SECOND WORLD IRRIGATION FORUM

http://www.worldirrigationforum.net

06-08 November 2016, Chiang Mai, Thailand

Background Paper / Document d'information

Sub-Theme / Thème de stratégie 1

Key Issues of Irrigation and Drainage in Balancing Water, Food, Energy and Ecology / Questions fondamentales d'irrigation et de drainage pour équilibrer l'eau, la nourriture, l'énergie et l'écologie

Dr. Reza Ardakanian (UNU-FLORES)

Dr. Tamara Avellán (UNU-FLORES)

Vice President Hon. Dr Hafied A. Gany (Indonesia)

Vice President Hon. Dr. Willem Vlotman (Australia)

Dr. Sylvain Perret (Chairman, WG-ENV, France)

Vice President Hon. Dr. Ragab Ragab (UK)

Ms. Hayati binti Zainal (ICID Young Professional, Malaysia)

Dr. Sangjun Im (Seoul National University, Korea)

ICID•CIID

International Commission on Irrigation and Drainage

48 Nyaya Marg, Chanakyapuri, New Delhi - 110021, India

E-mail: icid@icid.org, Website: http://www.icid.org

Background Paper / Document d'information

Key Issues of Irrigation and Drainage in Balancing Water, Food, Energy and Ecology

Questions fondamentales d'irrigation et de drainage pour équilibrer l'eau, la nourriture, l'énergie et l'écologie

ABSTRACT

The great challenge for the coming decades will be to increase food production with fewer resources - water, soil, energy, and biodiversity. The effective and sustainable use of resources for agriculture has become a global priority of vital importance, requiring urgent and immediate solutions in view of intensifying competition. In order to foster sustainable development it is essential to maintain the balance between water, energy, food, and ecosystem services. However, there are a number of issues that the irrigation and drainage sector is facing in terms of (1) safeguarding resource availability and its quality when designing new systems, (2) the operation and maintenance of existing systems and in turn their impact on resources and the environments that hold them, and (3) the stakeholder interaction and participation that lead to the governance of the systems and their underlying resources. The future challenges require unconventional thinking and solutions. Increasing water supply to meet the future demand requires a more efficient water use, use of non-conventional water resources, and water harvesting. Thinking within the water-energy-ecosystem-food nexus framework with water resources at its heart is essential. Sustainability can only be achieved within a complete water chain approach and with full stakeholder involvement from start to end and from farmer to minister. We need to adopt a more integrated holistic approach to understand and sustainably manage resources with the aim to produce more from less “more crop per drop per kilowatt” without hampering natural ecosystem services.

RESUME

Le grand défi des siècles prochains sera l’augmentation de la production alimentaire avec moins de ressources en eau, sol, énergie et biodiversité. L'utilisation efficace et durable des ressources pour l'agriculture est devenue une priorité mondiale d'une importance vitale nécessitant des solutions urgentes et immédiates en vue de l'intensification de la concurrence. Afin de stimuler le développement durable, il est nécessaire de maintenir l'équilibre entre les services de l'eau, l'énergie, la nourriture et les écosystèmes. Cependant, il existe un certain nombre de questions en face du secteur de l'irrigation et du drainage, telles que (1) la protection de la disponibilité des ressources et leur qualité lors de la conception de nouveaux systèmes, (2) l'exploitation et la maintenance des systèmes existants et à son tour, leur impact sur les ressources et les environnements qui les détiennent, et (3) l'interaction des parties prenantes et leur participation menant à la gouvernance des systèmes et leurs ressources critiques. Les défis futurs exigent la pensée et les solutions non conventionnelles. L'augmentation de l'approvisionnement en eau pour répondre à la demande future exige une utilisation plus efficace de l'eau, l'utilisation des ressources en eau non conventionnelles, et la collecte de l'eau. Il est nécessaire de penser dans le cadre de lien entre eau-énergie-écosystème-alimentation, les ressources en eau étant au cœur. La durabilité peut être réalisée par l’adoption d’une approche complète de la chaîne de l'eau et avec la participation totale des parties prenantes du début jusqu’à la fin et de l'agriculteur au ministre. Nous devons adopter une approche holistique plus intégrée pour comprendre et gérer durablement les ressources afin de produire plus avec moins «plus de grains par goutte par kilowatt" sans entraver les services écosystémiques naturels.

1. Introduction

For a few decades already, and under acceleration in the new millennium, the world is facing unprecedented transitions which interact with water management at large and irrigation sector in particular. Some of those transitions are continuous and somewhat foreseeable: demography, urbanization, biodiversity loss and environmental degradation. Other changes are more sudden or difficult to predict: the economic slow-down in most developed and transition countries since 2008, the technology and communication revolution, health crises, conflicts, and massive migrations. All of the above phenomena contribute to deepen poverty and food insecurity in many least–developed areas.

Demography and urbanization especially have indirect yet massive effects on irrigated agriculture: food demand grows and changes towards diversified diets; the emerging middle-class demands healthier, safer, more "ethical" products; energy demand keeps increasing (hence competing with other water uses); even in least developed areas, the young migrate or show low interest in agriculture, resulting in the rise of youth unemployment issues.

Global water demand is largely influenced by population growth, urbanization, food and energy security policies, and macro-economic processes such as trade globalization and changing consumption patterns. The global water demand is projected to increase sharply by 55% in 2050 (WWAP 2015).

