-scale systems to total equipped area is estimated. Therefore identification of large irrigation areas is necessary. For this purpose the global map of irrigated areas (Siebert et al., 2005) Version 3 is used[7]. The map shows the amount of area equipped for irrigation around 1995 as a percentage of the total area. The information is based on administrative units (country, state, smaller units) on a 5' grid, generated by use of irrigation statistics, maps and remote sensing data. In areas where irrigation is more important, information is usually available on a smaller scale and thus more precise (Döll & Siebert, 2002). This is identifiable on the provided map.

For grid cells covered with irrigation infrastructure to at least 50% it is assumed that the irrigation area is contiguous. To identify areas with more than 10,000 ha from this selection, adjacent cells are regarded as well. For bordering cells with more than 50% coverage each, it is assumed that the irrigated areas of all cells belong to a single command area. Compounds of neighbouring cells, which comprises more than 10,000 ha of area under irrigation, are identified as large-scale areas.

For each country the ratio of hectares in large-scale grid cells to the total command area is calculated and the country is accordingly assigned one scale type. In the majority of countries no large-scale irrigation has been detected, only in few countries the confirmed large-scale fraction is above 50%. In most countries with command areas above 10,000 ha, their share is below 40%.

Thus values for national large-scale area shares are set at 20% and 60%. All countries with some large-scale areas are parameterised with a 20% share. “Some” is defined as up to 40% of the total irrigated areas. All countries with a pronounced extent of large-scale areas are parameterised with a 60% share. These are all countries with more than 40% large-scale irrigation systems (Map 4).

Map 4 Global distribution of large-scale irrigation areas

The scale type is only applied for countries with surface and mixed irrigation, and used to assign a management factor to countries with extended open conveyance systems. Where

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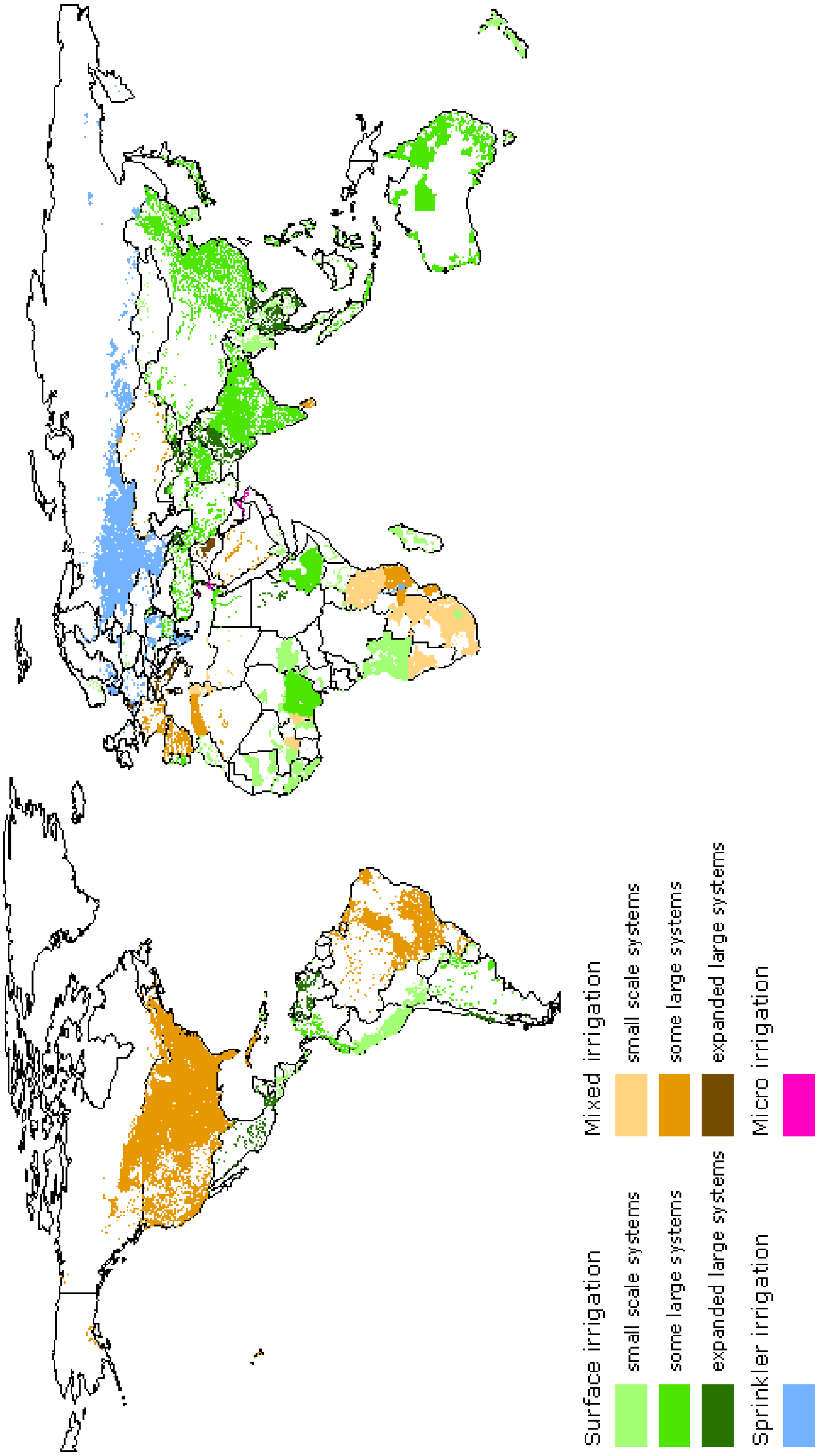
[7] FAO Aquastat published the data in the internet: http://www.fao.org/ag/agl/aglw/aquastat/irrigationmap/index10.stm.

pressurised irrigation is dominant, the scale is not considered for efficiency estimation. Therefore subtypes are not needed. The combination of method and scale type, if appropriate, results in eight Irrigation Functional Types: Micro-, Sprinkler, Mixed sss (small scale systems), Mixed sls (some large-scale), Mixed els (expanded large-scale), Surface sss(small scale systems), Surface sls (some large-scale), Surface els (expanded large-scale) (Table 4, Map 5).

Table 4 Overview of functional types of irrigation and their attributes

IFT	Application of priority list	Field application method	Conveyance system	Fraction of large-scale systems
Micro	No	Micro-irrigation	Pressurised	None
Sprinkler	No	Sprinkler irrigation	Pressurised	None
Surface sss	No	Surface irrigation	Open canals	None
Surface sls	No	Surface irrigation	Open canals	20%
Surface els	No	Surface irrigation	Open canals	60%
Mixed sss	Yes	50% Sprinkler 50% Surface	50% pressurised 50% open canals	None
Mixed sls	Yes	50% Sprinkler 50% Surface	50% pressurised 50% open canals	20% of Surface irrigated area
Mixed els	Yes	50% Sprinkler 50% Surface	50% pressurised 50% open canals	60% of Surface irrigated area



Map 5 Global map of irrigation functional types

5.2 Estimation of irrigation efficiency

The overall efficiency of an irrigation project consists of three partial efficiencies: conveyance efficiency, distribution efficiency and field application efficiency. They depend on field application method, conveyance system and management as already described. As mentioned above, the distribution efficiency is replaced by a management factor.

For the field application and conveyance efficiencies it is assumed that irrigation projects are well managed. These values describe the optimum of an irrigation system. Poor management can significantly reduce the ability of an irrigation system to provide water to crops. Average values for bad O&M are not available because the extent of failures is unknown.

In this section, the different efficiencies are first defined. With regard to scheduling (chapter 3.3), economic efficiency is introduced and some performance indicators are presented as well. Afterwards, values are assigned to the partial efficiencies for all IFTs. Based on the map of IFT distribution, a global map of irrigation efficiencies is finally presented.

5.2.1 Efficiency and performance of irrigation systems

Irrigation efficiencies (IE)[8] and irrigation performance indicators measure different aspects of compliance of irrigation systems. Irrigation is a complex task with widely varying non-uniform internal processes and numerous definitions have been established for both concepts.

Generally, efficiencies describe various outputs per unit of input, e.g. yield[t] per volume of water applied [m³] or profit[$] per cultivated area[ha]. On the contrary, performance is a broader concept. In general, the aim is to compare actual achieved levels of outputs with beforehand agreed target values.

Efficiency as ratio of output to input inflow can be applied to all irrigation system components separately. (Bos & Nugteren, 1990) offer the “most widely accepted” definitions of IE (SanaeeJahromi et al., 2001) and their definitions have been adopted in this study. The efficiency values are scaled between 0 and 1:

Conveyance efficiency (E_C) and distribution efficiency (E_D) both refer to the water delivery from the source to a specific outlet:

$$\mathbf{E_C = (V_D + V_2) / (V_C + V_1)}$$

with E_C = Conveyance Efficiency
V_C= Volume diverted or pumped from a source[m³]
V_D = Volume delivered to the distribution system [m³]
V_1= inflow from other sources to the conveyance system [m³]
V_2= non-irrigation deliveries from conveyance system [m³]

At the outlet separating conveyance and distribution canals, responsibility is handed over from a formal organization to farmers who might share an inlet or own them alone.

$$\mathbf{E_D = (V_F + V_3) / V_D}$$

with E_D = Distribution Efficiency
V_F = Volume of water furnished to the fields [m³]
V_3= non-irrigation deliveries from the distributary system [m³]

The combined conveyance and distribution efficiency gives the irrigation system efficiency (E_S)

$$\mathbf{E_S = (V_F + V_2 + V_3) / (V_C + V_1)}$$

with E_S= Irrigation System Efficiency

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[8] Instead of efficiency the term “consumptive use coefficient” is also used (Pereira, 1999). This expression offers a more precise description of the subject. However since the term ‘efficiency’ is more common, it is used here as well.

Field application efficiency (E_A) measures the irrigation systems' performance of its primary task of watering plant roots:

$$\mathbf{E_A = V_M/V_F}$$

with E_A = Field Application Efficiency
V_M = Volume of irrigation water needed and made available for crop evapotranspiration to avoid undesirable water stress [m^3]

Crop evapotranspiration (EVT) usually includes both plant transpiration and soil evaporation from the wetted surface (Perry, 1996).
These are the partial efficiencies of all irrigation system components. When multiplied, they allow for an estimation of the overall or project efficiency (E_P). This reflects the fraction of water diverted from a source for irrigation purposes and available for beneficial crop evapotranspiration:

$$\mathbf{E_P= (V_M + V_2 + V_3)/(V_C + V_1)}$$

Usually V_1,V_2, and V_3 are negligible small compared to V_C, V_D, V_F, and V_M. Therefore the partial efficiencies can be simplified as follows.

$$\mathbf{E_C= V_D/V_C}$$
$$\mathbf{E_D= V_F /V_D}$$
$$\mathbf{E_S= E_C*E_D = V_F /V_C}$$
$$\mathbf{E_A = V_M/V_F}$$
$$\mathbf{E_P = E_C*E_D*E_A = E_S*E_A = V_M /V_C}$$

Alternative concepts to define irrigation efficiency include economic approaches as well. Their purpose is usually to maximise net benefits of water use. Costs and benefits of different irrigation aspects are taken into account, e.g. water delivery, opportunity cost of irrigation and drainage activities, potential third-party effects, and externalities (Cai et al., 2001). Often economic efficiencies are related to production in terms of gross or net value measured at local or world market prices (Molden et al., 1998). Where units of water supply determine benefits, beneficial water use instead of crop EVT is the appropriate approach. But improving physical irrigation efficiency does not necessarily improve economic efficiency. It can be economically more rational to waste water instead of investing into loss reduction.

Besides irrigation efficiency, irrigation performance is assessed not only to improve accomplishment on field or scheme level but also to show developments over time or enable cross-system comparisons (Molden et al., 1998). Performances of irrigation systems are described with various parameters depending on the purpose of assessment.[9] They are composed of irrigation performance indicators (IPI). In general, these are ratios of actual values and intended values of beforehand agreed objectives (Bos, 1997). Traditional performance measures are *adequacy*, *equity*, and *reliability* (Bos & Bastiaanseen, 1999). However other parameters have been introduced as well. Among others these are dependability, efficiency, productivity, sustainability (Gorantiwar & Smout, 2005):

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[9] The parameters are sometimes also called performance measures and associated with types according to their functions, e.g. allocative and scheduling type performance measures (Gorantiwar & Smout, 2005) or operation performance and delivery schedule performance as components of delivery system performance (SanaeeJahromi, 2001).

Adequacy	reflects the allocation of water or the relative water supply, which is the ratio of plant water supply to demand
Equity	describes the spatial uniformity of water distribution within a system or among users
Flexibility	depicts the ability of irrigation water schedule to adapt dynamically
Productivity	compares the output of an irrigation system (in terms of produced crops (or their economic equivalents) with the input into the system (in terms of land, water finance)
Reliability	mirrors the timeliness of water delivery as scheduled, even so the amount of water might be below the scheduled requirement

Adequacy and reliability can be subsumed under the term dependability: “the delivery of a relatively known amount of water over time as expected by the water users” (SaneeJahromi et al., 2001).

5.2.2 Efficiency parameter

Parameters for field application efficiency and conveyance efficiency and a management factor instead of distribution efficiency are assigned to each IFT, according to its field application method and the scale of irrigation systems. A table with all efficiencies parameter is provided at the end of this chapter.

Mixed IFTs are addressed different from the other IFTs. For implementation in LPJmL, the parameters for surface and sprinkler irrigation should be applied on the respective areas. Yet, in maps and tables in this study, average values are specified:

$$E_{MIXED} = 0.5*E_{SURFACE} + 0.5*E_{SPRINKLER}$$

Field application efficiency E_A

In the case of field application efficiency three different values are assigned to the irrigation methods by adopting FAO- references values (Brouwer et al., 1989). These efficiencies are assumed for well managed systems. Surface irrigation is taken into account with E_A=0.6, sprinkler irrigation with E_A= 0.75 and micro-irrigation with E_A= 0.9 (Table 6).

The FAO values are supported by findings of (Bos & Nugteren, 1990) for surface and sprinkler irrigation. Values for micro-irrigation are not provided in that study. The authors compared several irrigation projects worldwide and measured the partial efficiencies in these projects. Surface irrigation application efficiencies in this study fluctuate around 0.6 with tendency downward. Efficiency values for basin irrigation with continuous flow are considerably lower. Yet a distinction between rotational and continuous flow schemes is not applied[10]. On the project level the lower E_A values are balanced out by higher conveyance efficiencies. Thus surface irrigation, whether rotational or continuous flow, has comparable E_A efficiencies. In the case of sprinkler irrigation, average E_A = 0.67 and values range from 0.58 to 0.75 (Bos & Nugteren, 1990). This indicates that FAO assumptions are slightly too high but still within those limits.

Land and Water Australia offer a broader range of values for all methods (Fairweather et al., 2004) than the FAO. They assume that all irrigation methods can reach maximum field application efficiencies of 0.9. The here adopted values for surface and sprinkler irrigation rank at the lower end of the Australian range ($E_{A, Surface}$ 0.6 – 0.9, $E_{A,Sprinkler}$ 0.65 – 0.9). Such high efficiencies for surface irrigation require an optimum management with maximum control of water conveyance and distribution. In Australia this results might be realistic since the country is an example of successful modernization (Plusquellec, 2002) in contrast to the majority of surface irrigating countries. The lack of modernization is not only a problem of developing countries, but it is a larger problem in these countries, especially in Asia. And “irrigation

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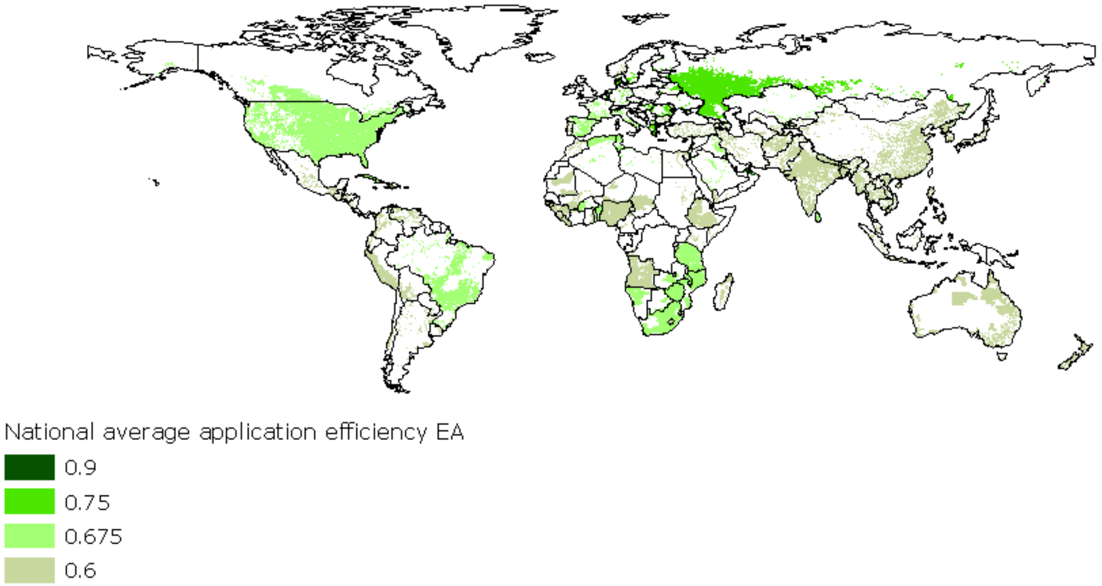
[10] A non-continuous distribution (rotational or proportional) is dominant in surface irrigated schemes. Continuous flow mainly takes place where basin irrigation is applied, such as in case of paddy rice. Rice can also be grown with different irrigation methods, although basin irrigation is still dominant. Basin irrigation is also suitable and applied to crops other than rice, such as cereals, sugar cane, fodder and pasture, fruits and vegetables, and cotton . But cropping patterns are not suitable to discern between continuous and rotational flow because. Any distinction would be imposed with additional uncertainties of unknown dimension (Bos & Nugteren, 1990; Guerra et al., 1998)

scene remains dominated by developing countries” in the coming decades (Bruinsma, 2003). Hence there is “little chance, that all gravity areas will be converted to more efficient pressure techniques” (Plusquellec, 2002). Therefore the chosen value stands for the application efficiency in most countries which are classified as surface IFT.

Micro-irrigation is different. According to Fairweather et al. efficiency rates might go down to 0.75 (2004). However the maximum value is assumed here. Due to high investment costs it is only economically suitable where water is scarce. There must be an efficiency gain when micro-irrigation is chosen instead of sprinkler irrigation. Hence there should be a remarkable difference between both application efficiency values.



Map 6 Global map of average field application efficiencies

Conveyance efficiency E_C

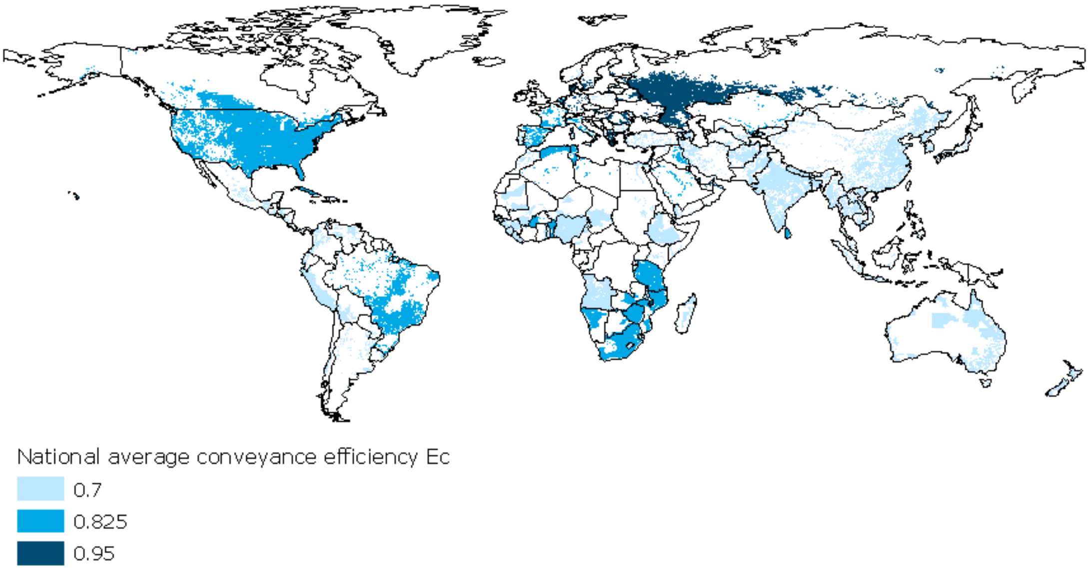
A conveyance system without any losses is unlikely. Hence conveyance efficiency is always below 1.

For open canals of surface irrigates systems $E_{C,Surface}$=0.7 is adopted and for pipelines of pressurised $E_{C,Pressurised}$=0.95. The value for surface irrigation is confirmed by two studies (Brouwer et al., 1989; Bos & Nugteren, 1990).

