

## Global Irrigation Demand – A Holistic Approach

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### Global Irrigation Demands

Agriculture is the world's largest consumer and withdrawer of freshwater resources, and irrigation has been historically instrumental in meeting the fast-pace growth of global food demands. Today irrigated agriculture accounts for more than 70% of total global water withdrawals and 85% of the consumptive use [1,2], where withdrawal is the amount of water taken from the water supply system (lakes, groundwater aquifers) and consumption is the amount of water that is made unavailable to users in a basin (e.g., evaporated, or transpired) [3]. With rising populations and their associated growing food demands, the demand for water in agriculture can be expected to continue to grow. Meeting these demands presents a formidable challenge to the world [4,5]. de Fraiture and Wichelns [6] argue that ensuring global food security requires water development and management strategies which can focus on (1) increasing productivity in rainfed agriculture, (2) investing in increasing irrigated area, (3) promoting agricultural trade from water abundant to water scarce areas, and (4) limiting potential increase in global food demand. Furthermore, meeting future irrigation water demands raises two prominent challenges. First is overdraft of groundwater and shifting of many areas from water scarce regions to water stressed regions. An important case in point is India, a country substantially dependent on irrigation for maintaining agriculture productivity. High dependence on groundwater has led to an alarming rate of decrease of the groundwater table [7,8] posing serious questions about the sustainability of irrigated agriculture in India and threatening the objective of self-sufficiency in food production. The second important and yet contrasting challenge is lack of irrigation in some other parts of the world resulting in huge underutilization of water resources limiting the potential for food production. Many African countries are facing this situation. Lack of basic irrigation infrastructure seriously impedes the continent's ability to increase crop productivity and ensure adequate food availability to its growing population [9]. Average crop productivity in African countries is among the lowest in the world while a substantial future population increase is expected to be in this region. Irrigation infrastructure is critically required in Africa to ensure that the gross cropped area increases substantially and crop productivity moves closer to the potential [10]. Improving crop productivity (yield) through irrigation will also help ensure that increase in cropped area is not at the expense of forested area. It is ironic that the two highlighted challenges to global irrigation are contrasting in nature- overdraft of water in some regions while underutilization of water resources in others.

Meeting current and future irrigation demands hinges on many interdependent factors. For example, significant demand for energy crops in the future [11,12] for meeting future global energy demands will intensify the pressure on irrigation water, while ensuring global food security puts pressure on global water resources and water scarcity. Other water demands are also rising at alarming rates (Figure 1) over recent decades [13,14]. Understanding food security and the adequacy of water supplies to meet future global irrigation water demands depends on the water demand by competing water users, the climatic forcing and how those are shaped by human activities, natural variability, and socio-economic and regulation drivers. Furthermore, the global water system is connected spatially through economic factors and global and regional trading markets of food and

other internationally traded products. This global flux of water among trading nations is referred to in the literature as virtual water trading – the total embedded water content of traded products [15,16]. Thus, by focusing solely on local processes, we are likely to overlook important global dynamics that may alter the state of water resources and the water cycle, and potentially impose irreversible impacts on society and nature [16]. In short, the problem of understanding irrigation systems is ultimately a global water management problem.

### The Global Water System

The global water system can be defined as the “the global suite of water-related human, physical, biological, and biogeochemical components and their interactions or as a coupled social-ecological system” [18,19]. A key challenge in developing an adequate understanding of the global water system is representing interdependencies and linkages to other components within the human-Earth system (Figure 2). Accounting for the availability of freshwater for human use, both blue and green water [20], for water re-use and desalinization, fossil groundwater resources, and the driving forces both physical and economical shaping their utilization is essential to adequately manage future water demands and to alleviate water scarcity. Ignoring the economic and social dynamics or the effect of globalization can set us up for failure in devising realistic solutions. Often shifts in water demand are not necessarily local in nature but are rather imposed by global economic forcing, for example, higher prices for bioenergy can change agricultural activities and cause social consequences – increases in food prices can lead to lower dietary consumptions and subsequently changes in levels of poverty. These external drivers can either induce positive and or negative feedback loops on the system. Embracing a holistic approach of water demands and supplies, market dynamics and institutional regulations, interdependencies between the water system and other human and physical systems (e.g., climate, land, energy, economy), the role of technology evolution and the penetration water conservation measures would allow the water resources community to better address questions such as: Is more irrigation the answer to food security? And what is the role of irrigation technologies in meeting global water demands?