Agriculture accounts for 70 percent of total global freshwater withdrawals, which is as high as 90% in many regions of the developing world, making the agricultural sector the largest water consumer (FAO 2015) (

Figure 1). Irrigation is of crucial importance to global food security. Irrigated crops account for 40% of global crop production while being cultivated on 20% of the global land surface (FAO 2016). Yet, if 37% of arable land is irrigated in Asia, 14 and 5% of land is irrigated in Latin America and Africa respectively. Times of rapid expansion and massive investments in irrigation are of the past. Indeed, FAO projects that only a small amount of additional land will be equipped for irrigation by 2050. Compared to 48 and 53 million hectares of land equipped with irrigation in East Asia and South Asia respectively during 1961/63 – 2005/07, only 8 and 3 million hectares respectively are projected to be added by 2050 (FAO 2015). Irrigation water use will increasingly compete with natural ecosystems needs, and increasing urban and industrial demands, in a context of increased resource scarcity, and climatic changes.

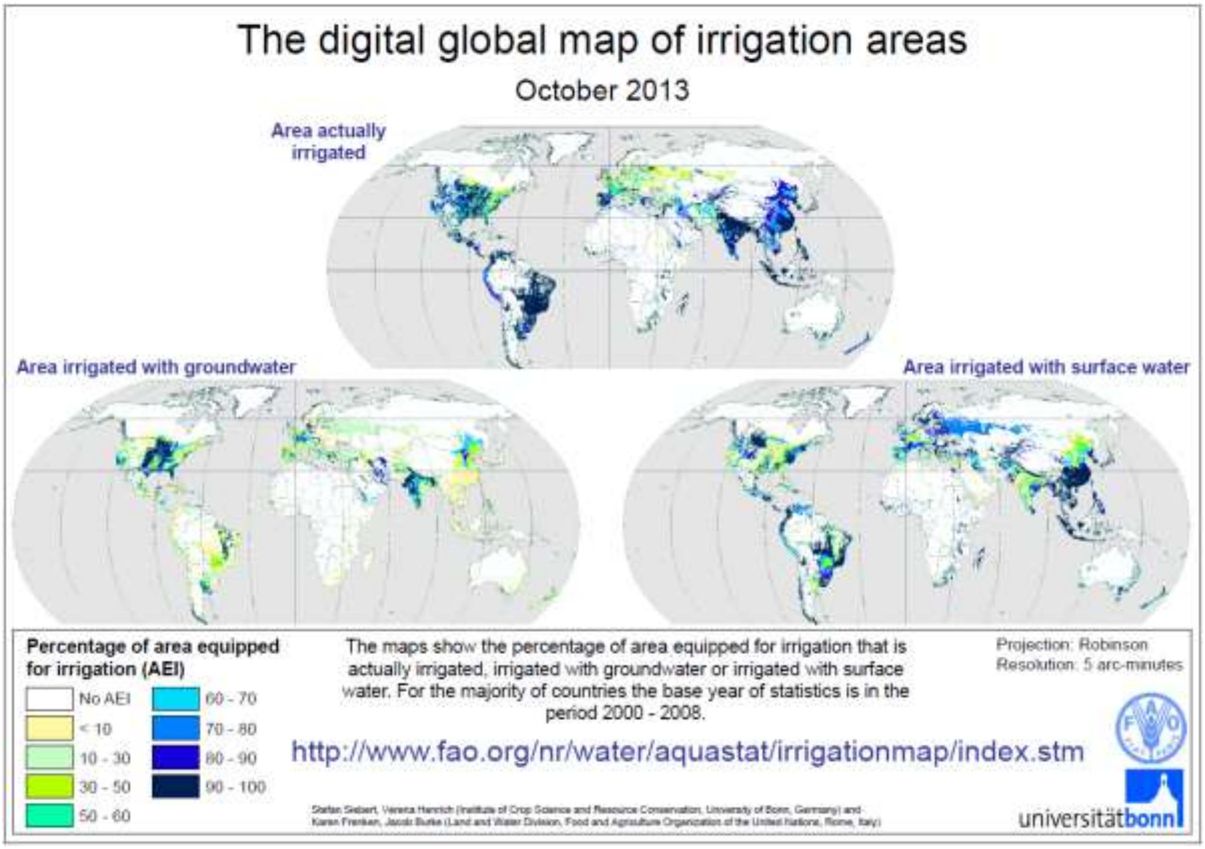

Figure 1. Global distribution of areas irrigated with groundwater and surface waters from "Stefan Siebert, Verena Henrich, Karen Frenken and Jacob Burke (2013). *Global Map of Irrigation Areas version 5.* Rheinische Friedrich-Wilhelms-University, Bonn, Germany / Food and Agriculture Organization of the United Nations, Rome, Italy"

Meanwhile, the food production and supply chain consumes about 30 percent of the total **energy** consumed globally (FAO 2011b). Energy is needed to produce, transport and distribute food as well as to extract, pump, lift, collect, distribute, transport and treat water. Conversely energy production from crops through biofuels and biogas is seen as a mitigation measure against increasing greenhouse gas emissions and as a CO2 neutral means of producing energy. **Competition for soil and water for the production of food versus energy** is an issue and will only increase in the near future as about 60 percent more food will needed to be produced by 2050 and energy demand is projected to grow by nearly one-third between 2013 and 2040 (OECD/IEA, 2015).