$E_{C,\ Surface}$ follows a FAO recommendation for canals of more than two kilometres and loamy soil, which is the mean value with regards to soil type influence. This value is supported by Bos & Nugteren (1990) as well. They examined the influence of command area size on conveyance efficiency. The measured overall average E_C is 0.68. Irrigation projects with less than 1000 ha show an average E_C of 0.68, too, within a range of 0.6 to 0.8. Command areas between 1000 and 10.000 ha are characterised by higher E_C values of 0.8 to 0.88 with an optimum between 4000 to 6000 ha. The estimated E_C is 10 to 18% below the empirical efficiency. For large schemes with more than 20.000 ha efficiencies are generally below 0.7 with an asymptotic convergence towards 0.55 (Bos & Nugteren, 1990).

However due to a lack of detailed information about extent distributions for equipped areas, the size cannot be used to distinguish between E_Cs in detail here. Countries are only classified into rough categories of countries with schemes below and above 10.000 ha. The higher losses are explained by management aspects, which are treated in the distribution efficiency/management factor section below.

In the case of both pressurised systems, with E_C=0.95, the maximum value of well-maintained lined canals is assigned as proposed by FAO (Doorenbos & Pruitt, 1977). Overall losses should not exceed those of lined canals because evaporation and percolation are generally avoided in closed conduits. Piped systems are theoretically protected from evaporation, deep percolation, weed growth, siltation and other causes for water losses on the way to the field. In addition, the management is less complicated to handle for skilled operators since full or partial automated control structures are easily implanted in technological advanced systems. Nevertheless, leakages and infrastructure damages are always possible and management failures cannot be excluded as well.



Map 7 Global map of conveyance efficiencies

Distribution efficiency/management factor

The parameter for distribution efficiency is replaced by a management factor M_F because E_D determination was too unconfident. Most influential on E_D are farms sizes, delivery period, and numbers of farmers sharing an inlet. The latter two factors are related to the first one. The lack of information in case of distribution efficiency E_D makes it extremely challenging to identify globally applicable average values. Data on rural tenure do not allow for prediction of the size of fields or management units. For example, in Latin America there is a tendency of smallholders to rent their farmland to larger farm management units (Burt & Styles, 1999). In Asia, smallholders frequently give up irrigated cultivation and seek for new sources of income, when agriculture does not provide sufficient revenues any more (Rice, 1997).

The management factor M_F is set to 1 for both pressurised IFTs. For mixed and surface IFTs, areas with small scale systems and those with large-scale systems are distinguished. M_F for areas with small-scale systems is 1 as well. For large-scale systems M_F is reduced to 0.5. This lowered factor is deduced from the experience that poor management reduces the system efficiency E_S to less than 50% (Rogers et al., 1997). Poor communication is also responsible for halving E_S (Doorenbos & Pruitt, 1977) from 65% to 30%[11]. Without an extra distribution efficiency, the conveyance efficiency E_C replaces E_S. The dimension of E_C is reduced to the dimension of large-scale E_S with M_F= 0.5 as first appraisal. The efficiency measurements collected by Bos & Nugteren (1990) indicate the same (Table 5).

Table 5 Average values of conveyance efficiency E_C, distribution efficiency E_D, and system efficiency E_S (= E_C*E_D), calculation based on sample efficiencies (Bos & Nugteren, 1990)

	Average E_C	**Average E_D**	**Average E_S**
1000 – 10.000 ha	0.85	0.81	0.69
>10.000 ha	0.59	0.72	0.43
Total	0.67	0.75	0.51

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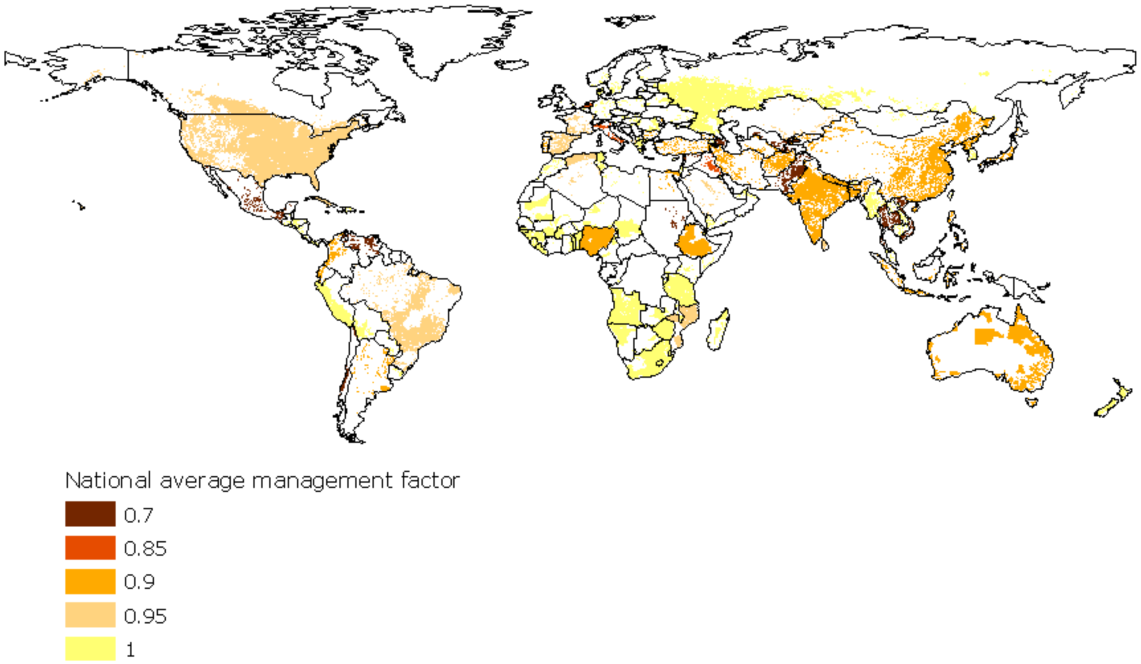
[11] Doorenbos et al. use a different defintion frame. The system efficiency is named distribution efficiency while the distribution efficiency is termed as field canal efficiency, but the definitions remain the same as applied in this study (Doorenbos & Pruitt, 1977).

M_F is only added to the large-scale fraction f_L of surface and mixed irrigation systems. In case of mixed systems, the management factor is only applied to the part irrigated by surface systems.
For Surface IFTs M_F is defined as

$$\mathbf{M_F = 0.5f_L + (1-f_L) = 1 - 0.5f_L}$$

For Mixed IFTs, the average M_F is defined as

$$\mathbf{M_F = 0.5*[0.5f_L + (1-f_L)] + 0.5*1 = 1 - 0.25f_L}$$



Map 8 Global map of management factors

Project efficiency EP

The overall project efficiency is a product of the partial efficiencies. As outlined in chapter 5.2.1, the project efficiency is defined as

$$\mathbf{E_P= E_C*E_D*E_A}$$

With E_D is replaced by a management factor, E_P is

$$\mathbf{E_P= E_C*M_F*E_A}$$

Table 6 presents an overview of all project efficiencies and their partial efficiencies. The global distribution of irrigation efficiencies is presented in map 9.

The maximum agricultural available water in each cell depends on the actual renewable water resources as total amount of available water, the volume of water discharged for industrial and urban purposes, claims of other riparian states and the minimum flow required to sustain ecosystems. These aspects are currently being implemented in LPJmL. Thus optimum and actual water supply for irrigation and optimum and actual water available for transpiration can be compared.

Table 6 Overview of efficiency parameters for all IFTs

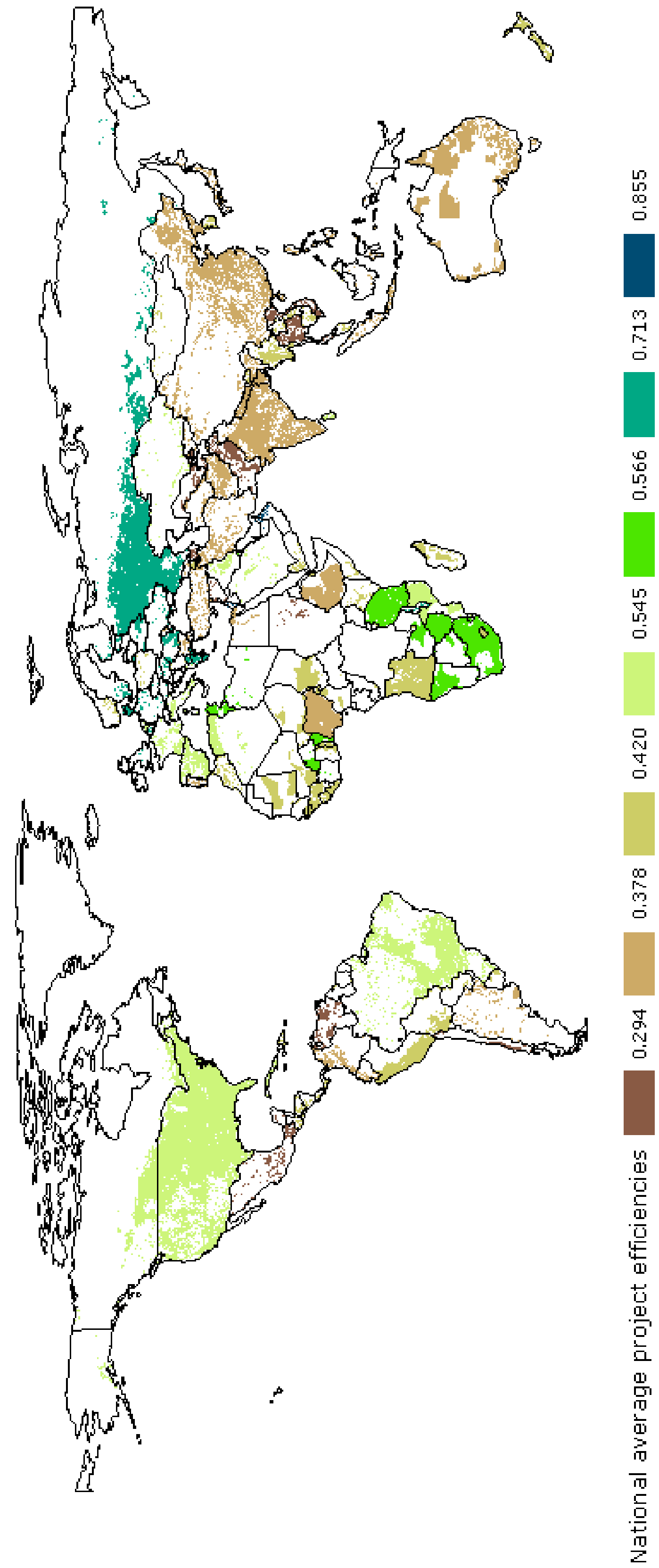
IFT	E_A	E_C	M_F	E_P
Surface small scale	0,600	0,700	1,000	0,420
Surface some large systems	0,600	0,700	0,900	0,378
Surface expanded large systems	0,600	0,700	0,700	0,294
Sprinkler	0,750	0,950	1,000	0,713
Mixed small scale	0,675	0,825	1,000	0,557
Mixed some large systems	0,675	0,825	0,950	0,529
Mixed expanded large systems	0,675	0,825	0,850	0,473
Micro	0,900	0,950	1,000	0,855

In LPJmL the project efficiency is applicable for different purposes. Gross irrigation water requirements $V_{C,\ GROSS}$ can be calculated with estimations of optimal crop transpiration demand $V_{M,OPT}$ and under consideration of effective precipitation and soil moisture:

$$V_{C\ ,GROSS} = V_{M\ ,OPT} / E_P$$

The actual volume of water available for transpiration $V_{M,ACT}$ can also be determined

$$V_{M,ACT} = E_P * \text{fraction of cell water available for agriculture}$$



Map 9 Global map of irrigation efficiencies

5.2.3 Quality assessment of the global map of irrigation efficiencies

An assessment of the quality of the map presented above is accomplished as first step towards validation. There are two sources for erroneous efficiency values: first, failures concerning the parametrising of partial efficiencies, and second, incorrect classification of countries with respect to IFTs. Errors due to mistaken parameters are hard to assess; hence, their reasons are discussed in the next chapter. In this section, the reliability of IFT assignment is evaluated, followed by a first comparison of regional average efficiencies with average regional values provided by (Döll & Siebert, 2002).

Quality of country classification

The classified IFT might lead to inadequate irrigation efficiencies. Six potential errors are presented in table 7, although not all of them are further assessed

Table 7 Potential errors, affected efficiencies and affected country groups

Error	Affected efficiency	Affected country group
Reliability of information about fractions of irrigation method	E_A, E_C, E_P	Irrigation method known
Difference between actual irrigation method fraction and IFT-fraction	E_A, E_C, E_P	Irrigation method known
Reliability of information about scale of irrigation systems	E_M, E_P	Irrigation method known Missing data
Difference between actual large-scale fraction and IFT-fraction	E_M, E_P	Irrigation method known Missing data
Wrong assignment of large-scale to method (only mixed IFT)	E_M, E_P	Irrigation method known Missing data
Reliability of assignment to IFT based on decision tree	E_A, E_C, E_P	Missing Data

In the case of reliability of information about the scale of irrigation systems, the used approach is introduced as initial appraisal of the influence of scale (and with it management) on irrigation efficiencies. It is likely that the identified areas are smaller than the actual ones because adjacent grid cells with a coverage rate below 40% might belong to the detected command area without being counted. Thus it is assumed that the determined areas are cores of large-scale systems. This assumption should be best tested, by comparison of selected areas with remote sensing data, which is not practicable within the scope of this study. Due to a lack of data for comparison, the reliability is equally reduced for all countries. Therefore, taking into account this aspect does not contribute to a distinction of quality of classification.

The same applies to the assignment of large-scale areas to the wrong irrigation method in mixed IFTs. No information is available when large-scale areas are mainly run with surface irrigation and when they are endowed with sprinklers. Therefore an equal distribution is assumed for all countries. Here again, the mistake is unknown for all countries and does not redound to an improved quality assessment.

The differences between assumed project efficiencies of an IFT and the calculated efficiencies can only be estimated for countries with known distribution of irrigation methods. The method pattern and the calculated fraction of large-scale schemes are both taken into account. The actual irrigation efficiency $E_{P,\ act}$ is the average of project efficiencies of all three irrigation methods.

$$\begin{aligned}\mathbf{E_{P,act}} &= \textbf{Surface fraction} * \mathbf{E_{SURFACE}} + \textbf{Sprinkler fraction} * \mathbf{E_{SPRINKLER}} \\ &\quad + \textbf{Micro fraction} * \mathbf{E_{MICRO}} \\ &= \textbf{Surface fraction} * \mathbf{(1-0.5fL)}*\mathbf{E_{C,SURFACE}}*\mathbf{E_{A,SURFACE}} \\ &\quad + \textbf{Sprinkler fraction} * \mathbf{E_{C,SPRINKLER}} *\mathbf{E_{A\ ,SPRINKLER}} + \textbf{Micro fraction} * \mathbf{E_{C,MICRO}}*\mathbf{E_{A,,MICRO}}\end{aligned}$$

These values are given in the overview of all countries in Annex B. A comparison of the actual efficiencies with IFT efficiencies proves that the averages chosen for IFTs classification are appropriate with an average difference 0.4%.

Differences above 10% (<9% of countries) are related to the fraction of large-scale areas, data only explaining a part of the irrigated area and to the affiliation with micro IFT since this IFT has the lowest threshold for classification. The overall effect of these differences is limited.

Assessment of data reliability

The reliability of IFT assignment remains to be assessed. Data reliability is used as proxy for this assessment. It is carried out in two steps:

1. The availability of data for each country is evaluated as high, medium, or low:
   high: information about the respective area of all three methods is on hand;
   medium: information about one or two methods exists;
   low: no information was detectable
2. For countries with a high or medium availability the consistency of this data is appraised. For countries with a low availability, instead the probability of a correct result after application of the decision tree is indicated.

Here a statement about the reliability of the country classification is made. In both cases reliability can vary from good, to acceptable or poor. A higher appraisal than good has not been chosen because the FAO advises to be cautious with their data since they need not to be comparable (for example FAO, 1997a). In addition, other sources have been included as well and thus potential non-comparability remains an issue (see chapter 5.1).

For countries with high or medium data availability, reliability is related to the area included in the information and to potentially contradictory information. Reliability is

Good	if the data comprise 95-105% of the area equipped for irrigation[12]
Acceptable	if the data covers 50-95% and the dominant method is identifiable
Poor	if below 50% of the area are explained or different values are published and the most recent is not detectable; special case: countries in transion

Countries in transition are treated differently. For these countries consistent but outdated information are available. The data are not dependable because it cannot be assumed that they reflect the situation during the last decade. It is known that major changes in the agricultural sector occurred, for instance that areas equipped for irrigation have diminished in Kazakhstan and Romania and most likely in the other countries as well (FAO, 1997a). Yet their extent and effect on irrigated agriculture can not be qualified.

For countries with low data availability, an IFT is assigned after application of the decision tree presented before. The quality of this classification is tested by a cross-validation. Since all countries with a known IFT have been included into the tree development, they are the only ones applicable as sample countries. Therefore the decision tree is applied to those countries with high or medium data availability. The assumption is made, that the quality of the assignment of the missing countries is the same as for sample countries.

The results are compared with the acquainted affiliation. For each region and IFT the numbers of correct and wrong assignment are gathered. The probability of a correct assignment P(IFT) is calculated as

P(IFT) = number of countries correctly assigned to IFT/ total number of countries assigned to IFT

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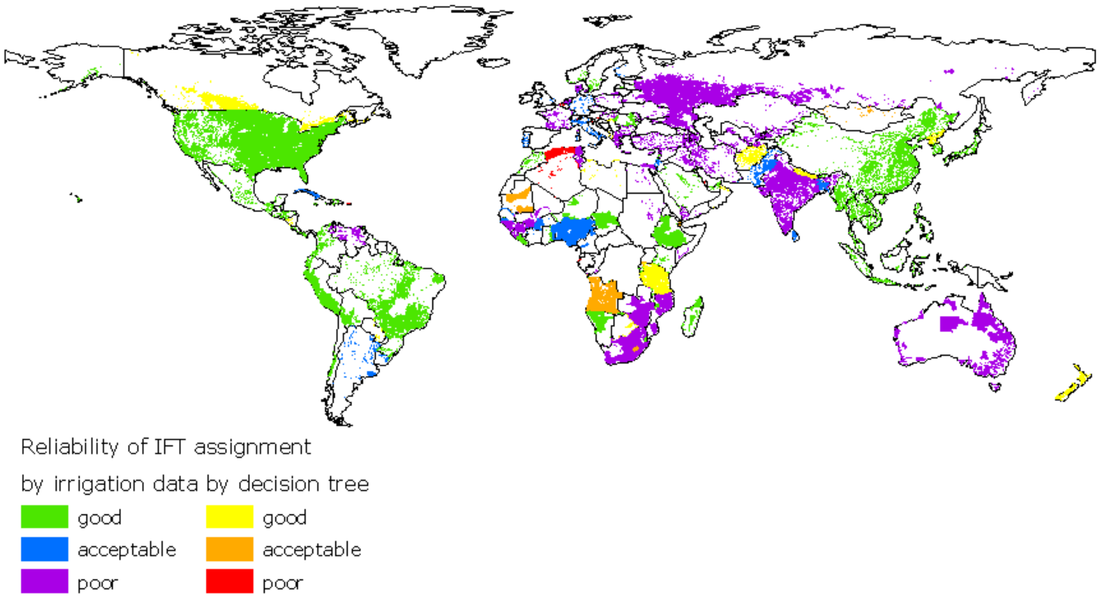
[12] Due to the combination of different sources of information, it is possible that the sum of areas irrigated with each of the three methods is larger than the total area equipped for irrigation, e.g. if the information has been gathered in different years or if differing definitions of “irrigated area” have been used.

This probability is evenly applied to all countries which belong to the respective IFT within one region. The reliability is assumed to be

Good	if P(IFT) >90%
Acceptable	if P(IFT) 90% to >50%
Poor	if P(IFT <=50%

The reliability values are also added to the overview table in Annex B. Overall 64% of all countries are rated to have a good (45%) or acceptable (19%) reliability. Those countries with a good reliability cover 48% of the global irrigated area. The remaining 36% of countries with a poor reliability are mainly countries where irrigation is of reduced importance. They cover together 41% of the globally equipped area. The larger percentage of covered area for poor reliability compared to the numbers of countries is caused by countries like India, where complete but contradictory sets of irrigation data were available.



Map 10 Reliability of global map of irrigation efficiencies

Comparison with earlier regional efficiency values

Here we compare the country level IFT values with roughly estimated regional average project efficiencies of Döll & Siebert (2002) to compute gross irrigation water requirements (table 8). Therefore, the regional averages of the country values are estimated. It is ensured that the regions comprise the same countries in both cases. Where possible, the regions are constructed as stated in Döll & Siebert (2002). Yet some of these regions are considered together, which is the case for Africa, except North Africa, Central and South America, and Asia. These regions are not broken down into countries and, thus, countries cannot be combined accordingly.

Average regional efficiencies are calculated once with project efficiencies weighted according to the area equipped per country and second as simple average of all country efficiencies. The simple averages are more often within the dimension of the Döll & Siebert (2002) values than the weighted averages. This is the case for Northern Africa, Eastern Europe, and the Middle East. For other regions, such as Latin America, the Sub-Saharan Africa, United States, Asia, and Japan, there are no remarkable differences between both values.

Weighted averages are only for OECD Europe South and the former Soviet Union closer to the reference values. Yet for two regions the estimated efficiencies rank on opposed ends of the scale: Oceania and Baltic States & Belarus.

