INTEGRATED WATER RESOURCES MANAGEMENT: EVOLUTION OF CONCEPT, PRINCIPLES AND APPROACHES

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INTEGRATED WATER RESOURCES MANAGEMENT: EVOLUTION OF CONCEPT, PRINCIPLES AND APPROACHES

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Abstract

The present document addresses the evolution of concept, basic principles and approaches in integrated water management with a particular attention of its implementation in agricultural sector. Water management plays an important role in society since it intersects different technical, economic, technological, environmental and societal sectors, and policy issues. The difficulties of properly approaching this topic are increasing since management solutions should be seen in the context of continuously altering spatial-temporal scenarios generated by climate variability and change, population growth and migration, land use transformation, uncontrolled pollution of resources and socio-economic concerns. Accordingly, the integrated water management concept embraces, in a comprehensive way, the numerous technical, socio-economic and environmental factors, institutional settings and stakeholders' interests interplaying throughout the scales in the water management process.

The concept of integrated water resources management has been evaluating during the last three decades with the aim to consider new challenges related to climate change, land/water/energy/food insecurity and a common need to achieve the sustainable development goals. The water management in agriculture should be seen in the same perspective of integration and consider different interests of stakeholders across administrative, hydrological and management scales. In this context, it is fundamental the resolution of conflicts between sectors with the aim to balance the "demand vs. availability" equation and the "agronomy-engineering" symbiosis and to optimize the use of resources and performance of irrigation networks. Consequently, the concept of nexus is introduced as a core strategy to deal with the global challenges. The adoption of the eco-efficiency approach as a modern management concept and indicator of sustainable water use represents one of win-win solutions.

Keywords: Water management, irrigation, eco-efficiency, sustainability.

INTRODUCTION

Water cycle has clear and well-defined hydrological boundaries and units interplaying harmoniously according to the hydrological laws when they are not affected by external factors. Nevertheless, water management scales differ among sectors and stakeholders, each having specific and frequently contrasting interest. In the last decades, the conflicts among the sectors and among the states are increasing due increased variability of hydrological parameters, pollution of resources and changed water demand by different sectors. It is particularly relevant in water-scarce regions where water availability and its efficient use are primary drivers of socio-economic development and environmental protection.

The agricultural sector is the principal consumer of freshwater resources especially in the water-scarce regions. On the global scale, around 70% of freshwater withdrawal is used for crop cultivation. This irrigation water is applied over only 20% of agricultural land. Nevertheless, it produces more than 40% of the world food requirements (Grafton et al., 2017). Thus, an efficient use of water in agriculture is of primary interest to all.

The concept of integrated water management has been evaluating continuously since the last decade of 20th Century. Water is recognised as a fundamental component of the development strategies at global and local scale and key-source for many inter—related issues as they are food security, environmental degradation, ecosystem functioning, energy production etc. Henceforth, the integrated water management intersects different technical, economic, technological, environmental and societal sectors, and policy issues. Consequently, the management solutions should be seen in the context of continuously altering spatial-temporal scenarios and needs to face numerous disputes at different scales and with various stakeholders' groups (Todorovic, 2018).

EVOLUTION OF CONCEPT, PRINCIPLES AND APPROACHES

The overall concept and strategies for integrated water management are inherently linked with the sustainable development approach that seeks to meet the needs and aspirations of the present generation without compromising the ability to meet those of the future (WCED, 1987). Then, the integrated water resources management (IWRM) concept had been endorsed as a globally recognized concept for sustainable water management at the "United Nation Conference on Environment and Development" (UNCED) held in 1992, in Rio de Janeiro, Brazil.

The Rio conference affirmed the perception of water as an integral part of the ecosystem, a natural resource and a social and economic good, whose quantity and quality determine the nature of its utilization (UNCED, 1992). Hence, IWRM is defined as a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (GWP, 2000).