As a result total global water withdrawals for food crop irrigation are projected to increase about 10 percent by 2050 (FAO 2011a) and water withdrawals for energy production, which currently account for 15% of the world's total, are expected to increase by 20% by 2035. While the water is used for agricultural production, forestry and fishery, utilization also to produce or transport energy in different forms, and supply chain consumes about 30 percent of total energy consumed globally (FAO, 2014). Biofuels offer an alternative energy source to fossil fuels. Their water-related impacts mainly depend on whether they are produced from rainfed or irrigated feedstock crops (Babel et al., 2012). The water requirements of biofuels produced from irrigated crops can be much larger than for fossil fuel resources and can therefore have important implications for local water availability (Gheewala et al., 2014), whereas rainfed production does not substantially alter the water cycle (WWAP, 2014).

Cities and the industry also claim increasingly more water, energy and land resources, and at the same time, face problems of environmental degradation and in some cases, resources scarcity (FAO, 2014). Cities import significant amounts of food, consumer goods and energy from outside the city, which requires large amounts of water at the point of production, transportation and sale. This **virtual water footprint of cities** greatly exceeds direct water use (Mekonnen & Hoekstra, 2016). Overall, since demand management approaches are to be favoured instead of supply-driven approaches, and that many sectors are concerned, IWRM is to be promoted further, and implemented in more systematic, radical, practical, adapted ways. IWRM now must be included in the Food-Energy-Water (WEF) Nexus, which reflects the imperative need to better understand the trade-offs in water-oriented thinking towards other resource use (Hülsmann & Ardakanian, 2014; Hoff, 2011), in the face of the newly set SDG (e.g. addressing hunger, poverty, food and energy insecurity).

This document provides an overview of the scope of the issues that are to be covered under Sub-theme 1 of the 2nd World Irrigation Forum (WIF2) "*Key issues of irrigation and drainage in balancing water, food, energy and ecology*". Two further sub-themes have been agreed upon: Sub-theme 2 "Management of climatic extremes with focus on floods and droughts" and Sub-theme 3 "Key and smart action to alleviate hunger and poverty through irrigation and drainage".

In this first sub-theme the conference expects to facilitate discussion on various related topics with respect to the following key issues:

1. Balancing the increasing demand of diverse sectors (*food, energy, ecology – would add water supply and sanitation*) against a limited water, land, energy and nutrient supply.
2. Minimizing the negative environmental effects of irrigation, and maximizing the provision of ecosystem services
3. Understanding the role of stakeholders in governing irrigation and drainage matters

Section 2: Issues and options for balancing water, food, energy and ecology in irrigation and drainage

2. Managing increasing resource demands from various sectors

Ambitious plans for large irrigation infrastructures exist, yet they are fraught with uncertainty and risks (climate change, droughts, declining groundwater resources, and salinization) and marked by past experiences of poor management and low productivity in developing countries. Recent analyses show that large, multipurpose dams in West Africa for example are no panacea. Irrigation efficiency and productivity remain low due to poor capacities, planning, land and governance issues. Globally, although resource development and mobilization remain crucial and feasible in few places, opportunities for further massive development seem unlikely in many countries, owing to financial issues. It is unlikely that further significant increases in abstraction of water for irrigation at reasonable costs are plausible without severe environmental or social disturbances in most countries.

As a consequence, supply-driven approaches must definitely leave room for demand management, use efficiency increases, optimized allocation of various resources, capacity development and sound governance. Water resources are limited and per capita water availability is decreasing. Surface irrigation has poor field efficiency. More efficient water use systems such as drip and sprinkler systems are required to replace such traditional systems, where possible. Novel strategies informed by different types of datasets and integrated through numerical models can help save water. In this way, for instance deficit irrigation techniques can be placed in areas where they make the most sense in terms of costs, social acceptance, and ecological usefulness.

2.1 Improving Water Productivity – Smart infrastructure

Modernization and rehabilitation of irrigation systems refers to the improvement of existing irrigation systems that includes planning, cost sharing, institutional arrangements and resulting required operation and maintenance, capacity development, canal control systems and development with respects to automation of such systems; use of internet, mobile communication and remote monitoring; standardization and codes of practices.

The increased efficiencies have come in great part from the improved understanding of the energy physics of water which led to modern evapo-transpiration (ET) theory and ET-based crop irrigation scheduling. Many water conservation techniques were developed in the last half of the 20th century, including drip and micro irrigation, which has spread from hyper-xeric conditions to nearly every climate and rainfall environment where there is a need, for one reason or another, to conserve water.

Use of Information and Communications Technologies (ICTs) for AWM is underway even in remote developing areas of Asia and Africa, with applications on irrigation scheduling, cost recovery, markets or flood hazards. However, high cost and high capacities are required for ICT maintenance. Therefore, application of this new technologies should be based on a sound feasibility study as well as cost-benefit ratio, and appropriate selection of ICT system and also consideration on technical level of personnel as well as installation and maintenance cost. Durable and hardened ICT systems have to be installed (because the systems are operated outdoor), and reliable and error free system require for successful system operation. Similarly, smart systems for the provision of the necessary energy for the pumping and distribution systems have been initiated. Solar powered pumping and distribution systems have been tested in Canada leading to >30% water and energy savings.