Most values however range in the same dimension. This might indicate that the most determining parameters have been correctly implemented in the chosen approach. Yet differing results do not allow for specification whose values are more appropriate. First, the efficiency determination has not been specified by Döll & Siebert (2002). Thus it is unknown how, and with what kind of input, their values are calculated. Second, instead of regionally aggregated values, efficiencies are calculated in this study on a higher resolution, namely on the country level. And third, if sophisticated and detailed information is available, project efficiencies are estimated with an accuracy of 5 to 15% at best (Bos & Nugteren, 1990; Burt & Styles, 1999). Nevertheless, severe deflection of values might point to some structural problems of the chosen approach of this study. Regarding both “extreme cases” more closely, potential causes of erroneous efficiency estimations are evident. In the case of Oceania, data reliability of Australia, the country with the maximum share of the regional irrigation area, is rated as “poor”. It is possible that Australia was misclassified. It is also possible that in Australia mainly modernised surface irrigation equipment is used. In this case, the assumed partial efficiencies would be too low.

The Baltic States and Belarus are countries in transitions. They experienced political upheaval and tremendous structural changes during the 1990s. It is possible that information is not up-to-date and that the political restructuring had major impacts on irrigation management.

Table 8 Comparison of regional project efficiencies

Region	weighted regional average E_P	simple regional average E_P	Döll & Siebert (2002)
Canada	0.545	0.545	0.7
United States	0.545	0.545	0.6
Central & South America / LAM	0.38	0.41	0.45
Northern Africa	0.428	0.6	0.7
Western, Eastern & Southern Africa /AFR	0.469	0.466	0.45-0.55
OECD Europe North	0.632	0.663	0.5
OECD Europe South	0.557	0.541	0.6
Eastern Europe	0.659	0.602	0.5
Baltic States, Belarus	0.713	0.713	0.5
Rest of former USSR	0.510	0.435	0.6
Middle East	0.437	0.495	0.6
South, East & Southeast Asia	0.366	0.399	0.35-0.4
Oceania	0.382	0.399	0.7
Japan	0.378	0.378	0.35

Areas include: for South & Central Americas: all countries belonging to LAM; Northern Africa: African MEA countries; Western, Eastern & Southern Africa: all countries belonging to AFR; OECD Europe North: Austria, Belgium, Denmark, Finland, Germany, Netherlands, Norway, Sweden, Switzerland, and United Kingdom; OECD Europe South: France, Greece, Italy, Portugal, and Spain, Malta is not modelled in LPJ; Eastern Europe: Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovakia, Slovenia; Baltic States, Belarus: Estonia is not included in LPJ; Rest of former USSR: all FSU countries, except for Belarus; Middle East: Non-African MEA countries; South, East & Southeast Asia: CPA, PAS, SAS countries, Oceania: Australia and New Zealand;

For paddy irrigation, Döll & Siebert assume efficiency to be 0.1 less.

Source: own calculations and Döll & Siebert, 2002.

5.3 Irrigation scheduling

The yield in an irrigation system per unit of water supply depends not only on project efficiency but also on the timing and duration of water delivery. Yet “ the accurate determination of an irrigation schedule is a time-consuming and complicated process” (Brouwer, Prins et al. 1989). The evaluation of the exact daily amount of irrigation water requires consideration of daily changes in soil moisture, precipitation patterns, humidity, crop water requirements, and root depth. This explains why limited scheduling information is utilised by a majority of farmers' worldwide (Pereira 1999). Nevertheless, scheduling rules are necessary for irrigation modelling.

In general, scheduling comprises two aspects, the extent of irrigation needed during the growing season (full vs. supplementary irrigation), and the rule of water allocation (crop-based/ demand based vs. water-based/supply based). Crop-based allocation is highly flexible and thus suitable for full and supplementary irrigation. In contrast, water-based allocation is specified in advance, without knowledge of the actual soil moisture conditions. Therefore it is difficult to meet the exact timing required for effective supplementary irrigation. The control mechanisms of conveyance systems (manual or semi-automated/automated) restrict their flexibility. As explained in chapter 2.1, the conveyance method is linked to the field application method. Hence scheduling rules differ for IFTs according to their dominant field application techniques.

Surface irrigation

In the case of surface irrigation rotational allocation is regularly applied except for paddy rice. Thus surface irrigation scheduling is different for rice and non-rice CFTs

Non-rice CFTs

Usually it is sufficient for farmers to estimate or roughly calculate irrigation intervals and to keep irrigation depth[13] and intervals constant over the growing season. The FAO provides estimated irrigation schedules for major field crops during peak water use periods (Brouwer et al., 1989). In this study, average values of these estimations are used for the scheduling proposal, see below. The values apply to a medium soil water holding capacity (loamy soil).

In LPJmL, after the sowing date, irrigation water is applied rotationally on all irrigated stands with an irrigation interval I_I of 10 days, meaning water is supplied every 10th day. This is average I_I for temperate cereals, tropical cereals, maize, temperate roots, sunflower, and soybeans, recommended by the FAO if evapotranspiration rates are not considered.

For further distinction the maximum transpiration rate under well-watered conditions LPJ's E_{max} is used with $I_I = 11$ for $E_{max} = 5$ and $I_I = 8$ for $E_{max} = 7$.

The application depth is defined as the lesser of WHC at field capacity and 60 mm. 60 mm is the FAO recommended maximum application depth for soils with a medium WHC (Brouwer et al., 1989). The lesser of both values is chosen because water supply supersaturating maximum soil water content is deducted from irrigation depth in advance by inclusion of the application efficiency E_A in the project efficiency E_P.

Rice

For LPJmL continuous flow is applied to uphold a saturated upper soil layer, meaning that the soil moisture is kept at maximum from the sowing date until harvest. For improved assessment of total water consumption on rice stands, soils should at least be completely saturated twice before planting. This is difficult to implement because crop stands are taken out of a pool exactly at the sowing day. Beforehand a spatial allocation of rice stands is not possible. Hence land preparation water requirements cannot be estimated.

Pressurised irrigation

Irrigated agriculture in LPJmL is regulated by crop-based water allocation. This approach is usually applied for pressurised irrigation. The current LPJmL solution is preserved for sprinkler irrigation.

For micro-irrigation the LPJ approach is suitable with a slight modification. Micro-irrigation aims at restricting soil water to the rooting zone to reduce soil evaporation. With this method, evaporation accounts for approximately 4% of total EVT. This is half of the evaporation rate of sprinkler irrigation system (Keller & Seckler, 2004). To take this difference into account, the soil moisture in the upper 20 cm of the soil column is kept below 100%.

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[13] Amount of water applied per irrigation turn (Brouwer et al., 1989).

Mixed irrigation

For mixed irrigation scheduling rules are applied to surface and sprinkler irrigated areas in accordance with the spatial distribution of both methods within a mixed IFT- country. For stands, assigned to surface irrigation, surface or rice scheduling respectively, is utilised. For stands, assigned to sprinkler irrigation, sprinkler scheduling is applied.

Scheduling during water shortages

If water supplies are decrease suddenly due to shortage, their distribution rules should be adopted to the changed circumstances.
The two possibilities are a proportional reduced flow rates for all irrigated stands or full supply for a reduced area. Reducing the area is at least more common for paddy irrigation where rotation tends to break down under shortages and tail-enders are cut off (Rice, 1997). Otherwise it is a problem of economic productivity if less irrigated area or less water per hectare is more suitable in a shortage situation. Economic efficiency indicators allow for this comparison of productivities. The question is which principle provides higher outputs either in tons of yields or in $ of production? Or the other way round, in which case are yield losses smaller? This decision mechanism requires a dynamic coupling of LPJmL with a land use model.
A proportional reduction is simpler to apply. The amount of water available at a given point in time and space is evenly distributed about the irrigated area.

5.4 Different features of spatial allocation of irrigated areas

In LPJmL for each grid cell it is predetermined which fraction of the cell is irrigated. The actually irrigated stands in each cell are determined by the irrigation of some CFTs corresponding to a list of priorities.
Beyond that, the actually irrigated area is usually less than the equipped area. The irrigation area has grown over time and the extensive use of sprinkler and micro-irrigation is a comparably new phenomenon. For a better understanding of irrigation processes on a global scale, these changes in spatial distribution of irrigation over time must be considered as well.
For an improved representation of the spatial distribution of irrigated areas within each grid cell and over time, and actually irrigated areas are here examined on a regional scale. Regions are used as spatial units (Table 9) because it is assumed that spatial patterns show a higher similarity within the same geographical and economic regions.

Table 9 Denotation of regions

AFR	Southern Africa
CPA	Centrally-Planned Asia
EUR	Europe
FSU	Former Soviet Union
LAM	Latin America
MEA	Middle East/Northern Africa
NAM	North America
PAO	Pacific OECD
PAS	Pacific Asia
SAS	Southern Asia

5.4.1 Actually irrigated area

Usually the area actually irrigated is smaller than the total area equipped for irrigation. This is due to rehabilitation needs (annually at least 2,5% of the total area due to the average 40 years life span of irrigation infrastructure), lack of water or other input or other economic or social reasons. Especially the transfer of inadequate technologies to developing countries and overoptimistic assumptions about potential command areas were widespread. The root causes are often rent-seeking behaviour of national irrigation agencies and a lack of feasibility studies by donor agencies (Plusquellec, 2002; Svendsen & Rosegrant, 1994).

Management failures reduce the possible irrigated area additionally. Especially silt and weed problems show a high potential to outgrow irrigation agencies coping capacities even if maintenance is fairly good otherwise (Rice 1997).

However, information about the actually irrigated areas is poor (Siebert et al., 2005). Based on the available data, WE calculated regional average actual irrigation area fractions (Table 10). The same country selection, which is used to identify cropping patterns, is utilised here again.

Table 10 Regional averages of actually irrigated area

Region	Actually irrigated area a of total equipped area [%]
AFR	93.61
CPA	89.91
EUR	67.66
FSU	84.73
LAM	77.34
MEA	99.74
NAM	78.26
PAO	63.05
PAS	81.76
SAS	98.66
Global	88.82

Globally less than 90% of the area equipped for irrigation should actually be irrigated in LPJmL. On average 10% of the national area, or the fraction indicated by the regional value, should be excluded from irrigation. The selection of the suspended areas can take place by random and can change annually.

5.4.2 Historical development of irrigated areas and irrigation techniques

Development of irrigated areas

In the late 19th and early 20th century large-scale irrigation reappeared on the political agenda. The colonial powers initiated irrigation expansion in Asia and Africa to increase revenue collection from agriculture (Barker & Molle, 2004; FAO, 2005). In the Hispanic world as well as in Australia, private and state investments in water works were made during the same time (Popp & Rother, 1993; Abernethy, 1996; FAO, 2000).

During the 1950s, the irrigation development gained momentum. Food security became a major issue when Asia was hit by severe famines in the 1960s and 1970s (Barker & Molle, 2004). Simultaneous droughts in the Soviet Union and the USA created a global “food panic”, pushing staple food prices and hence promising high return rates for investments in irrigation (Carruthers et al., 1997). As a consequence, irrigation expansion reached a peak during the 1970s (Bruinsma, 2003; Barker & Molle, 2004).

For donor agencies, the sharp decline of world market prices in the 1980s set an end to this incentive (Bruinsma, 2003). In the 1980s and 1990s the global annual irrigation area growth rate did not exceed 1.3% anymore (Plusquellec, 2002). Nevertheless, the FAO projects an increase of the global irrigated area of 40 million ha until the year 2030, despite the slowed down growth. By then 60% of the worldwide potential irrigation area will be in use, mainly in developing countries. The area under irrigation will often be increased by conversion of rain-fed cultivated land, thus reducing the possibility to satisfied food demand with green water.

The expansion of irrigation during the last century was no linear process as it is assumed in LPJmL. An improved account of the development of irrigated areas is possible for the last four decades. The FAO provides annual country information about irrigated areas since 1961. Since these data are easily available (http://faostat.fao.org/site/419/default.aspx, 08.09.2006) they are not listed in this study. Thus, for the period since 1961 this data should be incorporated into LPJmL. It can be used to adapt the linear growth rates to the actual for the according time period. For the period of 1901 to 1960 the current assumption of a linear trend should be followed since more precise data are not available.

Changes in irrigation methods

For the assignment of IFTs to countries without irrigation information, simple proxies have been chosen. Yet other socio-economic factors influence the choice of an irrigation method as well: mainly previous irrigation experiences and external influence factors

The thresholds used in the decision tree (see chapter 5.1) are coherent with general expectations about labour and capital input and climatic conditions. Nevertheless, distinct classes could not be identified.

The overall picture is ambiguous and suggests that traditions, colonial experiences and water development policies are possibly more constitutive for affiliation to an irrigation type than anticipated. Previous experiences with irrigation relate to societal persistency of customs and habits. Irrigation traditions show a great resistance against innovations. Thus in countries with a long lasting irrigation history, surface irrigation is more probable. Former colonial powers often also exerted influence on irrigation development and laid a cornerstone of later irrigation development policy (FAO, 1997b; Barker & Molle, 2004).

Irrigation development has been the responsibility of public authorities and donor agencies for decades. Infrastructure provision allows only for a limited choice of field application methods. Furthermore, access to technologies is sometimes restricted by policy, e.g. import restrictions. In contrast, subsidies and support programs are introduced to foster dispersal of political preferred methods. Among others, this has been the case in Bangladesh, India, the Russian Federation, Chile, Brazil and Spain (FAO, 1999; FAO, 1997b; FAO, 2000; Popp & Rother, 1993). Nowadays, private investment gains more and more influence.

For example, the current changes in irrigation patterns and customs in South Asian small scale systems could be the starting point for a shift in IFT assignment. The exploitation of aquifers laid the foundation for the adoption of new irrigation techniques and the latter is the basis for cultivation of high value crops. A current change in irrigation patterns and customs is the growth of small-scale pressurised systems in South Asia. Farmers respond to untimely and unreliable delivery by finding new ways to meet their requirements (Plusquellec, 2002). Where possible groundwater is used in conjunction to rotational water supplies, a proceeding is often more productive than on-demand scheduling (Barker & Molle, 2004). Here; a positive feedback coupling starts: Private investment in wells and pumps reduces incentives for cooperation by fostering individualistic strategies. Hence the reliability of the rotational supply further deteriorates. The pressure to invest into private infrastructure increases further. Therewith irrigation scheduling is more predictable for farmers but less for modelling.

When groundwater becomes scarce, investment into more efficient technologies starts. For the first time, smallholders can purchase low technology pressurised systems. Yet the adoption is still low and economic prosperity remains the indicator for the ruling method.

Alteration of cropping patterns becomes economically feasible with the technological development, as well. Smallholders tend to irrigate high value crops with pressurised methods to secure their return of investment rates (Cornish, 1998). Thus access to new technology (in this case pumping technology in the first instance) can trigger a complete shift of all parameters of an irrigation system. In case of pumping technology, the reliability, adequacy and flexibility of water supply is improved but this is costly and thus investment into more efficient irrigation technologies becomes of interest.

This shows that changes in irrigation method are dynamic processes. However, for LPJmL a point in time must be set, when irrigation methods have been introduced. At the beginning of the 20th century, all countries where classified as surface IFT because surface irrigation was the dominant method worldwide. Sprinkler and micro-irrigation have been applied on a grand scale since the 1960s. The complete replacement of old techniques takes time because irrigation equipment is long living.

Hence, it is necessary to decide about a point in time, when sprinkler and micro-irrigation are introduced and when new irrigated areas are developed within large-scale systems.

Sprinkler irrigation technology quickly spread in the USA during in the 1970s (Klohn, 1995). In the next decade, some other countries like India, Brazil, Egypt, and Saudi Arabia introduced sprinkler as well, although they never become dominant there (FAO, 1999; FAO, 2000; FAO, 1997b).

Micro-irrigation is technically more sophisticated and more recent than sprinkler irrigation. It is often introduced later. For example in India and Chile pilot plants were built in the 1990s (FAO, 1999, FAO, 2000). Yet in Cyprus, where micro-irrigation is dominant, this method has already been established in the mid-1970s (FAO, 1997b).

For sprinkler and micro IFTs, these methods should be introduced from the decided point in time. The already existing area should be replaced over time. The area which had been developed 40 years ago should be taken off from the surface irrigated area and added to the sprinkler or micro area. Older command areas should have been rehabilitated until the introduction of new techniques. Here a replacement time of 60 years is proposed.

For mixed IFTs, new areas are equipped with sprinkler irrigation like the sprinkler IFT. Existing areas are only transformed until the current area of sprinkler irrigation is covered. The rest of the area is left to surface irrigation as before.

This solution is still not optimal. The applicability of the decision tree for IFT assignment could be tested. Changes in the irrigation method could be compared with the simultaneous trends of income, population and agricultural water withdrawal.

6 Discussion and summary

Irrigation systems are differently well adapted to meet their main objective: delivering sufficient amounts of water to crops in due time to prevent severe damages caused by water stress. Some are capable of meeting this target, but may also be wasteful and operate at low efficiencies, while others fail to meet this objective although they may distribute the water available in a very efficient way.

These differences affect the water cycle and crop performance at the local and global scale. For the terrestrial biosphere, they are of major importance since they significantly affect land-use patterns (which are strongly influenced by land-use suitability and, thus, by crop performance and freshwater availability). For Dynamic Global Vegetation Models such as the LPJmL model, which are used for studying the terrestrial natural and agricultural vegetation as well as the linked carbon and water cycles, it is therefore of importance to represent well the effectiveness of irrigation systems and its spatial differences.

This can now be accomplished by use of the here defined country-scale IFTs (which can be applied for eadch irrigated grid cell in a given country). They enable the simulation of effects of irrigation on worldwide yields and on the global freshwater cycle. With the IFTs, a globally consistent basis has been introduced to estimate national average irrigation efficiencies and simple scheduling rules that describe the effects of temporal disparity of water delivery. They allow for a more precise and process-based estimation of the gross irrigation water requirement and, thus, a better quantification of the impact of agriculture on the global freshwater cycle, and a more realistic identification of regions with blue water scarcity, i.e. agricultural water limitation. Simulations of crop phenology, biomass production and yields are also expected to become more realistic. Simultaneously the changes in blue and green water fluxes due to irrigation can be assessed more precisely by the implementation of the IFTs. In effect, simulation results under the assumption of optimal irrigation (which is assumed in the current LPJmL version as described in Bondeau et al. (2006)) can be compared with those under consideration of the IFTs developed in the present study. Initial simulations (Jachner, unpublished manuscript) show that the IFTs substantially improve the LPJmL estimates of irrigation water requirements as compared to independent measurs and other modelling studies, which indicates that the IFTs defined here are well suited for global modelling studies.

The IFTs rely on input data about countrywide preferences of irrigation techniques and the scale of irrigation systems. These data have been collected for the major of irrigated areas, although the availability and reliability of information about irrigation techniques is generally limited. Due to the restricted information, the distribution of IFTs reflects the situation in the decade of 1995-2005. Overall, however, the global distribution of the IFTs is plausible. Surface irrigation is still the dominant method in most countries. This is especially the case in Asia, Latin America, and the northern half of Sub-Saharan Africa. Mixed irrigation is more common in countries with a moderate climate, mainly in Europe, Northern America, and Southern Africa. Sprinkler irrigation, in contrast to the former two groups, is a phenomenon of the countries in transition in Eastern Europe and the Former Soviet Union. Finally, micro-irrigation is rare and solely found in the broader Mediterranean area that is Middle East and North Africa as well as Cyprus and Malta. Large-scale irrigation systems exist on all continents. Yet, there is a distinct concentration and spreading of large-scale systems in Asia, Middle and Eastern Europe and Middle East and North Africa.

According to the combination of irrigation technique and system size, the overall irrigation project efficiencies range between 30 to 42% in those regions with surface irrigation. The dominance of this IFT in Asia, where two thirds of all irrigated areas are located, explains the low global average efficiency of less than 40% (Wallace & Gregory, 2002). Mixed IFTs show efficiencies around 55%. In countries in transition efficiencies are above 70% due to the widespread sprinkler irrigation and countries with mainly micro-irrigation reach efficiencies up to 86%. The global distribution of irrigation project efficiencies and of the partial efficiencies is also plausible.

Several potential caveats have to be kept in mind when applying the IFTs in the LPJmL model or any other largte-scale hydrological model. The applied irrigation efficiencies determine the amount of water which is actually available for crop transpiration. Thus water that is lost in the field to percolation, surface evaporation and runoff is already subtracted from these figures. A part of the water never reaches the field outlet. The prevalence of conveyance methods is related to the irrigation method. This means, in surface irrigated countries and partly also in mixed irrigated countries, approximately one third of the divided water gets lost during transportation. In pressurised systems these losses are almost negligible. In addition to the irrigation efficiencies scheduling methods are also related to irrigation methods. In surface and mixed IFTs a rotational delivery mode is most frequent, whereby water is distributed based on water availability. In these countries limited amounts of water are spread in intervals. In the Pacific Asia, Southern Asia and the Pacific OECD (Japan), paddy cultivation with continuous irrigation is widespread. On paddy stands permanent saturation of the soil is secured by daily refilling of the soil moisture. Pressurised systems, in contrast to surface systems, are supplied with water on-demand and therewith show a considerably higher flexibility to adapt to changes in crop water requirements.