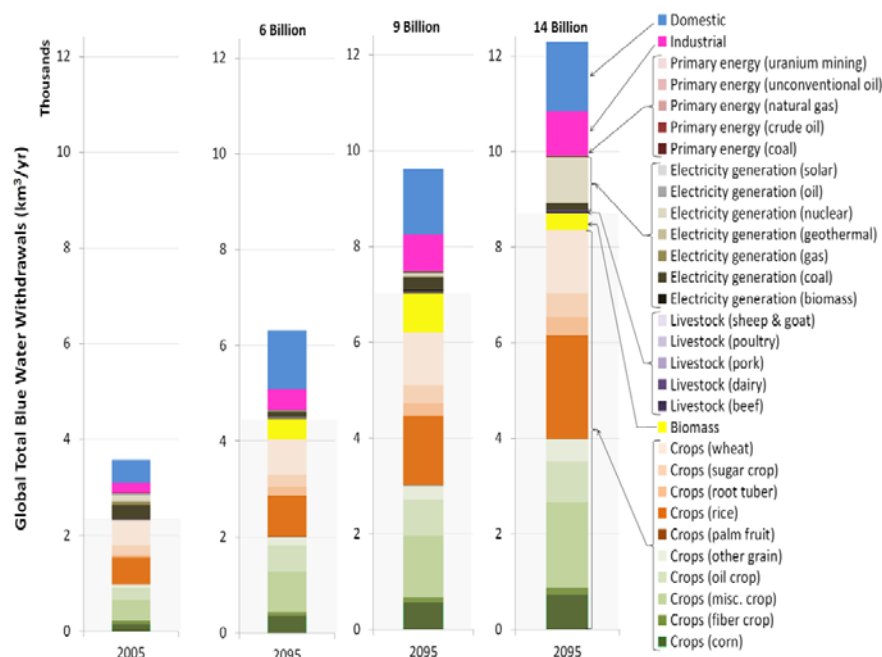
Nations are typically faced with two main water related challenges: 1) establishing institutional regulations that facilitate more economically productive, socially equitable, and environmentally sustainable water management practices (demand-side management), 2) maintaining adequate water infrastructure to meet the demands of human water use (supply-side management) [21]. Traditionally, governments around

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**Figure 1:** Global water demands by sector in years 2005 and 2095 (under three alternative scenarios with variations in technology, income, and population); shaded bars reflect total irrigations; results are taken from [17].

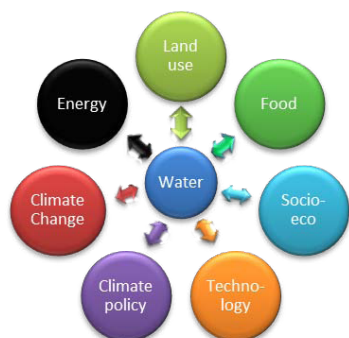
the globe have invested in enhancing the storage capacity infrastructure (e.g., reservoirs) to maintain adequate water resources for human use in regions where water is either scarce or variable in time. More recently, there has been more institutional effort to employ policy tools to reduce water use, improve water use efficiency, and reduce the need to expand water storage capacities known to have environmental consequences. For example, more nations are moving away from flat rate metering, which does not provide any incentive to save water, to more economically based systems such as variable block tariffs. Water pricing needs to do a better job distinguishing between withdrawals and consumption of water. Failing to recognize this distinction can lead to incentives that encourage the use of technology that reduce withdrawals, while increasing water consumption or vice versa. Understanding the trade-off between withdrawal and consumption and their effects on the water system and the health of the environment is not yet settled.

The largest global withdrawer and consumer of water remains the agricultural sector (approximately 70% of withdrawals) primarily for irrigation. Here water prices tend to reflect the delivery cost rather than the scarcity value of water. This in turn provides little incentive to use water efficiently in the agricultural sector. Numerous technological advancements could help improve the efficiency of water use in the agricultural sector. For example, the increase in efficiency can come with better water transport infrastructure like cemented canals and a transition to closed irrigation pipelines, as well as moving away from flooding irrigation technologies to more efficient end use water technologies like sprinkler and drip irrigation systems. A better understanding of the economic implications of new water technologies and policies is needed. This in turn implies a need for improved scientific research tools to address such questions, while connecting the pieces and placing irrigation within the context of other human systems such as domestic and international trade and commerce, agriculture, energy, land-use, and climate.