2.2 Augmenting water supply – Using non-conventional water resources

Reuse of agricultural drainage water can augment the available water in many countries where fresh water is in short supply. In some cases, the drainage water has low salinity level as it is generated by excessive use of fresh water in surface irrigation (e.g. Egypt and Syria). However, in some other cases, the drainage water is saline. In such case, water is mixed with fresh water before irrigation or used in alternatively with fresh water. Saline/brackish ground water can be used to irrigate salt tolerant crops (e.g. quinoa and amaranth) under a proper management system.

A truly integrated approach is essential to encourage the increased use of poor quality water for irrigation, in order to both minimize drainage disposal problems and maximize the beneficial use of multiple water sources. Agricultural use of non-conventional water is more easily accepted and implemented in water-short areas where irrigation is already practiced. However, skills development, appropriate institutions and strong extension services are required. Participatory bottom up approach is a cornerstone issue governing success and/or failure in any reuse irrigation project. Salt movement is intimately tied to water movement, and therefore salinity management is largely a function of water management in any irrigation system. Sustainability and success of non-conventional water uses depends on sound implementation and management.

Globally over 80 % of **wastewater** worldwide is not collected or treated, and urban settlements are the main source of pollution (WWAP 2012). Urban areas are both producers and consumers of large amounts of wastewater. Untreated or partially treated wastewater is increasingly being used for irrigation and will become the sole water source for many farmers in Sub-Saharan Africa (WHO, 2006). Nutrients and organic matter from wastewater can improve soil fertility and reduce the need to apply artificial fertilizers. Farmers can therefore benefit through increased productivity and yields and faster growing cycles, while decreasing their needs for artificial fertilizers and additional water sources (UNEP, UN-HABITAT, GRID-Arendal, 2010) as long as they adhere to a set of guiding principles to protect themselves and their families from waste water irrigation induced health risks (Figure 2). In areas with receding groundwater levels, injection of reclaimed wastewater into these aquifers can also be an alternative to the direct irrigation on fields.

Over-exploitation of groundwater in coastal areas (in which half of the world's population lives) not only causes drops in levels but also leads to the deterioration of water quality due to salt water intrusion (Van Weert et al. 2009). Depleted groundwater storage for agricultural purposes results in increased costs for accessing the receding groundwater. It also produces significant negative impacts on the environment and functioning of the groundwater system, degrades the water quality and in the long term, exhausts the aquifer. Managed aquifer recharge (MAR) as a means to boost their natural supply is becoming increasingly important in groundwater management (Alley at al., 2002) and started to be a matter of interest even for European Union legislators.

De-salinization of sea water increases the total amount of available water. However, the de-salinization technology is still questionable with respect to its economic feasibility for agriculture. De-salinization industry, however, creates several adverse environmental impacts which require proper mitigation. These include discharge to the near-shore marine environment of reject hot brine, residual chlorine, trace metals, volatile liquid hydrocarbons, anti-foaming and anti-scaling agents.

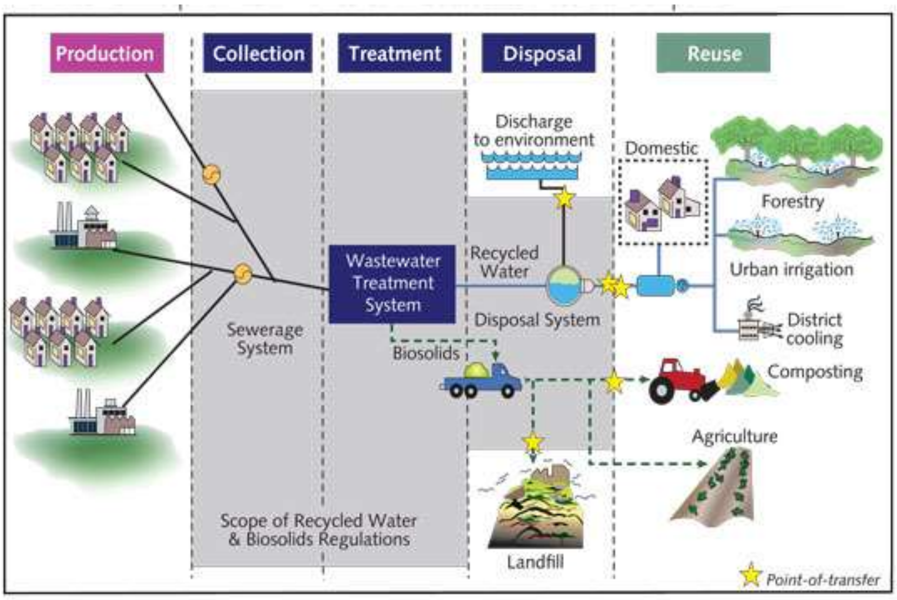

Figure 2. Schematic representation of the different aspects of wastewater re-use, including irrigation and the use of bio-solids as soil conditioner (from: Masdar Institute of Science and Technology, Abu Dhabi, UAE)