The impact of scheduling on irrigation productivity could be severe, especially on the portioning of blue and green water flows. Rotational supply, in contrast to delivery on demand, does not ensure that water is only supplied when the soil is ready to absorb it. Watering of almost saturated fields leads to an increase in percolation and runoff and thus to a lower increase in transpiration. Missing necessary irrigation turns because water is not available can lead to invariable drought damages. Gross irrigation water requirements are probably underestimated if on-demand scheduling is applied for surface systems. First, irrigation would not occur on almost or completely saturated fields and second, yields are too high because decreases due to water stress are not simulated. Overall, more water than intended by the applied efficiency factors, will reach the plants so that crop yields and green water flow calculations might be too high.

A similar problem occurs when irrigation losses are applied on the field in addition to the actual irrigation water (Figure 19).

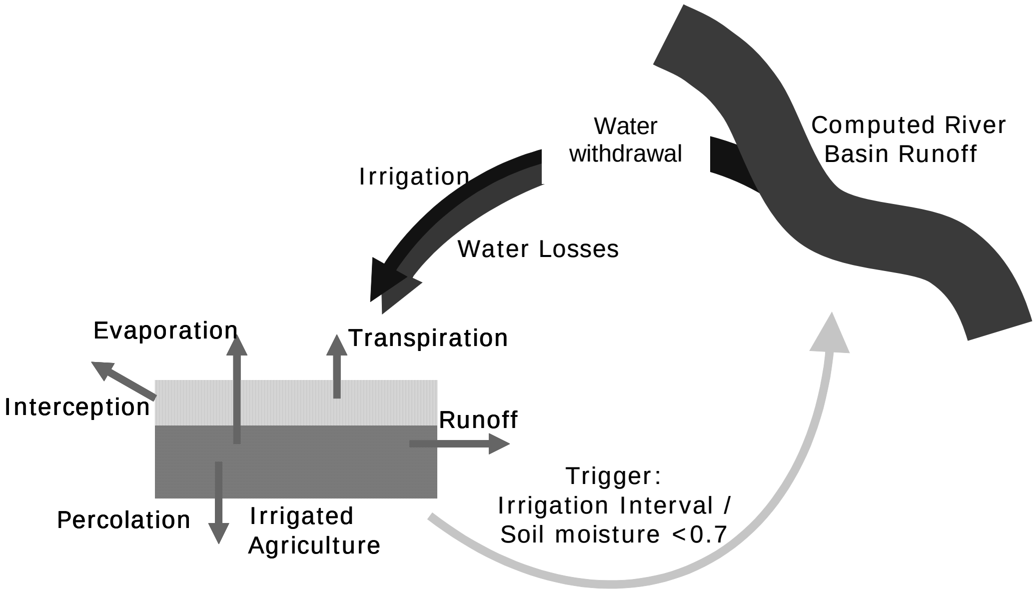

Figure 19 Irrigation implementation in LPJmL with irrigation losses additionally applied on the field

In LPJmL, the losses evaporate, percolate and run off, if water is abundant. Yet in the case of scarce water resources, it is highly likely, that this method leads to erroneous conclusions about water flows. For example, in small-scale surface IFTs, the gross irrigation requirement is 2.5 times the actual crop water requirement. If water resources are depleted, it is possible that only 70% of the gross water requirements are met. Consequently, only 70% of the crop water requirements are covered because the rest of water is lost before reaching the plant. Yet, if the total amount is applied on the field, the crop can still consume optimum amounts of water, in times of scarcity. This happens because water is spread equally on the field. Inflow and discharge rates of surface systems and nozzle pressure in pressurised systems are not anticipated in LPJmL. Hence, water which should drain off gets time to infiltrate into the soil. The water application rate in this case is too high and crops which would already have withered might still be flourishing. Thereby the share of green water vapour flows might be too high. In both cases, the application of schedules and the proper distribution of losses, the effect of scheduling and loss distribution on the overall results still has to be tested. Thus it is important to ensure that conveyance losses are actually lost before they reach the field or in case of LPJmL that they are not applied on the respective CFT-stand. These problems are currently being considered in the implementation of the IFTs in the model by applying them in the right order and ensuring evaporative losses in the conveyance system before the water is brought to the fields (Jachner, unpublished manuscript).

Also, a fine-tuning of scheduling may have to be considered in the model, as irregular water deliveries are frequent and as actual schedules differ from the announced onces, especially in Asia (FAO, 1999). For better modelling of this phenomenon, a random variability of irrigation intervals could be included. Water application could range between +/- one or two days around the irrigation interval. Also, a refined scheduling process could be considered, potentially specific to each CFT. For most CFTs 8, or 11 days, respectively, are appropriate I_I values. Crop water demands of fruits and vegetables frequently require either smaller (3/4 days) or larger (11/15 days) I_I -values.

Water for land preparation and inundation of paddy fields is not estimated in the LPJmL model. This aspect of irrigation is mostly limited to Asia and the Pacific OCED member Japan. A flooding module is not implemented, thus water for flooding would be portioned into runoff, percolation and evaporation. The extent and impact of evaporation and percolation of stored blue water in basin irrigation should be examined, before development of an additional flood module.

Finally, in case of water scarcity, a decision mechanism is needed to identify those crops that should still be irrigated if full supplied for a reduced area is intended. The aim is to maximise economic gains or yields with regard to limited water supplies. Water is provided to crops providing higher returns if their yields are secured, also other crops might need irrigation as well.

A similar approach is used for deficit irrigation. This is an optimizing strategy where crops deliberately experience a mild degree of water stress, allowing for minimal yield reductions. The economic benefit of this method is larger compared to a strategy of maximizing yields per unit of water because the saved water can be used to irrigate additional crops. This technique presupposes the adoption of suitable irrigations schedules. Nevertheless it is also practical in traditional surface irrigation systems (Perry & Narayanamurthy, 1998). Here dynamic coupling in sub-annual time steps with an economic model would be necessary to identify those crops, which ensure the highest return rates. Alternatively, a regional ranking of crop preferences could be defined and used. This list might be quite different from the regional priority lists offered in this study for years without uncommon water stress.

A problem in the determination of the overall project efficiency poses the dimension of the management factor. A special case is the former Eastern Bloc with its countries in transition. The high project efficiencies of these countries are remarkable. The reliability of these data has already been degraded due a lack of up-to-data information. The limited knowledge about the current situation suggests that irrigation efficiencies in these countries are lower than assumed for their IFTs, particularly in the case of sprinkler irrigation. Since independence, a re-organisation of the agricultural sector is ongoing in most countries. Privatisation of former state property is widespread. Restructurings of ownership and land tenures lead to a need for higher flexibility and compliance with more complex delivery schedules. This is only possible where infrastructure is adapted to the new conditions, including time and money consuming conversion and construction works. Due to the difficult economic situation, maintenance and rehabilitation costs are often not covered. During the last decade, especially sprinkler systems diminished. As a consequence, irrigation was completely abandoned in some areas (FAO, 1997a). The severe but disregarded lack of O&M could explain the disagreement between the estimated values and those proposed by Döll & Siebert (2002). As corrective, a management factor could be introduced for countries in transition classified as sprinkler IFT. The exact numerical value of these must be tested after implementation. The management factor of 0.5 applied to surface and mixed IFTs could be used as starting point. Yet it should not be limited to large-scale systems, but adopted for the complete country.

This case demonstrates that the management factor is a tool to adapt to changing circumstances and to couple the irrigation module with a dynamic economic model. On the one hand, management is a decisive factor for irrigation efficiency. On the other hand, average management factors are extremely difficult to assess because it is a highly variable issue. One or two simple errors in the institutional framework or design of a project are sufficient to drastically reduce the quality of management. Anyhow, it is not sufficient to repair one or two errors and expect that management will then improve (Burt & Styles, 1999).

The quality of operation and maintenance is affected, among others, by the capabilities and performance of individual staff members, the perception of the quality of water delivery by farmers, governance or lacks of governance in public authorities, democratisation and economic on the national scale (Plusquellec, 2002). Even the recent trend of ITM is no indicator for a higher level of management performance since creating WUAs alone is not sufficient to improve management (Burt & Styles, 1999).

Due to this diversity of in influences, the management factor for IFTs is restricted to a confirmed relation: a size above 10.000 ha comes along with a low level of operation and maintenance because it is difficult to reach the remote fields in due time, especially in traditional surface irrigation systems.

Yet the management factor can be adjusted and it can potentially be linked with a socio-economic irrigation model, as planned for the MAgPIE-LPJ coupling. MAgPIE[14] is an economic land use model and the coupling allows simulating shifts in agricultural production conditions due to climate change and the impact of competition for land on the extent of cultivable area. A dynamic interaction, which is not yet possible would allow for refinement of the proposed IFTs. With an enhanced cost-benefit analysis of irrigation, the timely component could be better included. Yet this requires additional information about real irrigation costs, which are needed to adjust shadow prices for irrigation water supply. These costs depend not only on operation and maintenance but also on irrigation development costs. The price of irrigation infrastructure construction varies among others according to land availability and tenure, existing infrastructure, labour requirement, and technology requirements. Assessing real costs is a long-term project and outruns the scope of this study.

The benefit of such a cost-benefit analysis could be a dynamic adaptation of irrigated cropping patterns and an optimization of land use with respect to the expansion or reduction of the area under irrigation.

Finally, the proposed solution for adaptation of IFTs and efficiencies during the last 100 years could be refined. The decision tree for IFT assignment of countries with missing irrigation data is a first approach. The variations of the chosen proxies over time could be compared with shifts in irrigation technologies to identify the transition from one IFT into another. However such a refinement requires large amounts of data and is time consuming. Therefore it should be considered if this would improve the temporal allocation of IFTs in such a manner that the effort is justifiable.

Simpler assumptions or the coupling with a socio-economic land use model might lead to satisfying results. Creating a linkage to a socio-economic model would also be favourable to identify changes in cropping patterns and irrigation priorities in the case of scarce water resources.

When linking LPJmL with an economic irrigation related model, it is important to verify the understanding of irrigation water needs. The term “beneficial water use” is sometimes ap-

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[14] MAgPIE is a “linear-programming model with a focus on agricultural production, land and water use” (Lotze-Campen et al., 2005) on a national or regional scale. The objective is an optimization of food production measured in minimal costs for a required amount of food energy. Irrigation is evenly applied to all crops, without any prioritisation. Crop land, pasture and water, measured in physical units, are constrained. Shadow prices are used to assign internal use values to land and water. A limited amount of irrigation water is available at adding costs. The functioning of MAgPIE and of the coupling with LPJmL is explained in Lotze-Campen (2005).

plied in the definition of irrigation efficiencies instead of crop EVT (for example Cai & Rosegrant, 2002). This term includes additional water uses such as leaching requirements or water for land preparation in paddy cultivation, but also crop cooling, frost protection and pesticide or fertiliser application (Rogers et al., 1997; Keller et al., 1996). Salt leaching and land preparation are often unavoidable or follow traditions (in case of paddy cultivation), but they consume water otherwise disposable for crop EVT. If economic efficiencies or productivities of irrigation systems are calculated, these water needs should be added as beneficial since yields might be reduced otherwise. Only if soil degradation is modelled in LPJmL, the leaching requirements must be added. In this case, the irrigation module should be modified by keeping the current definition of irrigation efficiency and adding the extra water need on top.

In sum, reliable irrigation functional types have been developed in this study based on irrigation efficiencies and scheduling rules. Yet there is still potential for improvement and refinement, especially in the cases of the management factor and of scheduling implementation for surface irrigation. The main problem which has to be tackled is the temporary dimension of IFTs or more precisely the question, when do new technologies become widely accepted? Those aspects which need mainly to be revised require a next step: the validation of the chosen efficiency parameters after implementation in LPJmL. A first simple assessment could be conducted by comparing the estimated irrigation efficiencies with other studies (such as Siebert et al., 2005; Cai & Rosegrant, 2002; Seckler, 1996). As mentioned above, this has already been accomplished in an initial analysis (Jachner, unpublished manuscript).
Second, comparing yields with yields from runs with the former irrigation module and with observed data could give valuable hints especially about cropping patterns and scheduling adjustment. If both fit well, then the calculated results should meet the measured ones. If the calculated yields are too high, this indicates that either the irrigated area is too large, or the scheduling is not appropriate and more water reaches the crop in the model than it actually does or finally, the irrigation efficiency is overoptimistic. If yields are too low, these indicates the contrary: too small irrigated areas, not enough water due to erroneous scheduling or too low irrigation.
Third, data on “effective efficiency” could be used for comparison with calculated efficiencies. Effective efficiency is a concept which takes into account that irrigation losses are not always completely lost for a basin. Where this water is reused, either by flow returning to surface water, recharging groundwater, or by collecting drainage water and runoff, the efficiency of the whole basin can be considerably higher than those of single irrigation systems (Bos & Nugteren, 1990; Fairweather et al., 2004). The concept of effective efficiency or basin efficiency defines irrigation efficiency as (Keller et al., 1996):

Effective Efficiency = Volume beneficial evapotranspiration / Volume water diverted
= Net crop EVT / Volume (inflow – outflow)

In larger regions with longer cascades of subsequent irrigation systems, the probability for drainage reuse increases. In closed basins[15], the effective efficiency could theoretical approximate 100% (Keller et al., 1996). Yet return flows often do not benefit downstream users but run directly into salt sinks (FAO 1999). “The quality of water is as important as the quantity of water in determining ultimately usable supply” (Seckler, 1996). Often the quality diminished due to additional input from intensive agriculture (Bos & Nugteren, 1990; Keller et al., 1996).
In LPJmL water within irrigation systems are treated like additional precipitation and allocated to evaporation, river discharge and percolation. The later two flow back into the drainage system and are added to the discharge again. Hence, reuse is possible and not limited by water quality since this is not yet factored in. Water flows with and without irrigation can be modelled for river basins or countries at the same time. Therewith, the total amount diverted for irrigation under consideration of reused water, can be calculated. The effective

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[15] A closed basin is a basin where “all of the water is evaporated upstream leaving no dry-season flow into sinks, or the flow is so polluted that the water is not usable” (Seckler, 1996) this is valid for many river basins in the Middle East and in Asia.

efficiency in LPJmL is currently calculated as follows:

E_{Eff}= (evapotranspiration with irrigation – evapotranspiration without irrigation) /
(water outflow without irrigation – water outflow with irrigation)

Seckler et al. (1998) conducted a study leading to country-scale effective efficiencies for quite a lot of countries. This study could be used for comparison.

Overall, the chosen approach of IFTs is not only applicable to compute consumptive water use and thus irrigation water requirements. The effects of irrigation as an intensive form of land use surpass mere water consumption. Irrigated agriculture is responsible for 70% of the global water withdrawal. Although this share might decrease in the forthcoming decades, the issue itself remains of outmost importance, not only with regard to the global food and water supply but also to its impact on the global freshwater cycle and the terrestrial carbon cycle. Irrigated agriculture remains a major component in a global strategy to feed a growing population. At the same time it is increasingly under pressure from competing water users as well as from other forms of land use. Thus it becomes eminent to improve the timeliness and adequacy of irrigation systems on a large-scale. Especially Asia and Latin America show a pronounced technical potential for such an adaptation. Yet social, economic and political conditions might aggravate such a change. However, LPJmL using the IFTs now has the potential to demonstrate the effect of enlarged irrigation efficiency on global yields. Moreover, simulating the competition for land and water resources between food grains and biofuels is another application field for IFTs.
Furthermore, irrigation has an impact on the on terrestrial water flows and atmospheric processes since it transforms blue water flows into green water flows. This means, IFTs contribute to an improved modelling of the terrestrial water cycle and by the link between photosynthesis and transpiration also of the carbon cycle. Simultaneously the role of green water in the worldwide food and fibre production and the consequences of water withdrawal for the potential natural vegetation are sizeable.

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Appendix

Glossary

Actually irrigated area: the area of an ***-> irrigation system*** which is actually irrigated is usually smaller then the total area equipped for irrigation.

Adequacy: -> performance indicator, reflects the allocation of water or the relative water supply, which is the ratio of plant water supply to demand

American Model: form of ***-> water user association*** which is basically a ***-> business association***.

Asian Model: form of ***-> water user association*** which is basically a ***-> social association***.

Basin efficiency -> effective efficiency

Basin irrigation: a ***-> field application method*** for ***-> surface irrigation*** where levelled fields are surrounded by dykes to keep the water on the field. This is the favourite method to grow paddy rice and the most common irrigation method worldwide.

Blue water: a concept introduced by Marlin Falkenmark and Johan Rockström (1993). The precipitation is divided into blue and ***-> green water flows*** after reaching the earth surface. Blue water is comprises the total runoff formed by surface runoff and groundwater recharge. A third category, ***-> white water***, is sometimes applied as well.

Border irrigation: a ***-> field application method*** for ***-> surface irrigation*** which combines elements of ->> ***basin*** and ***furrow irrigation***. Water is applied to land strips separated by dikes but open at the downstream end.

Business association: these ***-> water user associations*** are run like a business. Farmers delegate operation and maintenance to hired staff instead of relying on cooperation. This is typical for modern projects and also possible in modernised projects. The WUAs are responsible not only to organise water distribution and fee collection but also conflict resolution and representation in contact with public agencies. WUAs are strong, when they are able to ensure full cost recovery and reliable service. This requires ownership and accountability of the organization towards farmers not towards the government.

Command area: synonymous for ***-> irrigation system***

Consumptive water use(*): The quantity of water used by the vegetative growth of a given year in transpiration or building of the plant tissue and that evaporated from the soil or from intercepted vegetation on the area in any specific time. It is expressed in water depth per unit of time.

Conveyance efficiency E_C: ratio of the volume delivered to the distribution system and the volume diverted or pumped from a source.

Conveyance system: Network of open canals or closed pipelines which is used to distribute water within an irrigation system. The conveyance system comprises those parts of a supply network where the responsibility for ***-> operation and maintenance*** remains within a formal or informal organization.

Countries in transition: countries of the formers Soviet Union and Eastern Europe which experienced major political upheavals and changes in their political and economic systems since the collapse of the Soviet Union in 1990.

Crop-based scheduling: -> on-demand water delivery

Crop EVT –> evapotranspiration

Crop functional type (CFT): CFTs are generalised and climatically adapted plant prototypes designed to capture the most widespread types of agricultural plant traits. They are used in the -> ***Lund-Potsdam-Jena Model*** as complement to the ***-> plant functional types*** for the potential natural vegetation.

Cropping patterns: the shares of crops on cultivated areas are variable. The average combination of these shares forms a cropping pattern.

Crop water requirement(*): In irrigated agriculture this is the water required in addition to water from precipitation (soil moisture) for optimal plant growth during the growing season. Optimal plant growth occurs when actual evapotranspiration of a crop is equal to its potential evapotranspiration.

Distribution efficiency E_D: ratio of the volume of water furnished to the fields and the volume delivered to the distribution system

Distribution unit: The lowest (usually tertiary) level of the ***-> conveyance system*** before field application. Often several fields share a common outlet. Below this outlet, farmers take over responsibility for water distribution to the various fields and for maintenance of the distribution network. The optimum size of a distribution unit varies between 70 to 300 ha.

Dynamic global vegetation model (DGVM): global models which combine the representations of biogeochemical processes with representations of processes contributing to he dynamics of vegetation structure and composition and thus to changes in ecosystem geography.

Economic efficiency -> productivity

Effective efficiency: A concept of ***-> irrigation efficiency*** where water losses are not counted as losses. If this water is reused, either by flow returning to surface water, recharging groundwater, or by collecting drainage water and runoff, the efficiency of the whole basin is higher than those of single irrigation systems. Efficiency is measured as ratio the crop water requirements which have been met and the difference of inflow and outflow of the area under consideration.
In larger regions with longer cascades of subsequent irrigation systems, the probability for drainage reuse increases. In closed basins, where all of the water is evaporated upstrean, the effective efficiency could theoretical approximate 100%. The quality of water is as important as the quantity of water in determining ultimately usable supply. Often the quality diminished due to additional input from intensive agriculture. Hence return flows often do not benefit downstream users but run directly into salt sinks.

Efficiency parameter: the values of partial (***->> conveyance efficiency, field application efficiency***) and ***-> project efficiencies*** of the different ***-> irrigation functional types***

Effective precipitation: -> effective rainfall

Effective rainfall: the portion of precipitation stored in the rooting zone. Those parts adding to interception, surface runoff and deep percolation cannot be used by plants, hence they are not effective.

Equity: -> performance indicator, describes the spatial uniformity of water distribution within a system or among users

Evaporation (*): the process whereby liquid water is converted to water vapour (vaporization) and removed from the evaporating surface (vapour removal). Water evaporates from a variety of surfaces, such as lakes, rivers, pavements, soils and wet vegetation.

Evapotranspiration (EVT) (*): the evapotranspiration of a crop is the total amount of soil water used for ***-> transpiration*** by the plants and ***-> evaporation*** from the surrounding soil surface Both processes occur simultaneously and there is no easy way of distinguishing between them.

Farmer-management: These schemes are run by farmers alone. -> Operation and maintenance of all canal levels is organised by farmer groups. Those farmer organizations are usually named as -> ***water user associations*** (WUA). The infrastructure has either been provided by the government and later be transferred to the farmer groups or has already been constructed by the rural population.

Field application efficiency E_A: ratio of the volume of irrigation water needed and made available for crop and the volume of water furnished to the fields

Field application method: utilization of specific irrigation technology to supply water to crops if ***-> crop water requirements*** have to be met. There are two main groups of application method, ***->surface irrigation*** and ***-> pressurised irrigation***.