## Inter-Linkages

Much research is still needed to complement existing knowledge of the existing linkages (e.g., biophysical, socio-economic, and institutional) between the global water system and other systems that include physical, biological, biogeochemical, and human-mediated processes, which are also key determinants of global water systems [22]. Human water use through massive irrigation can enhance evaporation and subsequently affect the regional climate system. For example, Douglas et al. [23,24] showed that the dramatic increase in irrigation in India over the past several decades may destabilize the region's monsoon system, and consequently propagate westerly and affect other neighboring monsoons in India and Africa [25]. In Amazonia, deforestation and expansion of irrigation land over the past several decades has led to a 25% increase in runoff [26]. A positive (reinforcing) feedback loop where deforestation leads to less evapotranspiration and subsequently less precipitation which can lead to more deforestation, and so on has been postulated by Coe et al. [26]. These examples illustrate some of the known effects of human actions in the global water system and how it propagates to affect natural processes. Human induced climate change through elevated greenhouse gases emissions can also have a cascading effect on both the physical and the human systems [27]. For example, studies suggest that climate change is responsible for elevated temperatures, more extreme weather, elevated CO<sub>2</sub> fertilization, shifts in rainfall and runoff patterns, and ultimately changes on yield. Those changes can impose many important consequences to the human system. For example, depending on the prevailing climate change scenario, there will be different implications to human land, water, energy, and food choices. Those choices are likely to change the global map of water demand and scarcity, and consequently feedback to affect the water cycle.

Humans can influence the global water system through other means as well, such as: population growth, income growth, dietary changes, increasing food and energy demands, technological change,



**Figure 2:** Water as a central theme that is linked to other natural-human systems.

and mitigation and adaptation measures. Those variables are also influenced by institutional regulations and policy measures such as water price, water transfers, climate mitigation targets, subsidies, importation and exportation dynamics, technology investments and technological advancement, carbon sequestration and bioenergy exploitation targets, restorations and afforestation efforts, and water conservation measures. Understanding the implication of all the before mentioned factors on the global water system and the integrated water cycle is complex and requires a detailed understanding of the interconnections and the ability to model their interactions in a unified and consistent modeling framework. Some linkages are better understood than others. The institutional regulations and the economic forces shaping the human decision making process in the context of the global water system are not fully understood and there is a keen need to develop the research tools to model those dynamics.

## Integrated Assessment Models

To successfully tackle the water scarcity problem or more specifically the irrigation problem, it is essential to bridge the science and management of water resources across scales, sectors, and policies, and study water in a holistic approach. One potential avenue to facilitate this class of research is to model the global water system within a global integrated assessment modeling framework, which captures the feedbacks and inter-linkages between water demands and supplies and other sectors, such as, the economy (socioeconomics), energy, agricultural, land use, and climate sectors, and facilitates a platform to employ the rigor of scientific knowledge and intuition to understand the consequences of policies on the system as a whole. For example, food export/import policies, food, land, energy, and water subsidies, climate change mitigation policies are institutional measures designed to meet certain goals but their consequences are likely to propagate and influence the water scarcity situation elsewhere. Thus, understanding those inter-linkages will equip the research community with the research tools to investigate system inter-dependencies, tradeoffs and synergies, positive and negative feedbacks, and threshold behaviors, which are important to devise more sustainable policies.

## Conclusions

To develop a research track on global irrigation demand and the use of future water resources to help feed the world, we need to adopt a holistic approach to understand inter-dependencies and the main drivers of the global water system and unravel positive (reinforcing) and negative (balancing) feedback loops that can lead to cascading consequences. Thus, there needs to be more research dedicated to 1) the modeling of the agricultural and water systems as components

within the context of an integrated human-geophysical Earth system framework, 2) the understanding of the linkages between the physical processes and the human system, and to integrate them in an economic framework to capture the dynamics of market price, and institutional regulations. The Journal of Irrigation & Drainage Systems Engineering encourages this line of research that studies irrigation and the role of drainage system dynamics in the context of a broader framework that includes both human and other physical processes.

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