2.3 Integrated modelling

Global models can already tell us where irrigation can be found (Siebert et al., 2013) and how global food markets influence the production of crops (Mauser et al. 2015). Dam managers calculate the energy production with models that take weather, energy prices and demand into account. Virtual water models can show us how water used for the production of crops is exported in the form of produce to other countries (Makennen and Hoekstra, 2016). Recent advances in life cycle assessment in irrigation allow for complete evaluation of environmental impacts and resources use (Payen et al. 2015). Models of different disciplines are increasingly interconnected (e.g. hydro-economic models, Divakar et al., 2013; techno-economic models, Ullah et al. 2015; techno-environmental models, Babel et al. 2012; agro-climatic models, Avellan et al. 2012) and contribute to quantifying IWRM-inspired measures, policies and alternative solutions. Advances in meteorological short- and long-term modelling may aid in adjusting the placement of infrastructure at climate-proof locations but also in the daily weather smart decision-systems of when, where and how much to irrigate to maximize yield and minimize water and energy losses (WMO, 2014). By linking models that describe water supply and water demand from the agricultural, the ecological, the energy production and the municipal perspective we can gain insight into trade-offs, needs and overlaps, and can try to minimize losses by identifying synergies. Areas where irrigation will make sustainable sense can then be identified more clearly, whereas those areas where water and energy demand will exceed the supply in the long run can be marked and alternative solutions sought (re-use of wastewater, de-salinization while using solar energy, etc.). Investments can then become much more targeted.

Questions on the increase of resource use efficiency:

- How can the use of smart infrastructure help in minimizing the impacts on the environment and affected population while maximizing the yields? What management and governance strategies need to be established to support this?
- How can the use of non-conventional water sources aid in conserving fresh-water sources? What impacts do these have on other resources such as soil and energy or on human health? What measures need to be put in place to safeguard environmental and human well-being?
- How can the integration of different modelling aspects inform decision-making at various levels, from global policies of where to irrigate, to local decisions of when to irrigate? Which mechanisms need to be in place to allow for this?

3. Minimizing the negative environmental effects of irrigation, and maximizing its positive effects and the provision of ecosystem services

Irrigation systems and related infrastructure closely interact with all three environmental compartments (water, soil, air). Such interactions refer to direct environmental impacts (e.g. emissions, pollutions, salinization, sodization). They also interact with riparian ecosystem and regional areas (e.g. hosting or threatening diverse biome and species, mitigating or amplifying floods, recycling nutrients) and offer a number of services to local community and societies at large (e.g. micro climatic regulation, biomass production, specific products). Those interactions refer to ecosystem services.

3.1 Understanding the negative impacts

In some cases, **human-built infrastructure** can cause biodiversity loss and degradation of ecosystem services, yet it often directly depends on ecosystem services to maintain performance (WWAP 2015). Multipurpose dams can prevent nutrients and sediments from reaching oceans and alter the water cycle by increasing water ‘residence time’, altering the flow of matter, fish and energy in rivers which changes the conditions of these ecosystems entirely (Vörösmarty et al., 2010 in WWAP 2015). This can have a direct and negative impact on other sectors such as downstream wetlands, fisheries and agriculture. At the same time, dams only work effectively when supported by healthy ecosystems in order to avoid clogging, siltation, pollution, floods. In other cases, irrigated agriculture has, to some extent, also been proven to result in positive environmental effects. In particular, in arid to semi-arid areas field borders, canals, ditches, and reservoirs provide habitat expansion for a variety of wildlife (Jansen, M.E., 1997; Rhoades, 1997, in Sokja R.E., 2002).

Loss of productive capacity caused by soil salinization, sodification, and water logging, as well as runoff contamination, riparian habitat impairment, and species losses, high methane emissions by paddy fields, are often cited by critics of irrigation as evidence of fundamental drawbacks to irrigated agriculture. Surveys have indicated that of the existing irrigated lands, some 40-50 million ha show measurable degradation from water logging, salinization, and sodification (Rhoades, J.D., 1997 and Ghassemi, F.1995 in Sokja R.E., 2002). Erosion and sedimentation of reservoirs and channels cause failures of ancient irrigation schemes and limit the life expectancy of some modern dams to only a few decades as well (Reisner, M., 1986; Fukuda 1976 in Sokja RE, 2002). These problems demonstrate the need for intensified research and conservation, as well as improved dissemination and use of mitigating technologies. To support such actions, a wide range of methodologies are now available for assessing environmental impacts and quantifying ecosystem services in irrigation.

3.2 Maximizing positive effects

Ecosystem services of irrigation and drainage systems: Irrigation and drainage systems have long provided a number of ecosystem services that serve societies at large, in many dimensions. Those services are increasingly recognized and assessed (ICID, 2015). First, such services may be of supporting nature since irrigation systems host wildlife (birds, fish, biodiversity), and recycle nutrients. Second, provisioning services include food production (crops, fish, livestock), water supply to communities, fodder, fuelwood, medicinal resources. Third, irrigation systems regulate local climate, mitigate floods, and help purify water (regulating services). Fourth and finally, irrigation landscapes have socio-cultural and recreational values to many, including urbanites. These services have local, regional and global scope (e.g. when certain irrigation systems host endangered species or interact with climate). At the local level, the multi-functionality of irrigation systems is worth-mentioning, as they provide livelihoods, domestic and logistical services to communities, besides food production (e.g. boating and transport, domestic water supply, livestock watering, fishing, raw material collection, etc.). In South Africa, multi-functionality of small-scale gravity irrigation systems has been recognized and led to renewed, more inclusive and sustainable governance by local community, and ultimately to more efficient water uses (Perret, 2002).