Flexibility: -> performance indicator, depicts the ability of irrigation water schedule to adapt dynamically

Full irrigated: precipitation is not able to meet the crop transpiration demand at any time during the growing season. Thus the ***-> crop water requirement*** equals the total crop transpiration and the crops are permanently irrigated

Furrow irrigation: a ***-> field application method*** for ***-> surface irrigation*** where ditches are evenly spread on the field to wet the rooting zone of the crops growing between them.

Green water: a concept introduced by Marlin Falkenmark and Johan Rockström (1993). The precipitation is divided into -> ***blue*** and green ***water flows*** after reaching the earth surface. In the original concept, green water flows encompass the total evapotranspiration, the non-productive evaporation from soil, water or canopy surfaces and the productive transpiration. A third category, ***-> white water***, is sometimes applied as well, limiting green water flows to productive transpiration.

Gross Water Requirement: actual amount of water needed to meet ***-> crop water requirements*** taking into account the ***-> irrigation efficiency*** of an ***-> irrigation system***.

Irrigation: the artificial application of water to crops in contrast to natural precipitation, groundwater or morning dew. This means that these waters only reach the crop due to human interference like canal construction or water diversion.

Irrigation efficiency I_E: a physical concept describing, the ratio of irrigation water transpired by the crops of an irrigation farm or project during their growth period, over the water diverted from a river or other natural source into the farm or project canal or canals during the same period of time.

Irrigation Functional Type (IFT): IFTs are generalised prototypes of ***-> irrigation systems,*** developed for the implementation in the ***-> Lund-Potsdam-Jena model.*** In contrast to ***-> plant functional types*** and ***-> crop functional types*** they are not scale up on the grid cell level but on the country level.

Irrigation management: the management of an irrigation system comprises -> ***operation and maintenance*** of the system.

Irrigation management transfer (IMT): the turnover of basic ***-> irrigation management*** functions from a public authority t to a local or private entity, other expressions are privatization, disengagement, post-responsibility system, commercialization, and self-management

Irrigation system: An area equipped with the necessary physical and organizational infrastructure to irrigated all fields which belong to this area

Large-scale irrigation systems: -> irrigation systems covering an area of more than 10.000 ha

Lund-Potsdam-Jena/managed Land (LPJmL): LPJ is a ***-> dynamic global vegetation model*** of intermediate complexity. In LPJmL productivity and yield of the most important crops worldwide are simulated in addition to biophysical and biogeochemical processes.

Management factor M_F: a special factor assigned to surface and mixed ***-> irrigation functional type*** to take into account the higher complexity of ***-> irrigation management*** in ***-> large-scale irrigation systems***.

Micro-/localised irrigation: a ***-> field application method*** for ***–> pressurised irrigation***. Small amounts of water are directly applied to the crop rooting zone via low discharge emitters.

Mixed-management: In these schemes the responsibilities are shared between public agencies and farmers. The development of these schemes is either entirely conducted by the state authority or farmers must construct the tertiary system. Later on major and secondary ***-> conveyance systems*** are operated by public authorities while ***-> operation and maintenance*** of the tertiary canals remains with or is transferred to private groups of farmers.

On-demand water delivery: also ***-> crop-based scheduling***, an ***-> irrigation scheduling*** method where farmers receive water whenever they request it, thus when the crops actually need it.

Operation and maintenance (O&M): Principal task of irrigation management. Operation comprises the distribution of water within the irrigation system by regulation and control of runoff and discharge rates in accordance with the irrigation schedule. Operators have to balance the different needs and demands of farmers with the available water supplies. Often they are also responsible for fee collection. Maintenance comprises the control and repair of irrigation infrastructure and its upgrading when necessary to keep the system in good conditions.

Performance: assessments of the ability of an irrigation system to fulfil objectives, usually measured with ***-> performance indicators***.

Performance indicator: indicators describe different aspects of the ***-> performance*** of an irrigation system. Indicators are usually ratios of the actual value and intended valued of beforehand agreed objectives. The most common are ***-> adequacy, -> equity, -> flexibility, -> productivity, -> reliability.***

Plant functional type (PFT): The ***-> Lund-Potsdam-Jena model*** uses PFTs as generic plant prototypes designed to capture the variety of structure and functioning among plants. PFT characteristics are described for individuals and than scaled up on the grid cell level. The concept of PFTs has been transferred to ***-> crop functional types***.

Productivity: -> performance indicator, compares the output of an irrigation system (in terms of produced crops (or their economic equivalents) with the input into the system (in terms of land, water finance)

Project efficiency E_P: ratio of the volume of irrigation water needed and made available for crop and the volume of water diverted or pumped from a source.

Proportional water distribution: distribution rule for ***-> supply driven water delivery*** where farmers or ***-> distribution units*** receive a fixed share of the canal flow. This rule can be combined with ***-> rotational water distribution***: tertiary canals receive water rotationally while the users below the outlet share these flows on a proportional basis.

Pressurised irrigation: all ***-> field application methods*** where limited amounts of water are applied under pressure. The prevailing techniques are classified into ->> ***sprinkler*** and ***micro-irrigation***.

Public-management: In these schemes all decisions are made by government agencies. There are several models how public water management can be organised. The responsibilities for panning and realization of the construction works and later for ***-> operation and maintenance*** might be assigned to different authorities. Government agencies can be extremely influential and not decide not only about the delivery schedule but also about the cropping pattern. Then farmers are entirely dependable on them and are more like employees.

Reliability: -> performance indicator, mirrors the timeliness of water delivery as scheduled, even so the amount of water might be below the scheduled requirement

Rotational water distribution: distribution rule for ***-> supply driven water delivery*** where farmers or ***-> distribution units*** receive in turn the full canal discharge during a fixed period. This rule can be combined with ***-> proportional water distribution***: tertiary canals receive water rotationally while the users below the outlet share these flows on a proportional basis.

Scheduling: decision of when, how much and how often water is applied to the field. Scheduling approaches are either -***> water-based/supply driven delivery*** or ***-> crop-based/on-demand delivery***

Social association: these ***-> water user associations*** rely on social cohesion and cooperation instead of financial capital. They are often charged with collection and transfer of fees to the respective public authority. Frequently farmers are responsible to conduct rehabilitation works collectively. However they are not entitled or possess the necessary financial autonomy to decide about operation and maintenance expenses. These are ‘weak’ WUAs because they do not posses real power to decide about their own affairs, are seldom self-sustaining and often quite informal of structure.

Sprinkler irrigation: a ***-> field application method*** for ***–> pressurised irrigation***. Small droplets of water are sprayed over or under the crop canopy to imitate natural rainfall.

Supplementary irrigation: -> crop water requirements are only served during critical stages when limited additional amounts of water are delivered to the crops to secure yields. Usually precipitation is sufficient to meet the crop transpiration demand.

Supply driven water delivery: also ***-> water-based scheduling***, an ***-> irrigation scheduling*** method where water is supplied to farmers in accordance with a determined schedule. Water distribution is usually ***-> rotational*** or ***-> proportional***. Flexible adaptations of flow rate or discharge periods are often not possible.

Surface irrigation: all field application methods where water is applied to the surface of the field, usually by gravity flow. The prevailing techniques are flooding (***-> basin irrigation***) and distribution of water via small canals (***-> furrow irrigation***) or strips of land (-***>border irrigation***).

System efficiency E_S: the product of ***-> conveyance efficiency*** and ***-> distribution efficiency,*** the ratio of the volume of water furnished to the fields and the volume diverted or pumped from a source.

Transpiration: the loss of water from the surface of leaves of plants. Transpiration is an active process, in contrast to ***-> evaporation***. Plants open their stomata and release water in exchange for carbon dioxide intake. Simultaneously they volatilising water is cooling down the plant surface.

Water-based scheduling: -> Supply driven water delivery

Water scarcity: the concept of water scarcity was introduced by Marlin Falkenmark (1989). Benchmarking water availability is identified as social construct, which depends on population figures and water needs. Water is needed for food security, cash crops, households and industries. Water availability is measured in persons per flow unit, which are expressed in 1,000,000 m^3 water per year. Countries are water stressed if more than 600 persons rely on one flow unit and thus less than 1700 m^3 per capita is annually available. They suffer from absolute water scarcity if more than 1000 persons depend on one flow unit (1000 m^3 per capita per year). At 2000 persons per unit (500 m^3 per capita per year) a water barrier is crossed. From this point on it becomes technical difficult to sustainable satisfy the water demand.

White water: enhancement of the orginal concept of ->> ***blue*** and ***green water flows*** from Falkenmark and Rockström (1993)***.*** White water is the non-productive part of evaporation, thus soil moisture and interception water which is evaporated without contributing to biomass accumulation.

Water User Association (WUA): associations of farmers who share the responsibility for their irrigation systems. These associations can be formal or informal. There rights and duties are determined by their legal status. Two models are prevalent: the ***-> Asian model*** and the ***-> American model***.

(*) Definitions taken from FAO

Annex A Basic information about irrigation

Areas equipped for irrigation per country, in total area and per irrigation methods

	Country Code	Total Area	Total Area	Total Area	Surface Irrigation Area	Surface Irrigation per Total Equipped Area	Sprinkler Irrigation Area	Sprinkler Irrigation per Total Equipped Area	Micro-Irrigation Area	Micro-Irrigation per Total Equipped Area	Sum of all Irrigated Areas
Source	LPJ	Döll & Siebert	FAO[a]	ICID	FAO[a], and others[b]	FAO[a], and others[b]	FAO[a], and others[b]	FAO[a], and others[b]	FAO[a], and others[b]	FAO[a], and others[b]	
Time Period		1999	1997-2005	2003	1997-2005	1997-2005	1997-2005	1997-2005	1997-2005	1997-2005	
Unit		1000 ha	ha	Mha	ha	%	ha	%	ha	%	%
Afghanistan	AF	2799.996	NA	NA	NA		NA		NA		0.00
Albania	AL	340.000	353000.0	NA	0.00		0.00		0.00		0.00
Algeria	AG	555.501	569418.0	0.560	0.00		0.00		0.00		0.00
Angola	AO	75.000	80000.0	0.070	0.00		0.00		0.00		0.00
Argentina	AR	1699.999	1550233.0	1.560	1480472.52	95.50	65207.00	4.21	0.00	0.00	99.71
Armenia	AM	285.649	285649.0	NA	257941.05	90.30	27508.00	9.63	199.95	0.07	100.00
Australia	AS	2317.000	2545000.0	2.550	1829800.00	71.90	524480.00	20.61	190720.00	7.49	100.00
Austria	AU	4.000	4000.0	0.004	NA		3600.00	90.00	NA		90.00
Azerbaijan	AJ	1453.320	1453318.0	NA	1301700.00	89.57	148965.10	10.25	2618.00	0.18	100.00
Bangladesh	BG	3200.006	3751045.0	4.730	3751045.00	100.00	0.00	0.00	0.00	0.00	100.00
Belgium	BE	1.000	NA	0.040							0.00
Belize	BH	3.000	3000.0	NA	3000.00	100.00	0.00	0.00	0.00	0.00	100.00
Benin	BN	10.236	12258.0	NA	6328.00	51.62	4570.00	37.28	1360.00	11.09	100.00
Bhutan	BT	39.000	38734.0	NA	38734.00	100.00	0.00	0.00	0.00	0.00	100.00
Bolivia	BL	78.000	128239.0	NA	127982.52	99.80	256.48	0.20	0.00	0.00	100.00
Bosnia and Herzegovina	BK	2.000	3000.0	NA	0.00		0.00		0.00		0.00
Botswana	BC	1.381	1439.0	NA	0.00		0.00		0.00		0.00
Brazil	BR	3168.910	2870204.0	2.920	434818.95	15.15	1779167.46	61.99	540531.82	18.83	95.97
Brunei	BX	1.000	1000.0	NA	588.00	58.80	350.00	35.00	61.00	6.10	99.90
Bulgaria	BU	800.001	588000.0	0.590	588000.00	100.00	0.00	0.00	0.00	0.00	100.00
Burkina Faso	UV	24.330	25000.0	0.030	12500.00	50.00	12250.00	49.00	250.00	1.00	100.00
Burma	BM	1555.000	1555416.0	1.990	1312771.10	84.40	242644.90	15.60	0.00	0.00	100.00
Burundi	BY	14.400	21430.0	NA	21430.00	100.00	0.00	0.00	0.00	0.00	100.00

	Country Code	Total Area	Total Area	Total Area	Surface Irrigation Area	Surface Irrigation per Total Equipped Area	Sprinkler Irrigation Area	Sprinkler Irrigation per Total Equipped Area	Micro-Irrigation Area	Micro-Irrigation per Total Equipped Area	Sum of all Irrigated Areas
Source	LPJ	Döll & Siebert	FAO[a]	ICID	FAO[a], and others[b]	FAO[a], and others[b]	FAO[a], and others[b]	FAO[a], and others[b]	FAO[a], and others[b]	FAO[a], and others[b]	
Time Period		1999	1997-2005	2003	1997-2005	1997-2005	1997-2005	1997-2005	1997-2005	1997-2005	
Unit		1000 ha	ha	Mha	ha	%	ha	%	ha	%	%
Byelarus	BO	131.000	131000.0	NA	0.00	0.00	131000.00	100.00	0.00	0.00	100.00
Cambodia	CB	173.000	269461.0	NA	269461.00	100.00	0.00	0.00	0.00	0.00	100.00
Cameroon	CM	20.970	25654.0	NA	20224.00	78.83	5430.00	21.17	0.00	0.00	100.00
Canada	CA	709.998	785000.0	0.780	0.00		0.00		0.00		0.00
Central African Republic	CT	0.135	135.0	NA	0.00		0.00		0.00		0.00
Chad	CD	14.020	30273.0	0.020	26159.00	86.41	3754.00	12.40	360.00	1.19	100.00
Chile	CI	1265.000	1900000.0	1.900	1806900.00	95.10	30526.00	1.61	62153.00	3.27	99.98
China	CH	46003.992	52943200.0	54.930	51476200.00	97.23	1200000.00	2.27	267000.00	0.50	100.00
Colombia	CO	1037.001	900000.0	0.900	856800.00	95.20	36900.00	4.10	6300.00	0.70	100.00
Congo	CF	0.217	2000.0	NA	1999.00	99.95	0.00	0.00	1.00	0.05	100.00
Costa Rica	CS	126.000	103084.0	NA	85456.64	82.90	3917.19	3.80	13710.17	13.30	100.00
Croatia	HR	3.000	11000.0	0.003	0.00		0.00		0.00		0.00
Cuba	CU	910.000	870317.0	0.870	404697.41	46.50	443861.67	51.00	21757.93	2.50	100.00
Cyprus	CY	39.938	39938.0	0.040	1977.00	4.95	1977.00	4.95	35591.00	89.12	99.02
Czech Republic	EZ	24.000	24000.0	0.020	120.00	0.50	23760.00	99.00	120.00	0.50	100.00
Denmark	DA	NA	435000.0	NA	0.00	0.00	391500.00	90.00	43500.00	10.00	99.00
Djibouti	DJ	0.674	1012.0	NA	0.00		0.00		0.00		0.00
Dominican Republic	DR	259.000	269710.0	0.280	269710.00	100.00	0.00	0.00	0.00	0.00	100.00
Ecuador	EC	240.000	863370.0	0.860	863370.00	100.00	0.00	0.00	0.00	0.00	100.00
Egypt	EG	3245.998	3422178.0	3.400	3028853.00	88.51	171108.90	5.00	222441.57	6.50	100.01
El Salvador	ES	120.000	44993.0	NA	40043.77	89.00	4949.23	11.00	0.00	0.00	100.00
Equatorial Guinea	EK	0.000	0.0	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eritrea	ER	28.124	21590.0	NA	21590.00	100.00	0.00	0.00	0.00	0.00	100.00
Ethiopia	ET	189.556	289530.0	0.190	0.00	0.00	289530.00	100.00	0.00	0.00	100.00
Finland	FI	0.000	NA	NA	NA	0.00	NA	132.81	NA	1.09	133.91
France	FR	3.000	3000.0	NA	1288.73	42.96	1592.08	53.07	119.19	3.97	100.00
French Guiana	FG	NA	64000.0	NA	0.00		0.00		0.00		0.00
Gabon	GB	1630.000	2600000.0	2.600	759550.56	29.21	0.00	0.00	0.00	0.00	29.21
Gambia, The	GA	2.000	2000.0	NA	2000.00	100.00	0.00	0.00	0.00	0.00	100.00

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Time Period		1999	1997-2005	2003	1997-2005	1997-2005	1997-2005	1997-2005	1997-2005	1997-2005	
Unit		1000 ha	ha	Mha	ha	%	ha	%	ha	%	%
Georgia	GG	4.450	4450.0	NA	3728.66	83.79	721.35	16.21	0.00	0.00	100.00
Germany	GM	1.670	2149.0	NA	0.00	0.00	2326.24	108.25	22.15	1.03	109.28
Ghana	GH	469.000	469000.0	NA	373324.00	79.60	95676.00	20.40	0.00	0.00	100.00
Greece	GR	475.000	485000.0	0.490	0.00	0.00	436500.00	90.00	48500.00	10.00	99.00
Guatemala	GT	6.374	30900.0	0.010	30900.00	100.00	0.00	0.00	0.00	0.00	100.00
Guinea	GV	1328.000	1453000.0	1.430	1445958.05	99.52	4592.58	0.32	2449.38	0.17	100.00
Guinea-Bissau	PU	125.000	129803.0	NA	129803.00	100.00	0.00	0.00	0.00	0.00	100.00
Guyana	GY	92.880	94914.0	NA	94914.00	100.00	0.00	0.00	0.00	0.00	100.00
Haiti	HA	17.115	22558.0	NA	22558.00	100.00	0.00	0.00	0.00	0.00	100.00
Honduras	HO	130.000	150134.0	0.150	150134.00	100.00	0.00	0.00	0.00	0.00	100.00
Hungary	HU	90.000	91502.0	NA	0.00	0.00	82351.80	90.00	9150.20	10.00	100.00
India	IN	74.000	73210.0	0.080	0.00		0.00		0.00		0.00
Indonesia	ID	210.000	230000.0	0.230	225783.42	98.17	3022.99	1.31	1193.59	0.52	100.00
Iran	IR	0.000	NA	NA	NA	100.00	NA	0.00	NA	0.00	100.00
Iraq	IZ	50101.996	50101000.0	57.190	49475443.92	98.75	1373016.27	2.74	370485.07	0.74	102.23
Israel	IS	4579.977	4427922.0	4.810	2151649.67	48.59	1686925.57	38.10	589346.76	13.31	100.00
Italy	IT	7264.240	7264194.0	8.100	0.00		0.00		0.00		0.00
Ivory Coast	IV	3524.998	3525000.0	3.520	1786810.34	50.69	1750344.83	49.66	-12155.17	-0.34	100.00
Jamaica	JM	195.000	194000.0	0.190	146470.00	75.50	33950.00	17.50	13580.00	7.00	100.00
Japan	JA	2709.998	2750000.0	2.750	2488018.13	90.47	213629.52	7.77	48352.36	1.76	100.00
Jordan	JO	72.750	72500.0	0.070	22910.00	31.60	6380.00	8.80	43210.00	59.60	100.00
Kazakhstan	KZ	33.000	25214.0	NA	9581.29	38.00	15144.08	60.06	488.63	1.94	100.00
Kenya	KE	2700.004	3128079.0	2.600	2384837.37	76.24	743241.63	23.76	0.00	0.00	100.00
Korea, Democratic People's Republic of	KN	64.300	64300.0	0.080	0.00		0.00		0.00		0.00
Korea, Republic of	KS	3556.403	3556400.0	2.350	3556400.00	100.00	0.00	0.00	0.00	0.00	100.00
Kuwait	KU	66.610	103203.0	0.090	65327.50	63.30	13003.58	12.60	24871.92	24.10	100.00
Kyrgyzstan	KG	1460.001	1460000.0	NA	1409776.00	96.56	50224.00	3.44	0.00	0.00	100.00
Laos	LA	1334.998	888795.0	1.140	888795.00	100.00	0.00	0.00	0.00	0.00	100.00
Latvia	LG	4.770	4770.0	NA	0.00	0.00	4770.00	100.00	0.00	0.00	100.00

	Country Code	Total Area	Total Area	Total Area	Surface Irrigation Area	Surface Irrigation per Total Equipped Area	Sprinkler Irrigation Area	Sprinkler Irrigation per Total Equipped Area	Micro-Irrigation Area	Micro-Irrigation per Total Equipped Area	Sum of all Irrigated Areas
Source	LPJ	Döll & Siebert	FAO[a]	ICID	FAO[a], and others[b]	FAO[a], and others[b]	FAO[a], and others[b]	FAO[a], and others[b]	FAO[a], and others[b]	FAO[a], and others[b]	
Time Period		1999	1997-2005	2003	1997-2005	1997-2005	1997-2005	1997-2005	1997-2005	1997-2005	
Unit		1000 ha	ha	Mha	ha	%	ha	%	ha	%	%
Lebanon	LE	1077.100	1072600.0	1.070	655358.60	61.10	257424.00	24.00	159817.40	14.90	100.00
Lesotho	LT	177.000	155394.0	NA	0.00		0.00		0.00		0.00
Liberia	LI	20.000	20000.0	NA	19047.62	95.24	0.00	0.00	0.00	0.00	95.24
Libya	LY	87.500	87500.0	0.100	0.00		0.00		0.00		0.00
Lithuania	LH	2.722	2637.0	NA	0.00	0.00	2637.00	100.00	0.00	0.00	100.00
Luxembourg	LU	2.100	2100.0	NA	0.00		0.00		0.00		0.00
Macedonia	MK	470.000	470000.0	0.470	0.00	0.00	854545.45	181.82	4272.73	0.91	182.73
Madagascar	MA	9.247	9247.0	0.007	9226.57	99.78	20.43	0.22	0.00	0.00	100.00
Malawi	MI	NA	NA	NA	NA	11.27	NA	76.60	NA	9.66	97.54
Malaysia	MY	61.000	55000.0	0.050	55000.00	100.00	0.00	0.00	0.00	0.00	100.00
Mali	ML	1087.000	1086291.0	1.090	1086291.00	100.00	0.00	0.00	0.00	0.00	100.00
Mauritania	MR	28.000	56390.0	0.030	0.00		0.00		0.00		0.00
Mexico	MX	340.000	362600.0	0.360	336130.20	92.70	18130.00	5.00	8339.80	2.30	100.00
Moldova	MD	78.620	235791.0	0.140	230509.28	97.76	2570.12	1.09	2711.60	1.15	100.00
Mongolia	MG	49.200	49200.0	NA	0.00		0.00		0.00		0.00
Morocco	MO	6099.960	6256032.0	6.320	5184952.09	82.88	650731.84	10.40	420348.07	6.72	100.00
Mozambique	MZ	312.000	312000.0	NA	131040.00	42.00	156000.00	50.00	24960.00	8.00	100.00
Namibia	WA	80.000	84300.0	0.080	32838.37	38.95	36467.29	43.26	14994.34	17.79	100.00
Nepal	NP	1258.198	1484160.0	1.340	0.00		0.00		0.00		0.00
Netherlands	NL	106.710	118120.0	0.110	38979.60	33.00	38979.60	33.00	38979.60	33.00	99.00
New Zealand	NZ	6.142	7573.0	NA	0.00		0.00		0.00		0.00
Nicaragua	NU	885.000	1134334.0	1.140	0.00		0.00		0.00		0.00
Niger	NG	565.000	565000.0	NA	565000.00	100.00	0.00	0.00	0.00	0.00	100.00
Nigeria	NI	285.000	285000.0	0.290	232138.25	81.45	0.00	0.00	0.00	0.00	81.45
Norway	NO	88.000	61365.0	NA	61354.53	99.98	10.47	0.02	0.00	0.00	100.00
Oman	MU	66.480	73663.0	0.070	0.00		0.00		0.00		0.00
Pakistan	PK	232.821	293117.0	0.230	275236.86	93.90	7914.16	2.70	9965.98	3.40	100.00
Panama	PM	100.000	127000.0	NA	127000.00	100.00	0.00	0.00	0.00	0.00	100.00
Papua New Guinea	PP	62.550	61550.0	NA	45731.65	74.30	14772.00	24.00	1046.35	1.70	100.00
Paraguay	PA	15729.400	15729448.0	17.800	0.00		0.00		0.00		0.00

	Country Code	Total Area	Total Area	Total Area	Surface Irrigation Area	Surface Irrigation per Total Equipped Area	Sprinkler Irrigation Area	Sprinkler Irrigation per Total Equipped Area	Micro-Irrigation Area	Micro-Irrigation per Total Equipped Area	Sum of all Irrigated Areas
Source	LPJ	Döll & Siebert	FAO[a]	ICID	FAO[a], and others[b]	FAO[a], and others[b]	FAO[a], and others[b]	FAO[a], and others[b]	FAO[a], and others[b]	FAO[a], and others[b]	
Time Period		1999	1997-2005	2003	1997-2005	1997-2005	1997-2005	1997-2005	1997-2005	1997-2005	
Unit		1000 ha	ha	Mha	ha	%	ha	%	ha	%	%
Peru	PE	32.000	34626.0	0.030	34626.00	100.00	0.00	0.00	0.00	0.00	100.00
Philippines	RP	0.000	0.0	NA	0.00	98.40	0.00	1.00	0.00	0.60	100.00
Poland	PL	67.000	67000.0	NA	67000.00	100.00	0.00	0.00	0.00	0.00	100.00
Portugal	PO	1752.997	1195228.0	1.200	1154590.25	96.60	40637.75	3.40	0.00	0.00	100.00
Puerto Rico	RQ	1580.003	1550000.0	1.550	0.00	0.00	95384.62	6.15	23846.15	1.54	7.69
Qatar	QA	100.000	100000.0	0.100	0.00		0.00		0.00		0.00
Romania	RO	632.000	650000.0	0.650	79950.00	12.30	570050.00	87.70	0.00	0.00	100.00
Russia	RS	40.000	40000.0	NA	1600.26	4.00	38399.74	96.00	0.00	0.00	100.00
Rwanda	RW	12.520	12520.0	NA	0.00		0.00		0.00		0.00
Saudi Arabia	SA	3110.010	3077000.0	3.070	1046715.80	34.02	1969050.37	63.99	61233.83	1.99	100.00
Senegal	SG	5158.000	6124000.0	4.600	6124000.00	100.00	0.00	0.00	0.00	0.00	100.00
Serbia	SR	4.000	8500.0	NA	0.00		0.00		0.00		0.00
Sierra Leone	SL	1607.997	1608000.0	1.620	1608000.00	100.00	0.00	0.00	0.00	0.00	100.00
Slovakia	LO	71.400	119680.0	0.070	0.00	0.00	118483.20	99.00	1196.80	1.00	100.00
Slovenia	SI	65.000	32000.0	0.020	0.00		0.00		0.00		0.00
Somalia	SO	29.360	29360.0	NA	29360.00	100.00	0.00	0.00	0.00	0.00	100.00
South Africa	SF	299.000	183000.0	0.180	61081.44	33.38	100173.56	54.74	21744.99	11.88	100.00
Spain	SP	2.000	3000.0	0.004	1800.00	60.00	718.51	23.95	725.35	24.18	108.13
Sri Lanka	CE	200.000	200000.0	NA	200000.00	100.00	0.00	0.00	0.00	0.00	100.00
Sudan	SU	1270.002	1498000.0	1.490	1498000.00	100.00	0.00	0.00	0.00	0.00	100.00
Suriname	NS	3526.990	3780000.0	3.800	3715740.00	98.30	64260.00	1.70	0.00	0.00	100.00
Swaziland	WZ	550.000	570000.0	0.640	296041.37	51.94	239067.67	41.94	34890.96	6.12	100.00
Sweden	SW	1946.207	189300.0	1.950	0.00	0.00	189300.00	100.00	0.00	0.00	100.00
Switzerland	SZ	60.000	51180.0	0.050	0.00		0.00		0.00		0.00
Syria	SY	67.400	49843.0	NA	48248.02	96.80	1495.29	3.00	99.69	0.20	100.00
Tajikistan	TI	115.000	115000.0	NA	115000.00	100.00	0.00	0.00	0.00	0.00	100.00
Tanzania, United Republic of	TZ	25.000	25000.0	0.030	0.00		0.00		0.00		0.00
Thailand	TH	1013.274	1013273.0	1.330	1013273.00	100.00	0.00	0.00	0.00	0.00	100.00
Togo	TO	719.200	718000.0	0.720	491780.82	68.49	0.00	0.00	0.00	0.00	68.49
Trinidad	TD	150.000	184330.0	0.170	143408.74	77.80	35022.70	19.00	5898.56	3.20	100.00

	Country Code	Total Area	Total Area	Total Area	Surface Irrigation Area	Surface Irrigation per Total Equipped Area	Sprinkler Irrigation Area	Sprinkler Irrigation per Total Equipped Area	Micro-Irrigation Area	Micro-Irrigation per Total Equipped Area	Sum of all Irrigated Areas
Source	LPJ	Döll & Siebert	FAO[a]	ICID	FAO[a], and others[b]	FAO[a], and others[b]	FAO[a], and others[b]	FAO[a], and others[b]	FAO[a], and others[b]	FAO[a], and others[b]	
Time Period		1999	1997-2005	2003	1997-2005	1997-2005	1997-2005	1997-2005	1997-2005	1997-2005	
Unit		1000 ha	ha	Mha	ha	%	ha	%	ha	%	%
Tunisia	TS	5004.012	5003724.0	4.960	615940.64	12.31	1142982.64	22.84	78738.80	1.57	36.73
Turkey	TU	7.008	7300.0	NA	7079.43	96.98	206.23	2.83	14.35	0.20	100.00
Turkmenistan	TX	22.000	3600.0	NA	3599.17	99.98	0.00	0.00	0.83	0.02	100.00
Uganda	UG	385.000	394000.0	0.380	0.00		0.00		0.00		0.00
Ukraine	UI	4185.910	4185910.0	5.210	843609.50	20.15	3342300.50	79.85	0.00	0.00	100.00
United Arab Emirates	TC	1744.103	1744100.0	1.800	664502.10	38.10	97669.60	5.60	981928.30	56.30	100.00
United Kingdom	UK	9.120	9150.0	0.009	0.00	0.00	7535.29	82.35	538.24	5.88	88.24
United States	US	2605.004	2605000.0	2.260	1089015.92	41.80	1268619.84	48.70	153886.58	5.91	96.41
Uruguay	UY	66.682	66682.0	NA	66682.00	100.00	0.00	0.00	0.00	0.00	100.00
Uzbekistan	UZ	108.000	170000.0	0.170	169820.89	99.89	0.00	0.00	179.11	0.11	100.00
Venezuela	VE	23548.466	22385000.0	22.500	17728920.00	79.20	3626370.00	16.20	1029710.00	4.60	100.00
Vietnam	VM	140.000	181200.0	NA	181200.00	100.00	0.00	0.00	0.00	0.00	100
Western Sahara	WI	4280.605	4280600.0	4.280	0.00		0.00		0.00		0
Yemen	YM	185.000	570219.0	0.570	569078.56	99.80	570.22	0.10	570.22	0.10	100
Zaire	CG	1999.996	3000000.0	3.000	2857142.86	95.24	0.00	0.00	0.00	0.00	95.24
Zambia	ZA	0.000	NA	NA	NA	58.00	NA	32.00	NA	10.00	100
Zimbabwe	ZI	481.520	481520.0	0.500	130011.76	27.00	312988.00	65.00	38521.60	8.00	100.00

Sources:

[a] FAO, 1997a; FAO, 1997b; FAO, 1999a; FAO, 2000; FAO, 2005.

[b] ICID, 2001; Veneman et al., 2004; Insitute for European Environmental Policy, 2000; Australian Bureau of Statistics, 2005; Secretaria General Tecnica, 2005

Annex B Irrigation Functional Types

Overview of IFT assignment and IFT parameters of every country with areas equipped for irrigation

	Region	Country Code	IFT	Category	Application Efficiency EA	Conveyance Efficiency EC	Large-Scale Fraction	Management Factor MF
Afghanistan	SAS	AF	Surface	assigned	0.60	0.70	20.00	0.90
Albania	EUR	AL	Mixed	assigned	0.68	0.83	20.00	0.95
Algeria	MEA	AG	Mixed	assigned	0.68	0.83	20.00	0.95
Angola	AFR	AO	Surface	assigned	0.60	0.70	0.00	1.00
Argentina	LAM	AR	Surface	known	0.60	0.70	20.00	0.90
Armenia	FSU	AM	Surface	known	0.60	0.70	0.00	1.00
Australia	PAO	AS	Surface	known	0.60	0.70	20.00	0.90
Austria	EUR	AU	Sprinkler	known	0.75	0.95	0.00	1.00
Azerbaijan	FSU	AJ	Surface	known	0.60	0.70	60.00	0.70
Bangladesh	SAS	BG	Surface	known	0.60	0.70	20.00	0.90
Belgium	EUR	BE	Sprinkler	assigned	0.75	0.95	0.00	1.00
Belize	LAM	BH	Surface	known	0.60	0.70	0.00	1.00
Benin	AFR	BN	Mixed	known	0.68	0.83	0.00	1.00
Bhutan	SAS	BT	Surface	known	0.60	0.70	0.00	1.00
Bolivia	LAM	BL	Surface	known	0.60	0.70	0.00	1.00
Bosnia and Herzegovina	EUR	BK	Surface	assigned	0.60	0.70	0.00	1.00
Botswana	AFR	BC	Mixed	assigned	0.68	0.83	0.00	1.00
Brazil	LAM	BR	Mixed	known	0.68	0.83	20.00	0.95
Brunei	PAS	BX	Mixed	known	0.68	0.83	0.00	1.00
Bulgaria	EUR	BU	Surface	known	0.60	0.70	20.00	0.90
Burkina Faso	AFR	UV	Mixed	known	0.68	0.83	0.00	1.00
Burma	SAS	BM	Surface	known	0.60	0.70	0.00	1.00
Burundi	AFR	BY	Surface	known	0.60	0.70	0.00	1.00
Byelarus	FSU	BO	Sprinkler	known	0.75	0.95	0.00	1.00
Cambodia	CPA	CB	Surface	known	0.60	0.70	0.00	1.00
Cameroon	AFR	CM	Surface	known	0.60	0.70	0.00	1.00
Canada	NAM	CA	Mixed	assigned	0.68	0.83	20.00	0.95
Central African Republic	AFR	CT	Surface	assigned	0.60	0.70	0.00	1.00
Chad	AFR	CD	Surface	known	0.60	0.70	0.00	1.00
Chile	LAM	CI	Surface	known	0.60	0.70	60.00	0.70
China	CPA	CH	Surface	known	0.60	0.70	20.00	0.90
Colombia	LAM	CO	Surface	known	0.60	0.70	20.00	0.90
Congo	AFR	CF	Surface	known	0.60	0.70	0.00	1.00
Costa Rica	LAM	CS	Surface	known	0.60	0.70	0.00	1.00
Croatia	EUR	HR	Sprinkler	assigned	0.75	0.95	0.00	1.00
Cuba	LAM	CU	Mixed	known	0.68	0.83	20.00	0.95
Cyprus	EUR	CY	Micro	known	0.90	0.95	0.00	1.00
Czech Republic	EUR	EZ	Sprinkler	known	0.75	0.95	0.00	1.00
Denmark	EUR	DA	Sprinkler	known	0.75	0.95	0.00	1.00
Djibouti	AFR	DJ	Surface	assigned	0.60	0.70	0.00	1.00
Dominican Republic	LAM	DR	Surface	known	0.60	0.70	0.00	1.00
Ecuador	LAM	EC	Surface	known	0.60	0.70	20.00	0.90
Egypt	MEA	EG	Surface	known	0.60	0.70	20.00	0.90
El Salvador	LAM	ES	Surface	known	0.60	0.70	0.00	1.00
Equatorial Guinea	AFR	EK	Surface	assigned	0.60	0.70	0.00	1.00
Eritrea	AFR	ER	Surface	known	0.60	0.70	0.00	1.00
Ethiopia	AFR	ET	Surface	known	0.60	0.70	20.00	0.90
Finland	EUR	FI	Sprinkler	known	0.75	0.95	0.00	1.00
France	EUR	FR	Mixed	known	0.68	0.83	20.00	0.95

	Region	Country Code	IFT	Category	Application Efficiency EA	Conveyance Efficiency EC	Large-Scale Fraction	Management Factor MF
French Guiana	LAM	FG	Surface	assigned	0.60	0.70	0.00	1.00
Gabon	AFR	GB	Surface	assigned	0.60	0.70	0.00	1.00
Gambia, The	AFR	GA	Surface	known	0.60	0.70	0.00	1.00
Georgia	FSU	GG	Surface	known	0.60	0.70	20.00	0.90
Germany	EUR	GM	Sprinkler	known	0.75	0.95	0.00	1.00
Ghana	AFR	GH	Surface	known	0.60	0.70	0.00	1.00
Greece	EUR	GR	Sprinkler	known	0.75	0.95	60.00	1.00
Guatemala	LAM	GT	Surface	known	0.60	0.70	0.00	1.00
Guinea	AFR	GV	Surface	known	0.60	0.70	0.00	1.00
Guinea-Bissau	AFR	PU	Surface	known	0.60	0.70	0.00	1.00
Guyana	LAM	GY	Surface	known	0.60	0.70	0.00	1.00
Haiti	LAM	HA	Surface	known	0.60	0.70	0.00	1.00
Honduras	LAM	HO	Surface	known	0.60	0.70	0.00	1.00
Hungary	EUR	HU	Sprinkler	known	0.75	0.95	20.00	1.00
India	SAS	IN	Surface	known	0.60	0.70	20.00	0.90
Indonesia	PAS	ID	Surface	known	0.60	0.70	20.00	0.90
Iran	MEA	IR	Surface	known	0.60	0.70	20.00	0.90
Iraq	MEA	IZ	Mixed	known	0.68	0.83	60.00	0.85
Israel	EUR	IS	Micro	known	0.90	0.95	0.00	1.00
Italy		IT	Mixed	known	0.68	0.83	60.00	0.85
Ivory Coast	AFR	IV	Mixed	known	0.68	0.83	0.00	1.00
Jamaica	LAM	JM	Surface	known	0.60	0.70	0.00	1.00
Japan	PAO	JA	Surface	known	0.60	0.70	20.00	0.90
Jordan	MEA	JO	Micro	known	0.90	0.95	0.00	1.00
Kazakhstan	FSU	KZ	Mixed	known	0.68	0.83	20.00	0.95
Kenya	AFR	KE	Surface	known	0.60	0.70	0.00	1.00
Korea, Democratic People's Republic of	PAS	KN	Surface	assigned	0.60	0.70	20.00	0.90
Korea, Republic of	PAS	KS	Surface	known	0.60	0.70	0.00	1.00
Kuwait	MEA	KU	Mixed	known	0.68	0.83	0.00	1.00
Kyrgyzstan	FSU	KG	Surface	known	0.60	0.70	20.00	0.90
Laos	CPA	LA	Surface	known	0.60	0.70	0.00	1.00
Latvia	EUR	LG	Sprinkler	known	0.75	0.95	0.00	1.00
Lebanon	MEA	LE	Mixed	known	0.68	0.83	0.00	1.00
Lesotho	AFR	LT	Surface	assigned	0.60	0.70	0.00	1.00
Liberia	AFR	LI	Surface	known	0.60	0.70	0.00	1.00
Libya	MEA	LY	Mixed	assigned	0.68	0.83	0.00	1.00
Lithuania	EUR	LH	Sprinkler	known	0.75	0.95	0.00	1.00
Luxembourg	EUR	LU	Sprinkler	assigned	0.75	0.95	0.00	1.00
Macedonia	EUR	MK	Sprinkler	known	0.75	0.95	0.00	1.00
Madagascar	AFR	MA	Surface	known	0.60	0.70	0.00	1.00
Malawi	AFR	MI	Sprinkler	known	0.75	0.95	0.00	1.00
Malaysia	PAS	MY	Surface	known	0.60	0.70	0.00	1.00
Mali	AFR	ML	Surface	known	0.60	0.70	0.00	1.00
Mauritania	AFR	MR	Surface	assigned	0.60	0.70	0.00	1.00
Mexico	LAM	MX	Surface	known	0.60	0.70	60.00	0.70
Moldova	FSU	MD	Surface	known	0.60	0.70	20.00	0.90
Mongolia	CPA	MG	Surface	assigned	0.60	0.70	0.00	1.00
Morocco	MEA	MO	Surface	known	0.60	0.70	0.00	1.00
Mozambique	AFR	MZ	Mixed	known	0.68	0.83	20.00	0.95
Namibia	AFR	WA	Mixed	known	0.68	0.83	0.00	1.00
Nepal	SAS	NP	Surface	assigned	0.60	0.70	20.00	0.90
Netherlands	EUR	NL	Mixed	known	0.68	0.83	60.00	0.85
New Zealand	PAO	NZ	Surface	assigned	0.60	0.70	0.00	1.00
Nicaragua	LAM	NU	Surface	known	0.60	0.70	0.00	1.00