Payment for ecosystem services (PES): Ecosystem valuation can be broadly described as what users would be willing to pay directly for the services, or what it would cost to replace the same services with built infrastructure (Boelee, 2011). Such valuations can be incorporated into national income accounts, or used to clarify comparative options in land use planning, payment for ecosystem services and common asset trusts (Costanza et al., 2014). Valuations help in building the case for a green economy in the post-2015 development agenda. New contractual relationships between societies and irrigators may lead to payment for environmental services all the same. Measures are already put in place in Thailand to compensate rice farmers for accepting additional water in their paddy fields for flood mitigation.

The Water-Food-Energy (WEF) Nexus: The future challenges require unconventional thinking and solutions. Increasing pressures on environmental resources may undermine the resilience of ecosystems, limit economic growth and threaten goals related to human well-being including water, food and energy security (Hoff, 2011; Ringler and others, 2013). The WEF nexus links multiple resource-use practices and focuses on the efficiency of the system rather than on the productivity of isolated sectors (Hoff, 2011). Thinking within the water-energy-food nexus framework with the water resources at its heart is essential (Vlotman and Ballard 2014). We need to adopt a more integrated holistic approach to manage the water resources with the aim to produce more from less “more crop per drop per kilowatt” and involve stakeholders from farmer to minister.

Questions on understanding the effects of irrigation and drainage systems on the environment:

- How can the negative impacts be assessed objectively and measures be taken to mitigate or avoid these? What systems are needed for this?
- How can ecosystem services and multi-functionality of irrigation and drainages systems be assessed objectively? How can systems for payment for ecosystem services be implemented? Which mechanisms need to be in place to allow for this?

4. The role of stakeholders in governing irrigation

The role of stakeholders in governing irrigation, or in governing water management systems that includes drainage needed for water logging and salinity control is complex and will be different in each country. However it is not so much that we need to describe the role of stakeholders in water management systems, but more importantly we need to find out what they consider that their role is, or should be, and should not be.

Examples of the complexity of the institutional arrangements of irrigation and drainage management were formulated when modernization of systems was considered. For instance the modernization of irrigation and drainage is a highly interdisciplinary matter with institutional and organizational aspects that require a number of prerequisites including: sustainable operation and maintenance of irrigation and drainage systems; certainties on water regulatory authorities, land priority questions, water rights and financing of operation and maintenance; certainty of roles responsibilities and requirement for sustainable Water Users Association (WUA); appropriate water accounting and auditing at various levels of irrigation and drainage systems; effective irrigation/drainage management transfers (IDMT), including legislation and institutional requirements; effective Public Private Partnerships (PPP) in irrigation and drainage implementation. In order to start the process of stakeholder involvement the following should be considered:

- Carry-out an assessment of existing institutional arrangements with all stakeholders
- Ask stakeholders what needs to be established in order to become more involved (gap analysis)
- Identify the challenge & demand of the stakeholders
- Identify the need for continuity of participation and support capacity building
- Identify the need for political commitment, innovation and advocacy for involvement …..

4.1 Active stakeholder involvement in policy and planning

Engagement with policy and planning activities requires in most cases first a top down approach where by the powers in place show a willingness to involve their target population in decision making. Secondly the population also needs to show an interest in being involved in policy and planning. For this to happen the state of development of the population needs to be assessed. The population includes farmers, the irrigators, the tertiary water management organisation such as Water User Associations, and all levels of government up to the minister. From this a gap analysis can be performed and a development plan initiated.

In other words as mentioned above to achieve active stakeholder involvement a planned process will need to be executed that involves:

- Assessment of state of institutional development at all levels;
- Needs assessment;
- Plan development reflecting:
    - Who you will engage with;
    - Why you will engage them;
    - Why they will want to engage with you;
    - How you will engage them;
    - When you will engage them, and how you will monitor and evaluate your engagement approach?

4.2 Incentives

The key for involvement of stakeholders in irrigation operation, management and maintenance (OMM) is the central question "what is in it for me?" Incentives do not necessarily need to be economic in nature. They can be improvement in lifestyle, improvements in physical environment and in general improvement in social well-being. Hence, in order to involve stakeholders in irrigation and drainage management it is essential to find out first in what type of environment they operate and what their needs are, not just involvement in irrigation but considering all aspects of being a successful irrigator. All stakeholders from farmer to system operator to top level regional and national government staff need to have a clear understanding of the potential benefits of being involved and they need assurance that those benefits are sustainable. Stakeholder engagement is a planned process with the specific purpose of working across organisations, stakeholders and communities to shape the decisions and actions of the members of the community, the stakeholders and the organisations involved. Typical questions to be asked in planning for the involvement of water managers at all levels, including foremost farmers, are:

- What issues do you face in being successful in your (water operation, management and maintenance) enterprise/organisation?
- Do you consider ecological aspects in your day to day operations?

4.3 Capacity Development

Capacity development in water management is teaching and training stakeholders in matters they should know to be able to distribute, use and dispose of water more effectively and efficiently at the lowest cost and least environmental impact. In fact it is not an environmental impact; rather knowledge of the ecologies upstream of-, at location of- and downstream of water management systems is essential in a water-energy-food nexus approach to food production that espouses the sustainability principle.

Triple bottom line elements should be considered; i.e. environment, people and economics. Precursor to capacity development should be a needs assessment; what arrangements are already in place and which are not.

There are at least five integrated aspects that must be examined to assess the institutional arrangements of Irrigation and Drainage management. These are among others: Availability of “Human Resources” for conducting effective function of irrigation and drainage infrastructures; Effective “Institution & Organization” to secure interagency working relationship; Availability of “appropriate technology” for sustainable O&M irrigation and drainage schemes; Sustainable “budget allocation” for conducting effective O&M; Effective “Regulatory Instrument” and Subsequent Enforcement.
Questions to be raised include:

- What is the level of current training and knowledge of the stakeholders
- What capacity development tools are currently available
- What is the awareness of stakeholders of existing and new know-how in the field of water management;

Questions on understanding the role of stakeholders:

- Who are the stakeholders and what interests do they have? What level of capacity do they currently have; what level is needed for their day-to-day work?
- What mechanisms need to be in place to be able to reach the various stakeholders? What systems are needed to reach them, to teach them, to provide them with incentives to safeguard the environment and society at large?

5. Conclusions and future outlook

The great challenge for the coming decades will be to increase food production with less water, particularly in countries with limited water and land resources. The effective and sustainable use of water for agriculture has become a global priority of vital importance, requiring urgent and immediate solutions in view of intensifying competition. However, it is critical that the ecology upstream of -, within- and downstream of an irrigation and drainage management system is considered at the same time. Sustainability can only be achieved with a complete water chain approach and with full stakeholder involvement from start to end and from farmer to minister.

Future increases in irrigated area will likely come mainly from the development of supplemental irrigation in humid rain fed areas, from improvements in (1) water use efficiencies associated with the utilization of existing irrigation resources in a smart way, (2) in the use of non-conventional water sources such as the reuse of municipal, industrial and agricultural wastewaters, and (3) the integration of modelling across different disciplines to better plan irrigation schemes at various spatio-temporal scales.

Balancing irrigation needs against environmental needs can be challenging. A paradigm shift towards the multi-functionality of irrigation systems can help in overcoming the negative impacts of poorly managed schemes. Approaches that view irrigation and drainage structures as suppliers of ecosystem services and require payment for them can be embedded in the Water-Energy-Food Nexus, thus opening discussion about resources beyond just water. At the same time, strategies to avoid negative impacts such as over-abstraction of fresh water or salinization of soils need to be stepped up, and mechanisms for discontinuing existing mal-functioning systems be implemented.

Stakeholder involvement and capacity development rather than infrastructure should be the central focus of resource management. Considerable attention has been paid to describing who, what, where and how of stakeholder engagement. Capacity development is an important aspect of stakeholder engagement but is only one element in a much more complex process of stakeholder engagement. New in this engagement is the broadened scope when considering the water-energy-food nexus in relation with the ecologies upstream of water management system, within the system and downstream of the system. It is not just the environmental impact but it is the integration of ecology, and consideration of the ecological water needs, both in terms of quantity and quality, in the resource management chain.

The irrigation and drainage community has come a long way from designing large infrastructure projects all the way to valuing schemes that integrate into the landscape, provide eco-system services and are considered part of the cultural heritage of civilization. Nonetheless, many questions about the integration of different resource needs and balancing the trade-offs remain open. Under this sub-theme we expect to obtain some answers to the questions raised throughout the text.

6. References

Alley, W. M.; Healy, R.W.; LaBaugh, J. W.; Reilly, T. E.; 2002. Flow and Storage in Groundwater Systems. *Science* 2002: Vol. 296, Issue 5575, pp. 1985-1990 DOI: 10.1126/science.1067123

Avellan, T., Zabel, F.; Mauser, W.; 2012. 'The Influence of Input Data Quality in Determining Areas Suitable for Crop Growth at the Global Scale – a Comparative Analysis of Two Soil and Climate Datasets'. *Soil Use and Management* 28 (2): 249–65. doi:10.1111/j.1475-2743.2012.00400.x.

Babel, M.S.; Shrestha, B.; Perret, S.R.; 2011. Hydrological impact of biofuel production: A case study of the Khlong Phlo Watershed in Thailand, *Agricultural Water Management*, Volume 101, Issue 1, Pages 8-26, ISSN 0378-3774, http://dx.doi.org/10.1016/j.agwat.2011.08.019.

Boelee, E.; (ed) 2011. Ecosystems for water and food security. Nairobi: United Nations Environment Programme; Colombo: International Water Management Institute.

Costanza, R.; de Groot, R.; Sutton, P.; van der Ploeg, S.; Anderson, S.; Kubiszewski, I.; Farber, S.; Turner, K.; 2014. Changes in the global value of ecosystem services, *Global Environmental Change*, Volume 26, ISSN 0959-3780, http://dx.doi.org/10.1016/j.gloenvcha.2014.04.002.

Divakar, L.; Babel, M.S.; Perret, S.R.; Das Gupta, A.; 2011. Optimal allocation of bulk water supplies to competing use sectors based on economic criterion – An application to the Chao Phraya River Basin, Thailand, *Journal of Hydrology*, Volume 401, Issues 1–2, ISSN 0022-1694, http://dx.doi.org/10.1016/j.jhydrol.2011.02.003.