	Region	Country Code	IFT	Category	Application Efficiency EA	Conveyance Efficiency EC	Large-Scale Fraction	Management Factor MF
Niger	AFR	NG	Surface	known	0.60	0.70	0.00	1.00
Nigeria	AFR	NI	Surface	known	0.60	0.70	20.00	0.90
Norway	EUR	NO	Surface	known	0.60	0.70	0.00	1.00
Oman	MEA	MU	Micro	known	0.90	0.95	0.00	1.00
Pakistan	SAS	PK	Surface	known	0.60	0.70	60.00	0.70
Panama	LAM	PM	Surface	known	0.60	0.70	0.00	1.00
Papua New Guinea	PAS	PP	Surface	known	0.60	0.70	0.00	1.00
Paraguay	LAM	PA	Surface	known	0.60	0.70	0.00	1.00
Peru	LAM	PE	Surface	known	0.60	0.70	0.00	1.00
Philippines	PAS	RP	Surface	known	0.60	0.70	20.00	0.90
Poland	EUR	PL	Surface	known	0.60	0.70	0.00	1.00
Portugal	EUR	PO	Surface	known	0.60	0.70	20.00	0.90
Puerto Rico	NAM	RQ	Surface	assigned	0.60	0.70	0.00	1.00
Qatar	MEA	QA	Mixed	assigned	0.68	0.83	0.00	1.00
Romania	EUR	RO	Sprinkler	known	0.75	0.95	60.00	1.00
Russia	FSU	RS	Sprinkler	known	0.75	0.95	20.00	1.00
Rwanda	AFR	RW	Surface	assigned	0.60	0.70	0.00	1.00
Saudi Arabia	MEA	SA	Mixed	known	0.68	0.83	20.00	0.95
Senegal	AFR	SG	Surface	known	0.60	0.70	0.00	1.00
Serbia	EUR	SR	Surface	assigned	0.60	0.70	0.00	1.00
Sierra Leone	AFR	SL	Surface	known	0.60	0.70	0.00	1.00
Slovakia	EUR	LO	Sprinkler	known	0.75	0.95	20.00	1.00
Slovenia	EUR	SI	Mixed	assigned	0.68	0.83	0.00	1.00
Somalia	AFR	SO	Surface	known	0.60	0.70	0.00	1.00
South Africa	AFR	SF	Mixed	known	0.68	0.83	0.00	1.00
Spain	EUR	SP	Mixed	known	0.68	0.83	0.00	1.00
Sri Lanka	SAS	CE	Mixed	known	0.68	0.83	20.00	0.95
Sudan	AFR	SU	Surface	known	0.60	0.70	60.00	0.70
Suriname	LAM	NS	Surface	known	0.60	0.70	0.00	1.00
Swaziland	AFR	WZ	Mixed	known	0.68	0.83	0.00	1.00
Sweden	EUR	SW	Sprinkler	known	0.75	0.95	0.00	1.00
Switzerland	EUR	SZ	Sprinkler	assigned	0.75	0.95	0.00	1.00
Syria	MEA	SY	Surface	known	0.60	0.70	60.00	0.70
Tajikistan	FSU	TI	Surface	known	0.60	0.70	60.00	0.70
Tanzania, United Republic of	AFR	TZ	Mixed	assigned	0.68	0.83	0.00	1.00
Thailand	PAS	TH	Surface	known	0.60	0.70	60.00	0.70
Togo	AFR	TO	Surface	known	0.60	0.70	0.00	1.00
Trinidad	LAM	TD	Surface	known	0.60	0.70	0.00	1.00
Tunisia	MEA	TS	Mixed	known	0.68	0.83	0.00	1.00
Turkey	EUR	TU	Surface	known	0.60	0.70	20.00	0.90
Turkmenistan	FSU	TX	Surface	known	0.60	0.70	20.00	0.90
Uganda	AFR	UG	Surface	assigned	0.60	0.70	0.00	1.00
Ukraine	FSU	UI	Sprinkler	known	0.75	0.95	60.00	1.00
United Arab Emirates	MEA	TC	Micro	known	0.90	0.95	0.00	1.00
United Kingdom	EUR	UK	Sprinkler	known	0.75	0.95	0.00	1.00
United States	NAM	US	Mixed	known	0.68	0.83	20.00	0.95
Uruguay	LAM	UY	Surface	known	0.60	0.70	0.00	1.00
Uzbekistan	FSU	UZ	Surface	known	0.60	0.70	60.00	0.70
Venezuela	LAM	VE	Surface	known	0.60	0.70	60.00	0.70
Vietnam	CPA	VM	Surface	known	0.60	0.70	60.00	0.70
Western Sahara	AFR	WI	Surface	assigned	0.60	0.70	0.00	1.00
Yemen	MEA	YM	Surface	known	0.60	0.70	0.00	1.00

	Region	Country Code	IFT	Category	Application Efficiency EA	Conveyance Efficiency EC	Large-Scale Fraction	Management Factor MF
Zaire	AFR	CG	Surface	known	0.60	0.70	0.00	1.00
Zambia	AFR	ZA	Mixed	known	0.68	0.83	0.00	1.00
Zimbabwe	AFR	ZI	Mixed	known	0.68	0.83	0.00	1.00

Overview of IFT assignment and IFT parameters (continued)

	Project Efficiency EP	Actual Project Efficiency EP,act	Data Availability	Data Consistency	Assignment Reliability	Data Reliability	Assignment according to decision tree (only category 'known')
Afghanistan	0.38	0.00	3.00		1.00	good	
Albania	0.55	0.00	3.00		1.00	good	
Algeria	0.55	0.00	2.00	3.00	3.00	poor	
Angola	0.42	0.00	3.00		2.00	acceptable	
Argentina	0.38	0.39	2.00	2.00		acceptable	Sprinkler
Armenia	0.42	0.45	1.00	3.00		poor	Sprinkler
Australia	0.38	0.48	2.00	3.00		poor	Mixed
Austria	0.71	0.63	2.00	3.00		poor	Mixed
Azerbaijan	0.29	0.34	1.00	3.00		poor	Surface
Bangladesh	0.38	0.38	1.00	2.00		acceptable	Surface
Belgium	0.71	0.00	3.00		3.00	poor	
Belize	0.42	0.42	1.00	1.00		good	Surface
Benin	0.57	0.58	1.00	2.00		acceptable	Surface
Bhutan	0.42	0.42	1.00	1.00		good	Surface
Bolivia	0.42	0.42	2.00	1.00		good	Surface
Bosnia and Herzegovina	0.42	0.00	3.00		1.00	good	Surface
Botswana	0.57	0.00	1.00	2.00	1.00	good	Surface
Brazil	0.55	0.66	2.00	1.00		good	Surface
Brunei	0.57	0.55	1.00	1.00		good	Mixed
Bulgaria	0.38	0.38	1.00	3.00	1.00	poor	Surface
Burkina Faso	0.57	0.57	2.00	2.00		acceptable	Surface
Burma	0.42	0.46	1.00	1.00		good	Surface
Burundi	0.42	0.42	1.00	1.00		good	Surface
Byelarus	0.71	0.71	1.00	3.00		poor	Surface
Cambodia	0.42	0.42	1.00	1.00		good	Surface
Cameroon	0.42	0.48	1.00	2.00		acceptable	Surface
Canada	0.55	0.00	3.00		1.00	good	
Central African Republic	0.42	0.00	3.00		2.00	acceptable	Surface
Chad	0.42	0.46	2.00	1.00		good	Surface
Chile	0.29	0.32	1.00	1.00	2.00	good	
China	0.38	0.39	1.00	1.00	3.00	good	Surface
Colombia	0.38	0.40	1.00	1.00		good	Surface
Congo	0.42	0.42	2.00	3.00		poor	Surface
Costa Rica	0.42	0.49	1.00	1.00		good	Sprinkler
Croatia	0.71	0.00	3.00		3.00	poor	
Cuba	0.55	0.56	1.00	2.00		acceptable	Surface
Cyprus	0.86	0.82	1.00	3.00		poor	Micro
Czech Republic	0.71	0.71	1.00	3.00		poor	Sprinkler
Denmark	0.71	0.72	2.00	3.00		poor	Sprinkler
Djibouti	0.42	0.00	3.00		2.00	acceptable	Surface
Dominican Republic	0.42	0.42	1.00	1.00		good	Surface
Ecuador	0.38	0.38	1.00	1.00	1.00	good	Surface
Egypt	0.38	0.43	1.00	3.00	1.00	poor	Surface
El Salvador	0.42	0.45	1.00	1.00		good	Surface
Equatorial Guinea	0.57	0.00	3.00	3.00		poor	Mixed

	Project Efficiency EP	Actual Project Efficiency EP,act	Data Availability	Data Consistency	Assignment Reliability	Data Reliability	Assignment according to decision tree (only category 'known')
Eritrea	0.42	0.42	2.00	3.00		poor	Surface
Ethiopia	0.38	0.71	1.00	1.00	1.00	good	Sprinkler
Finland	0.71	0.96	2.00	2.00		acceptable	Sprinkler
France	0.55	0.57	1.00	3.00		poor	Mixed
French Guiana	0.42	0.00	3.00		2.00	acceptable	
Gabon	0.57	0.12	2.00	3.00		poor	
Gambia, The	0.42	0.42	1.00	1.00		good	Surface
Georgia	0.38	0.43	2.00	3.00	2.00	poor	Surface
Germany	0.71	0.78	2.00	2.00		acceptable	Mixed
Ghana	0.42	0.48	1.00	1.00		good	Surface
Greece	0.71	0.72	2.00	3.00		poor	Sprinkler
Guatemala	0.42	0.42	1.00	1.00		good	Surface
Guinea	0.42	0.42	1.00	3.00		poor	Surface
Guinea-Bissau		0.42	2.00	3.00		poor	Surface
Guyana	0.42	0.42	1.00	1.00		good	Surface
Haiti	0.42	0.42	1.00	1.00		good	Surface
Honduras	0.42	0.42	1.00	1.00		good	Surface
Hungary	0.71	0.73	2.00	3.00		poor	Sprinkler
India	0.38	0.00	2.00	3.00	1.00	poor	Surface
Indonesia	0.38	0.38	1.00	1.00	3.00	good	Surface
Iran	0.38	0.38	2.00	3.00	3.00	poor	Sprinkler
Iraq	0.50	0.32	2.00	3.00		poor	Mixed
Israel	0.86	0.59	2.00	2.00		acceptable	Micro
Italy	0.50	0.00	1.00	2.00		acceptable	Mixed
Ivory Coast	0.57	0.56	2.00	2.00		acceptable	Surface
Jamaica	0.42	0.50	1.00	1.00		good	Surface
Japan	0.38	0.41	2.00	1.00	3.00	good	Surface
Jordan	0.86	0.71	1.00	2.00		acceptable	Sprinkler
Kazakhstan	0.55	0.59	1.00	3.00		poor	Mixed
Kenya	0.42	0.49	1.00	1.00		good	Surface
Korea, Democratic People's Republic of	0.38	0.00	3.00		1.00	good	
Korea, Republic of	0.42	0.42	1.00	1.00		good	Surface
Kuwait	0.57	0.56	1.00	1.00		good	Mixed
Kyrgyzstan	0.38	0.39	1.00	3.00		poor	Surface
Laos	0.42	0.42	1.00	1.00		good	Surface
Latvia	0.71	0.71	2.00	1.00		good	Sprinkler
Lebanon	0.57	0.56	2.00	1.00		good	Micro
Lesotho	0.42	0.00	3.00		2.00	acceptable	
Liberia	0.42	0.40	2.00	1.00		good	Surface
Libya	0.57	0.00	3.00			good	
Lithuania	0.71	0.71	1.00	3.00		poor	Sprinkler
Luxembourg	0.71	0.00	3.00		3.00	poor	
Macedonia	0.71	1.30	2.00	3.00		poor	Sprinkler
Madagascar	0.42	0.42	1.00	1.00		good	Surface
Malawi	0.71	0.68	1.00	1.00		good	Surface
Malaysia	0.42	0.42	1.00	1.00		good	Surface
Mali	0.42	0.42	1.00	3.00		poor	Surface
Mauritania	0.42	0.00	3.00		2.00	acceptable	
Mexico	0.29	0.33	1.00	1.00		good	Surface
Moldova	0.38	0.39	1.00	3.00		poor	Surface
Mongolia	0.42	0.00	3.00		2.00	acceptable	
Morocco	0.42	0.48	1.00	1.00		good	Surface
Mozambique	0.55	0.58	1.00	3.00		poor	Surface
Namibia	0.57	0.62	1.00	1.00		good	Surface
Nepal	0.38	0.00	3.00		1.00	good	
Netherlands	0.50	0.61	2.00	3.00		poor	Mixed
New Zealand	0.42	0.00	3.00		1.00	good	
Nicaragua	0.42	0.00	1.00	1.00	2.00	good	
Niger	0.42	0.42	1.00	1.00		good	Surface

	Project Efficiency EP	Actual Project Efficiency EP,act	Data Availabili-ty	Data Consisten-cy	Assignment Reliability	Data Reliability	Assignment according to decision tree (only category 'known')
Nigeria	0.38	0.31	1.00	2.00		acceptable	Surface
Norway	0.42	0.42	1.00	1.00		good	Surface
Oman	0.86	0.00	1.00	1.00	3.00	good	
Pakistan	0.29	0.32	1.00	2.00		acceptable	Surface
Panama	0.42	0.42	1.00	1.00		good	Surface
Papua New Guinea	0.42	0.50	1.00	1.00		good	Surface
Paraguay	0.42	0.00	1.00	1.00	2.00	good	
Peru	0.42	0.42	1.00	1.00		good	Surface
Philippines	0.38	0.38	1.00	1.00		good	Surface
Poland	0.42	0.42	2.00	3.00		poor	Sprinkler
Portugal	0.38	0.39	2.00	2.00		acceptable	Surface
Puerto Rico	0.57	0.06	2.00	3.00		poor	Mixed
Qatar	0.57	0.00	3.00		3.00	poor	
Romania	0.71	0.66	2.00	1.00		good	Sprinkler
Russia	0.71	0.70	1.00	3.00		poor	Sprinkler
Rwanda	0.42	0.00	3.00		2.00	acceptable	
Saudi Arabia	0.55	0.60	1.00	1.00		good	Sprinkler
Senegal	0.42	0.42	1.00	2.00		acceptable	Surface
Serbia	0.42	0.00	3.00		1.00	good	
Sierra Leone	0.42	0.42	1.00	3.00		poor	Surface
Slovakia	0.71	0.71	2.00	3.00		poor	Sprinkler
Slovenia	0.57	0.00	3.00		3.00	poor	
Somalia	0.42	0.42	2.00	3.00		poor	Surface
South Africa	0.57	0.63	1.00	3.00	3.00	poor	Mixed
Spain	0.57	0.63	1.00	3.00		poor	Sprinkler
Sri Lanka	0.55	0.38	1.00	2.00		acceptable	Surface
Sudan	0.29	0.29	1.00	3.00		poor	Surface
Suriname	0.42	0.42	1.00	1.00		good	Surface
Swaziland	0.57	0.57	1.00	1.00		good	Mixed
Sweden	0.71	0.71	2.00	1.00		good	Sprinkler
Switzerland	0.71	0.00	3.00		3.00	poor	
Syria	0.29	0.31	1.00	3.00		poor	Mixed
Tajikistan	0.29	0.29	1.00	3.00		poor	Surface
Tanzania, United Republic of	0.57	0.00	3.00		1.00	good	
Thailand	0.29	0.29	1.00	1.00		good	Surface
Togo	0.42	0.29	2.00	2.00		acceptable	Surface
Trinidad	0.42	0.49	1.00	1.00		good	Surface
Tunisia	0.57	0.23	1.00	3.00		poor	Surface
Turkey	0.38	0.39	1.00	3.00		poor	Sprinkler
Turkmenistan	0.38	0.38	1.00	3.00		poor	Surface
Uganda	0.42	0.00	3.00		2.00	acceptable	
Ukraine	0.71	0.63	1.00	3.00		poor	Surface
United Arab Emirates	0.86	0.68	1.00	1.00		good	Mixed
United Kingdom	0.71	0.64	2.00	2.00		acceptable	Mixed
United States	0.55	0.56	1.00	1.00		good	Sprinkler
Uruguay	0.42	0.42	1.00	2.00		acceptable	Surface
Uzbekistan	0.29	0.29	1.00	3.00		poor	Surface
Venezuela	0.29	0.39	1.00	3.00		poor	Surface
Vietnam	0.29	0.29	1.00	1.00		good	Surface
Western Sahara	0.42	0.00	3.00		2.00	acceptable	Surface
Yemen	0.42	0.42	1.00	3.00		poor	Surface
Zaire	0.42	0.40	2.00	1.00		good	Surface
Zambia	0.57	0.56	1.00	3.00		poor	Surface
Zimbabwe	0.57	0.64	1.00	3.00		poor	Surface

Results of the cross validation of the decision mechanism for IFT assignment.

Region			AFR	CPA	EUR	FSU	LAM	MEA	NAM	PAS	PAO	SAS
Actual IFT	Surface	total in figures	22	4	5	8	21	5	0	2	6	6
	Sprinkler	total in figures	10	0	4	1	7	5	2	0	1	0
	Mixed	total in figures	2	0	15	3	0	0	0	0	0	0
	Micro	total in figures	0	0	2	0	0	3	0	0	0	0
	Total	total in figures	34	4	26	12	28	13	2	2	7	6
Correct Assignment	Surface	total in figures	22	4	3	7	18	3	0	1	6	6
	Sprinkler	total in figures	3	0	3	1	0	2	1	0	1	0
	Mixed	total in figures	1	0	2	1	0	0	0	0	0	0
	Micro	total in figures	0	0	0	0	0	1	0	0	0	0
False Assignment	Surface	total in figures	8	0	0	2	2	1	0	0	0	0
	Sprinkler	total in figures	0	0	3	0	0	2	0	1	0	0
	Mixed	total in figures	0	0	3	1	3	3	1	0	0	0
	Micro	total in figures	0	0	0	0	0	1	0	0	0	0
Total Assignment	Surface	total in figures	30	4	3	9	20	4	0	1	6	6
	Sprinkler	total in figures	3	0	6	1	0	4	1	1	1	0
	Mixed	total in figures	1	0	5	2	3	3	1	0	0	0
	Micro	total in figures	0	0	0	0	0	2	0	0	0	0
Propability of Correct Assignment	Surface		0.73	1.00	1.00	0.78	0.90	0.75	0.00	1.00	1.00	1.00
	Sprinkler		1.00	0.00	0.50	1.00	0.00	0.50	1.00	0.00	1.00	0.00
	Mixed		1.00	0.00	0.40	0.50	0.00	0.00	0.00	0.00	0.00	0.00
	Micro		0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00

Correct Assignment: countries which have been assigned to their acutal IFT based on their country profil (for country profiles see Annex C).
False Assignment: countries which have been assigned to an incorrect IFT based on their country profil.
Total Assignment: sum of correct and false assignment
Probability of Correct Assignment: Correct Assignment/Total Assignment.

Annex C Country Profiles

Socio-economic and climatic parameters of each country, used in the decision mechanism for IFT assignment.

	Region	Country Code	Income Category	Income Range	Rural of total population	Economic active in agriculture of total population	Economic active in agriculture of rural population	Average temperatur during vegetation period	Average monthly precipitation during vegetation period	Annual precipitation	Agricultural water withdrawal per irrigated area	Agricultural water withdrawal of total water withdrawal
Source		LPJ	WorldBank[c]	WorldBank[c]	FAO[d]	FAO[d]	FAO[d]	CRU[e]	CRU[e]	FAO[d]	FAO[d]	FAO[d]
Time Period			2000	2000	1998-2002	1998-2002	1998-2002	2000	2000	1998-2002	1998-2002	1998-2002
Unit				US$	%	%	%	°C	mm	mm	m³/ha	%
Afghanistan	SAS	AF	Low income	<=825	77.30	27.00	34.93	12.94	31.29	327.00	NA	98.19
Albania	EUR	AL	Lower middle income	826-3025	57.21	23.75	41.51	9.52	73.18	1485.00	3117.65	61.99
Algeria	MEA	AG	Lower middle income	826-3025	41.81	8.51	20.35	14.53	38.08	89.00	6919.35	64.91
Angola	AFR	AO	Lower middle income	826-3025	NA	NA	NA	NA	115.19	1010.00	NA	60.00
Argentina	LAM	AR	Upper middle income	3026-10065	10.07	3.84	38.16	17.80	78.71	591.00	13881.78	73.72
Armenia	FSU	AM	Lower middle income	826-3025	36.04	6.35	17.62	11.86	40.45	562.00	6791.55	65.76
Australia	PAO	AS	High income: OECD	>=10066	8.21	2.26	27.54	22.24	75.11	534.00	7076.62	75.26
Austria	EUR	AU	High income: OECD	>=10066	34.25	2.17	6.34	11.97	90.50	1110.00	5000.00	0.95
Azerbaijan	FSU	AJ	Lower middle income	826-3025	49.95	11.68	23.38	17.08	36.52	447.00	8016.14	67.54
Bangladesh	SAS	BG	Low income	<=825	76.11	27.25	35.80	26.37	255.46	2666.00	20354.33	96.16
Belgium	EUR	BE	High income: OECD	>=10066	2.83	0.70	24.74	22.89	65.04	847.00	0.00	
Belize	LAM	BH	Upper middle income	3026-10065	51.79	10.76	20.77	26.08	74.98	1705.00	10000.00	20.00
Bhutan	SAS	BT	Low income	<=825	91.78	45.30	49.35	13.74	147.97	2200.00	10326.84	94.12
Bolivia	LAM	BL	Lower middle income	826-3025	37.14	18.02	48.52	23.56	136.07	1146.00	9045.61	80.61
Bosnia and Herzegovina	EUR	BK	Lower middle income	826-3025	55.87	2.06	3.69	13.97	127.23	1028.00	0.00	NA
Botswana	AFR	BC	Upper middle income	3026-10065	NA	NA	NA	NA	79.73	416.00	NA	41.24
Brazil	LAM	BR	Lower middle income	826-3025	17.62	7.19	40.80	25.12	64.95	1782.00	12762.16	61.77
Brunei	PAS	BX	High income: nonOECD	>=10066	24.57	0.29	1.16	24.99	176.13	2722.00	0.00	NA
Bulgaria	EUR	BU	Lower middle income	826-3025	30.62	3.21	10.50	15.08	231.40	608.00	3350.34	18.76