FAO. 2011a. The state of the world's land and water resources for food and agriculture (SOLAW) – Managing systems at risk. Rome: Food and Agriculture Organization of the United Nations and London, Earthscan.

FAO. 2011b. Energy-smart food for people and climate. Issue Paper. Rome: Food and Agriculture Organization of the United Nations.

FAO. 2011c. Climate change, water and food security. FAO Water Reports No. 36. Rome: Food and Agriculture Organization of the United Nations.

FAO, 2014. Food and Agriculture Organization of the United Nations: The Water-Energy-Food Nexus; A new approach in support of food security and sustainable agriculture*,* Rome, 2014.

FAO, IFAD and WFP. 2015. The State of Food Insecurity in the World 2015. Meeting the 2015 international hunger targets: taking stock of uneven progress*.* Rome, FAO.

FAO. 2016. AQUASTAT website. Food and Agriculture Organization of the United Nations (FAO). Website accessed on [07 April 2016]

Gheewala, S. H.; Silalertruksa, T.; Nilsalab, P.; Mungkung, R.; Perret, S. R.; Chaiyawannakarn, N.. 2014. "Water Footprint and Impact of Water Consumption for Food, Feed, Fuel Crops Production in Thailand." *Water* 6, no. 6: 1698-1718.

Hoff, H., 2011. Understanding the Nexus. Background Paper for the Bonn 2011 Conference: The Water, Energy and Food Security Nexus. Stockholm, Sweden: Stockholm Environment Institute (SEI).

Hülsmann, S.; Ardakanian, R., eds. 2014. White Book on Advancing a Nexus Approach to the Sustainable Management of Water, Soil and Waste. Dresden: UNU-FLORES

ICID, International Workshop on 'Ecosystem Services and Multi-Functionality of Irrigation and Drainage Systems', October 13th 2015, Montpellier

Mauser, W., Klepper G., Zabel F., Delzeit R., Hank T., Putzenlechner B., and Calzadilla A.; 2015. 'Global Biomass Production Potentials Exceed Expected Future Demand without the Need for Cropland Expansion'. *Nat Commun* 6 (November). http://dx.doi.org/10.1038/ncomms9946.

Mekonnen, M. M., Hoekstra A. Y.. 2016. 'Four Billion People Facing Severe Water Scarcity'. *Science Advances* 2 (2). doi:10.1126/sciadv.1500323.

OECD/IEA, 2015. World Energy Outlook, IEA Publishing.

Payen, S.; Basset-Mens, C.; Perret, S.; 2015. LCA of local and imported tomato: an energy and water trade-off, *Journal of Cleaner Production*, Volume 87, ISSN 0959-6526, http://dx.doi.org/10.1016/j.jclepro.2014.10.007.

Perret, S.; 2002. Water policies and smallholding irrigation schemes in South Africa: a history and new institutional challenges, *Water Policy*, Volume 4, Issue 3, ISSN 1366-7017, http://dx.doi.org/10.1016/S1366-7017(02)00031-4.

Ringler, C., Bhaduri A., and Lawford R.; 2013. The nexus across water, energy, land and food (WELF): Potential for improved resource use efficiency? *Current Opinion in Environmental Sustainability*, vol. 5, pp. 617–624.

Siebert, S.; Henrich, V.; Frenken, K.; Burke, J.; 2013. Global Map of Irrigation Areas version 5. Rheinische Friedrich-Wilhelms-University, Bonn, Germany / Food and Agriculture Organization of the United Nations, Rome, Italy

Sojka, R.E.; Bjorneberg, D.L.; 2002. J.A. Irrigation: an Historical Perspective Soil Scientist, Irrigation Engineer, and Soil Microbiologist, Kimberly, Idaho, U.S.A. *Encyclopaedia of Soil Science* 745 Marcel Dekker, Inc.

Ullah, A.; Perret, S.; Gheewala, S.; Soni, P; 2015. Eco-efficiency of cotton-cropping systems in Pakistan: an integrated approach of life cycle assessment and data envelopment analysis, *Journal of Cleaner Production*, ISSN 0959-6526, http://dx.doi.org/10.1016/j.jclepro.2015.10.112.

UNEP, UN-HABITAT, GRID-Arendal. 2010. Sick Water? The central role of wastewater management in sustainable development. A Rapid Response Assessment.

Van Weert, F. J. van der Gun and Reckman, J. (2009). Global Overview of Saline Groundwater Occurrence and Genesis. Utrecht/Paris, IGRAC/UNESCO. http://www.un-igrac.org/dynamics/modules/SFIL0100/view.php?fil_Id=135

Vlotman, W.F. and Ballard, C. 2014. Water, Food and Energy Supply Chains for a Green Economy. *Irrig. and Drain.* 63: 232–240 (2014). DOI: 10.1002/ird.1835.

WHO. 2006. Guidelines for the safe use of wastewater, excreta and greywater. World Health Organization

World Meteorological Organization (WMO), 2014. Implementation Plan of the Global Framework for Climate Services

WWAP (United Nations World Water Assessment Programme). 2012. The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk. Paris, UNESCO

WWAP (United Nations World Water Assessment Programme). 2014. The United Nations World Water Development Report 2014: Water and Energy. Paris, UNESCO

WWAP (United Nations World Water Assessment Programme). 2015. The United Nations World Water Development Report 2015: Water for a Sustainable World. Paris, UNESCO.

❖❖❖❖❖