	Region	Country Code	Income Category	Income Range	Rural of total population	Economic active in agriculture of total population	Economic active in agriculture of rural population	Average temperatur during vegetation period	Average monthly precipitation during vegetation period	Annual precipitation	Agricultural water withdrawal per irrigated area	Agricultural water withdrawal of total water withdrawal
Source		LPJ	WorldBank[c]	WorldBank[c]	FAO[d]	FAO[d]	FAO[d]	CRU[e]	CRU[e]	FAO[d]	FAO[d]	FAO[d]
Time Period			2000	2000	1998-2002	1998-2002	1998-2002	2000	2000	1998-2002	1998-2002	1998-2002
Unit				US$	%	%	%	°C	mm	mm	m^3/ha	%
Burkina Faso	AFR	UV	Low income	<=825	82.60	43.37	52.51	27.64	48.47	748.00	27600.00	86.25
Burma	SAS	BM	Low income	<=825	71.09	37.74	53.09	23.53	136.58	2091.00	20984.74	98.22
Burundi	AFR	BY	Low income	<=825	90.49	47.29	52.26	20.78	193.13	1274.00	10359.31	77.08
Byelarus	FSU	BO	Lower middle income	826-3025	29.64	6.55	22.10	14.00	113.89	618.00	6412.21	30.11
Cambodia	CPA	CB	Low income	<=825	81.88	34.50	42.13	26.67	242.61	1904.00	14844.45	98.04
Cameroon	AFR	CM	Low income	<=825	49.37	23.67	47.94	24.19	171.21	1604.00	28455.60	73.74
Canada	NAM	CA	High income: OECD	>=10066	19.89	1.19	5.97	13.60	49.37	537.00	6900.51	11.77
Central African Republic	AFR	CT	Low income	<=825	57.63	33.28	57.75	24.65	157.66	1343.00	7407.41	4.00
Chad	AFR	CD	Low income	<=825	75.48	33.43	44.29	27.01	111.28	322.00	6276.22	82.61
Chile	LAM	CI	Upper middle income	3026-10065	13.35	6.31	47.26	8.04	64.69	1522.00	4194.74	63.51
China	CPA	CH	Lower middle income	826-3025	24.04	8.49	35.33	14.09	83.02	2612.00	8062.41	45.94
Colombia	LAM	CO	Lower middle income	826-3025	46.68	15.83	33.90	24.22	205.97	1646.00	5466.67	8.70
Congo	AFR	CF	Low income	<=825	39.81	7.96	20.00	24.47	137.10	2926.00	2000.00	53.36
Costa Rica	LAM	CS	Upper middle income	3026-10065	41.02	6.75	16.47	23.99	247.59	1410.00	13872.18	66.08
Croatia	EUR	HR	Upper middle income	3026-10065	41.68	3.47	8.32	6.85	81.23	1113.00	0.00	NA
Cuba	LAM	CU	Lower middle income	826-3025	24.63	6.71	27.23	26.13	104.80	1335.00	NA	68.78
Cyprus	EUR	CY	High income: non OECD	>=10066	31.03	3.89	12.55	14.20	55.76	498.00	195.33	70.83
Czech Republic	EUR	EZ	Upper middle income	3026-10065	25.96	4.31	16.62	13.65	69.79	677.00	1502.33	2.33
Denmark	EUR	DA	High income: OECD	>=10066	14.73	1.91	12.94	12.30	58.09	703.00	22500.00	42.52
Djibouti	AFR	DJ	Lower middle income	826-3025	16.74	38.67	23.10	24.44	NA	220.00	2964.43	15.79
Dominican Republic	LAM	DR	Lower middle income	826-3025	38.75	9.73	25.12	25.10	126.60	2087.00	NA	82.21
Ecuador	LAM	EC	Lower middle income	826-3025	57.99	12.02	20.73	21.78	162.39	51.00	51759.30	86.38
Equatorial Guinea	AFR	EK	Upper middle income	3026-10065	52.81	28.69	54.33	24.01	173.21	2156.00	22.23	0.93
Eritrea	AFR	ER	Low income	<=825	84.66	35.62	42.07	26.11	64.26	848.00	NA	93.63
Ethiopia	AFR	ET	Low income	<=825	73.85	39.63	53.66	22.09	103.29	836.00	0.00	65.36
Finland	EUR	FI	High income: OECD	>=10066	39.06	2.50	6.40	9.05	55.61	536.00	22000.00	2.67

	Region	Country Code	Income Category	Income Range	Rural of total population	Economic active in agriculture of total population	Economic active in agriculture of rural population	Average tempera-tur during vegetation period	Average monthly precipitation during vegetation period	Annual precipitation	Agricultural water withdrawal per irrigated area	Agricultural water withdrawal of total water withdrawal
Source		LPJ	WorldBank[c]	WorldBank[c]	FAO[d]	FAO[d]	FAO[d]	CRU[e]	CRU[e]	FAO[d]	FAO[d]	FAO[d]
Time Period			2000	2000	1998-2002	1998-2002	1998-2002	2000	2000	1998-2002	1998-2002	1998-2002
Unit				US$	%	%	%	°C	mm	mm	m³/ha	%
France	EUR	FR	High income: OECD	>=10066	23.97	1.37	5.70	12.84	70.30	867.00	61250.00	9.81
French Guiana	LAM	FG		0.00	24.71	7.47	30.23	NA	NA	2895.00	0.00	
Gabon	AFR	GB	Upper middle income	3026-10065	16.62	15.77	94.93	25.14	155.35	1831.00	11235.96	41.67
Gambia, The	AFR	GA	Low income	<=825	47.81	9.62	20.12	27.29	168.70	1026.00	9306.65	59.00
Georgia	FSU	GG	Lower middle income	826-3025	54.92	28.04	51.06	11.42	66.61	1187.00	4541.58	66.40
Germany	EUR	GM	High income: OECD	>=10066	12.15	1.12	9.22	13.43	67.02	700.00	19600.00	19.79
Ghana	AFR	GH	Low income	<=825	54.05	16.64	30.79	26.73	133.50	1996.00	NA	80.10
Greece	EUR	GR	High income: OECD	>=10066	39.20	6.86	17.51	13.34	52.99	652.00	NA	80.44
Guatemala	LAM	GT	Lower middle income	826-3025	65.67	41.02	62.47	23.58	188.64	1651.00	NA	90.07
Guinea	AFR	GV	Low income	<=825	66.87	35.54	53.15	25.09	183.34	1577.00	60289.03	82.29
Guyana	LAM	GY	Lower middle income	826-3025	63.20	26.70	42.24	26.13	187.48	1440.00	NA	93.94
Haiti	LAM	HA	Low income	<=825	54.80	11.52	21.02	24.60	103.90	1976.00	10163.71	80.23
Honduras	LAM	HO	Lower middle income	826-3025	71.91	25.75	35.81	23.95	164.59	1083.00	9424.94	86.46
Hungary	EUR	HU	Upper middle income	3026-10065	35.44	4.77	13.45	13.71	53.38	589.00	10652.17	32.07
India	SAS	IN	Low income	<=825	55.48	23.01	41.47	25.18	151.99	2702.00	11145.29	91.33
Indonesia	PAS	ID	Lower middle income	826-3025	34.08	9.36	27.48	25.99	205.25	228.00	17073.47	90.88
Iran	MEA	IR	Lower middle income	826-3025	47.89	10.01	20.91	NA	28.49	2051.00	9117.32	48.78
Iraq	MEA	IZ	Lower middle income	826-3025	32.48	2.55	7.86	13.54	47.96	216.00	11171.63	92.22
Israel	EUR	IS	High income: non OECD	>=10066	8.17	1.08	13.20	14.29	62.53	435.00	NA	62.44
Italy		IT	High income: OECD	>=10066	32.59	2.12	6.51	12.15	74.27	832.00	7383.76	45.10
Ivory Coast	AFR	IV	Low income	<=825	55.59	19.11	34.37	26.05	135.50	1348.00	8275.86	64.52
Jamaica	LAM	JM	Lower middle income	826-3025	34.73	1.93	5.54	24.27	127.43	1668.00	7932.10	62.46
Japan	PAO	JA	High income: OECD	>=10066	61.69	38.89	63.04	15.69	149.89	630.00	17656.20	63.92
Jordan	MEA	JO	Lower middle income	826-3025	21.05	3.60	17.11	13.44	18.85	111.00	NA	75.25
Kazakhstan	FSU	KZ	Lower middle income	826-3025	44.81	8.32	18.57	15.79	23.67	250.00	8050.28	81.80
Kenya	AFR	KE	Low income	<=825	20.15	4.55	22.58	24.65	75.58	1274.00	9786.54	47.98

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Source		LPJ	WorldBank[c]	WorldBank[c]	FAO[d]	FAO[d]	FAO[d]	CRU[e]	CRU[e]	FAO[d]	FAO[d]	FAO[d]
Time Period			2000	2000	1998-2002	1998-2002	1998-2002	2000	2000	1998-2002	1998-2002	1998-2002
Unit				US$	%	%	%	°C	mm	mm	m^3/ha	%
Korea, Democratic People's Republic of	PAS	KN	Low income	<=825	39.23	14.74	37.58	12.19	122.42	1054.00	3397.26	54.99
Korea, Republic of	PAS	KS	High income: OECD	>=10066	66.09	4.55	22.58	16.43	153.45	533.00	10036.06	93.75
Kuwait	MEA	KU	High income: non OECD	>=10066	3.40	0.57	16.87	NA	NA	121.00	48218.03	52.27
Kyrgyzstan	FSU	KG	Low income	<=825	79.83	38.22	47.87	8.59	32.40	1834.00	8810.37	90.00
Laos	CPA	LA	Low income	<=825	53.38	25.41	47.60	24.17	197.28	2391.00	17375.19	54.55
Latvia	EUR	LG	Upper middle income	3026-10065	34.18	6.18	18.09	12.83	65.56	641.00	2000.00	13.33
Lebanon	MEA	LE	Upper middle income	3026-10065	12.49	1.20	9.58	9.73	63.97	661.00	10514.29	66.67
Lesotho	AFR	LT	Low income	<=825	82.17	15.50	18.86	NA	92.69	788.00	3792.19	20.00
Liberia	AFR	LI	Low income	<=825	73.74	35.12	47.63	25.15	170.38	1513.00	28571.43	95.66
Libya	MEA	LY	Upper middle income	3026-10065	14.01	1.85	13.24	NA	36.43	56.00	7540.43	83.04
Lithuania	EUR	LH	Upper middle income	3026-10065	33.42	5.77	17.27	13.38	66.66	656.00	2162.86	7.41
Luxembourg	EUR	LU	High income: OECD	>=10066	8.28	0.89	10.81	13.40	76.20	934.00	NA	NA
Madagascar	AFR	MA	Low income	<=825	36.25	7.49	20.66	23.50	187.05	2875.00	13173.27	62.08
Malawi	AFR	MI	Low income	<=825	84.17	39.47	46.90	23.22	142.74	1181.00	14364.25	80.20
Malaysia	PAS	MY	Upper middle income	3026-10065	68.43	37.51	54.82	25.47	231.92	282.00	15444.02	90.13
Mali	AFR	ML	Low income	<=825	24.82	8.35	33.62	28.72	113.03	752.00	25022.16	77.14
Mauritania	AFR	MR	Low income	<=825	39.69	23.41	58.98	15.07	56.92	92.00	30487.80	88.24
Mexico	LAM	MX	Upper middle income	3026-10065	54.38	10.91	20.07	22.42	93.93	450.00	9645.09	32.90
Moldova	FSU	MD	Low income	<=825	43.24	14.21	32.87	15.05	47.26	346.00	2435.90	87.38
Mongolia	CPA	MG	Low income	<=825	43.73	11.96	27.35	13.36	45.63	241.00	2728.35	52.27
Morocco	MEA	MO	Lower middle income	826-3025	78.39	40.11	51.17	14.29	38.30	151.00	7418.34	95.41
Mozambique	AFR	MZ	Low income	<=825	65.37	42.28	64.67	25.49	134.44	1032.00	4656.28	87.30
Namibia	AFR	WA	Lower middle income	826-3025	68.08	15.86	23.30	23.59	63.46	285.00	28126.24	71.00
Nepal	SAS	NP	Low income	<=825	85.31	44.28	51.91	10.45	110.06	1500.00	8657.06	96.46
Netherlands	EUR	NL	High income: OECD	>=10066	34.61	1.46	4.21	12.84	67.55	778.00	0.00	33.88
New Zealand	PAO	NZ	High income: OECD	>=10066	14.12	4.37	30.94	13.84	NA	1732.00	3122.81	42.18
Nicaragua	LAM	NU	Low income	<=825	43.02	7.40	17.21	21.61	188.12	2391.00	17599.61	83.08
Niger	AFR	NG	Low income	<=825	54.14	12.56	23.19	29.63	77.07	1150.00	28236.70	68.79

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Source		LPJ	WorldBank[c]	WorldBank[c]	FAO[d]	FAO[d]	FAO[d]	CRU[e]	CRU[e]	FAO[d]	FAO[d]	FAO[d]
Time Period			2000	2000	1998-2002	1998-2002	1998-2002	2000	2000	1998-2002	1998-2002	1998-2002
Unit				US$	%	%	%	°C	mm	mm	m³/ha	%
Nigeria	AFR	NI	Low income	<=825	22.60	2.22	9.80	26.44	157.49	1414.00	18797.95	10.50
Norway	EUR	NO	High income: OECD	>=10066	66.28	17.12	25.83	6.81	72.62	494.00	NA	96.02
Pakistan	SAS	PK	Low income	<=825	43.21	8.16	18.88	20.84	51.40	2692.00	10340.48	28.05
Panama	LAM	PM	Upper middle income	3026-10065	86.79	34.80	40.10	25.10	231.02	3142.00	NA	1.41
Papua New Guinea	PAS	PP	Low income	<=825	26.48	11.29	42.63	24.89	216.60	1738.00	NA	81.57
Paraguay	LAM	PA	Lower middle income	826-3025	43.45	12.74	29.31	24.81	114.27	1130.00	5223.88	71.43
Peru	LAM	PE	Lower middle income	826-3025	39.79	16.15	40.58	20.67	139.81	2348.00	13737.96	73.98
Philippines	PAS	RP	Lower middle income	826-3025	38.22	10.77	28.18	25.52	202.35	600.00	13612.90	8.33
Poland	EUR	PL	Upper middle income	3026-10065	46.17	6.06	13.13	13.26	60.45	854.00	13500.00	78.24
Portugal	EUR	PO	High income: OECD	>=10066	51.12	32.71	63.99	12.20	75.40	686.00	11137.80	92.98
Puerto Rico	NAM	RQ	High income: non OECD	>=10066	3.24	0.75	23.20	24.70	123.65	2054.00	0.00	NA
Qatar	MEA	QA	High income: non OECD	>=10066	8.15	0.67	8.16	25.29	NA	74.00	16773.16	72.41
Romania	EUR	RO	Lower middle income	826-3025	45.67	6.59	14.43	13.46	53.01	637.00	4293.14	56.99
Russia	FSU	RS	Upper middle income	3026-10065	26.81	5.39	20.12	8.72	47.23	460.00	2227.30	17.79
Rwanda	AFR	RW	Low income	<=825	9.13	1.21	13.24	NA	101.80	3000.00	0.00	NA
Saudi Arabia	MEA	SA	High income: non OECD	>=10066	12.99	2.89	22.25	22.19	19.21	59.00	9589.55	89.03
Senegal	AFR	SG	Low income	<=825	62.62	22.73	36.31	28.31	127.58	2526.00	17254.34	92.11
Serbia	EUR	SR	Lower middle income	826-3025	48.32	8.83	18.27	NA	56.87	795.00	0.00	NA
Sierra Leone	AFR	SL	Low income	<=825	65.82	29.97	45.53	25.39	228.91	282.00	11920.98	99.70
Slovakia	EUR	LO	Upper middle income	3026-10065	43.05	4.72	10.97	12.47	73.75	824.00	0.00	NA
Slovenia	EUR	SI	High income: non OECD	>=10066	49.24	0.81	1.64	20.02	102.27	1162.00	0.00	NA
Somalia	AFR	SO	Low income	<=825	62.01	23.54	37.96	27.21	40.80	416.00	NA	96.65
South Africa	AFR	SF	Upper middle income	3026-10065	43.34	3.71	8.56	19.28	69.96	495.00	5230.97	62.71
Spain	EUR	SP	High income: OECD	>=10066	23.56	2.98	12.64	12.32	51.28	636.00	7019.98	68.03
Sri Lanka	SAS	CE	Lower middle income	826-3025	78.94	20.59	26.09	26.38	133.67	1712.00	21052.63	95.16
Sudan	AFR	SU	Low income	<=825	24.54	7.18	29.25	27.03	105.09	2331.00	190544.11	92.54

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Time Period			2000	2000	1998-2002	1998-2002	1998-2002	2000	2000	1998-2002	1998-2002	1998-2002
Unit				US$	%	%	%	°C	mm	mm	m³/ha	%
Suriname	LAM	NS	Lower middle income	826-3025	49.91	8.99	18.02	25.83	204.16	252.00	NA	94.89
Swaziland	AFR	WZ	Lower middle income	826-3025	76.61	11.32	14.77	24.56	75.58	788.00	20183.38	96.55
Sweden	EUR	SW	High income: OECD	>=10066	16.75	1.59	9.49	8.51	56.87	624.00	2260.87	8.78
Syria	MEA	SY	Lower middle income	826-3025	75.16	13.27	17.65	13.36	37.62	691.00	18682.03	91.64
Tajikistan	FSU	TI	Low income	<=825	68.44	32.72	47.81	9.07	26.96	1622.00	15264.62	95.05
Tanzania, United Republic of	AFR	TZ	Low income	<=825	65.57	40.65	61.99	25.05	121.33	1071.00	25128.85	40.00
Thailand	PAS	TH	Lower middle income	826-3025	65.32	24.85	38.04	26.73	175.68	1168.00	16537.68	44.97
Togo	AFR	TO	Low income	<=825	24.96	3.78	15.12	26.39	147.56	2200.00	10410.96	6.45
Trinidad	LAM	TD	Upper middle income	3026-10065	34.36	20.90	60.84	NA	NA	593.00	5555.56	74.23
Tunisia	MEA	TS	Lower middle income	826-3025	36.78	9.85	26.77	15.37	42.69	207.00	5494.92	82.01
Turkey	EUR	TU	Upper middle income	3026-10065	54.86	14.73	26.84	12.93	46.50	161.00	6655.66	97.53
Turkmenistan	FSU	TX	Lower middle income	826-3025	7.61	5.57	73.26	19.53	20.58	1265.00	13783.61	96.19
Uganda	AFR	UG	Low income	<=825	87.85	37.97	43.21	8.15	104.23	1180.00	13114.75	NA
Ukraine	FSU	UI	Lower middle income	826-3025	32.96	6.98	21.16	14.62	51.58	565.00	7558.54	52.46
United Arab Emirates	MEA	TC	High income: nonOECD	>=10066	15.12	2.42	15.99	NA	NA	78.00	23544.58	68.26
United Kingdom	EUR	UK	High income: OECD	>=10066	11.14	0.86	7.69	11.86	66.79	1220.00	1647.06	2.94
United States	NAM	US	High income: OECD	>=10066	20.14	1.00	4.96	13.33	65.86	715.00	8834.04	41.26
Uruguay	LAM	UY	Upper middle income	3026-10065	63.14	11.69	18.52	15.95	100.44	206.00	16721.85	93.20
Uzbekistan	FSU	UZ	Low income	<=825	12.59	3.12	24.80	15.38	31.68	1875.00	12701.49	47.43
Venezuela	LAM	VE	Upper middle income	3026-10065	74.74	35.16	47.04	25.25	171.32	1821.00	6962.24	68.10
Vietnam	CPA	VM	Low income	<=825	74.77	15.12	20.23	25.25	178.59	167.00	16206.67	95.32
Western Sahara	AFR	WI	NA	0.00	6.64	13.62	205.00	23.26	NA	NA	NA	NA
Yemen	MEA	YM	Low income	<=825	69.01	26.05	37.75	25.00	23.86	1543.00	13125.10	30.56
Zaire	AFR	CG	Low income	<=825	NA	NA	NA	23.40	147.36	NA	10476.19	NA

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Source		LPJ	WorldBank[c]	WorldBank[c]	FAO[d]	FAO[d]	FAO[d]	CRU[e]	CRU[e]	FAO[d]	FAO[d]	FAO[d]
Time Period			2000	2000	1998-2002	1998-2002	1998-2002	2000	2000	1998-2002	1998-2002	1998-2002
Unit				US$	%	%	%	°C	mm	mm	m³/ha	%
Zambia	AFR	ZA	Low income	<=825	64.87	28.72	44.28	23.34	137.62	1020.00	8466.31	75.86
Zimbabwe	AFR	ZI	Low income	<=825	65.56	27.99	42.70	NA	114.95	657.00	19122.49	78.91
Time Period			2000	2000	1998-2002	1998-2002	1998-2002	2000	2000	1998-2002	1998-2002	1998-2002

Sources:

[c] The World Bank Data & Statistics, Country classification: http://web.worldbank.org/WBSITE/EXTERNAL/DATASTATISTICS/0,,contentMDK:20420458~menuPK:64133156~pagePK:64133150~piPK:64133175~theSitePK:239419,00.html, 19.06.2006;

[d] The aggregated CRU data were supplied by C. Awalt (personal communication). The original CRU climate data were supplied by the Climate Impact LINK Project (UK Department of the Environment Contact EPG 1/1/16) on behalf of the climatic Research Unit, University of East Anglia.

[e] FAO AQUASTAT online database: http://www.fao.org/ag/agl/aglw/aquastat/dbase/index.stm, 11.09.2006

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