IWRM invokes the adoption of a holistic and multi-stakeholders driven approach built on the common basic principles and objectives (UNCED, 1992):

- To promote a dynamic, interactive, iterative and multi-sectoral approach to water resources management,
- To identify/protect all potential sources of freshwater supply,
- To monitor/evaluate water withdrawal/pollution by potential users,
- To integrate technological, socio-economic, environmental and human health considerations,

- To plan for the sustainable and rational utilization, protection, conservation and management of water resources based on community needs and priorities within the framework of national economic development policy,
- To design, implement and evaluate projects and programmes that are both economically efficient and socially appropriate,
- To promote full public participation, including that of women, youth, indigenous people and local communities in water management policy and decision-making,
- To identify/strengthen/develop the appropriate institutional, legal and financial mechanisms,
- To ensure that water policy and its implementation are a catalyst for sustainable social progress and economic growth.

The concept of IWRM has been reaffirmed and reviewed during the last 25 years on several occasions. The International Conference on Freshwater, held in Bonn, Germany, in 2001, focused on the guiding principles for practical implementation of IWRM and identified the priority actions in the fields of governance, mobilization of economic resources, capacity building and knowledge sharing. The 2002 World Summit on Sustainable Development (WSSD), held in Johannesburg, adopted the Bonn recommendations and extended the concept of IWRM:

- To embrace the impact of climate change on water resources, and to adopt adaptation and mitigation measures and initiatives in water management plans,
- To recognize the priority of the water-food security issue in water development plans especially in the less developed areas/countries,
- To promote the public-private partnership initiatives for funding and implementation of water management plans,
- To consider the link between water and energy sector in water development and management.

The Rio+20 Conference, in 2012, confirmed the need for full and permanent consideration of climate change adaptation and mitigation including the extreme weather events (i.e. floods and droughts), endorsed the relevance of water-energy-food security nexus in sustainable water management and promoted the concept of green economy as an opportunity to implement innovative ("clean") technological solutions that achieve management objectives while consuming less resources and reducing the negative impact on environment (EC, 2014a).

The implementation and functioning of IWRM requires the creation of a proper three-dimensional mechanism/framework (Fig. 1) at the national level that includes: a) Enabling environment (policies, legislation, financing structures), b) Institutional arrangements (regulatory, implementation, assessment, service provider and capacity building roles) and c) Management tools (water supply/demand monitoring, multi-objective assessment, Decision Support Systems and Shared Vision Planning, communication tools, efficiency evaluation, economic instruments).

The purpose is to build a set of comprehensive and complementary goals/rules/institutions/instruments for all stakeholders in the IWRM process (from the national down to river basin and watershed/community/farm level) to achieve sustainable water management goals while balancing social, economic and environmental needs (GWP, 2017). In this context, water governance tends to be decentralized and the institutional decision-making should be based on the principles of subsidiarity scaling down management actions to the lowest appropriate level.

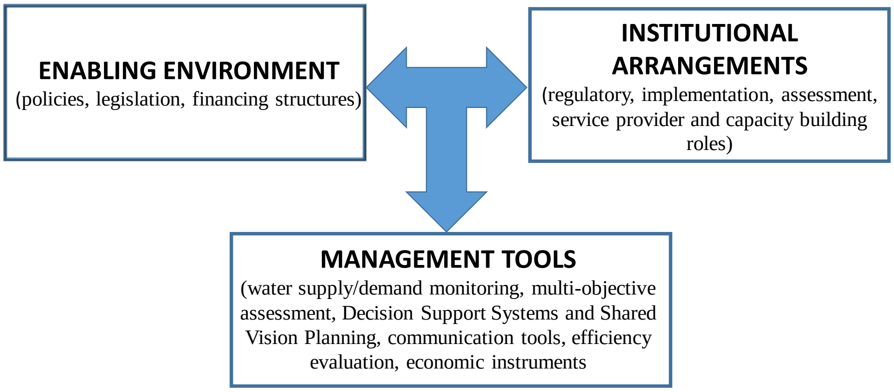

Figure 1. Three-dimensional mechanism/framework for implementation and functioning of IWRM

The IWRM comprises systematic monitoring and coordinated administration of water availability within a hydrological/administrative unit, water storage in physical structures (reservoirs), and water delivery, distribution and use by different sectors (Fig. 2).

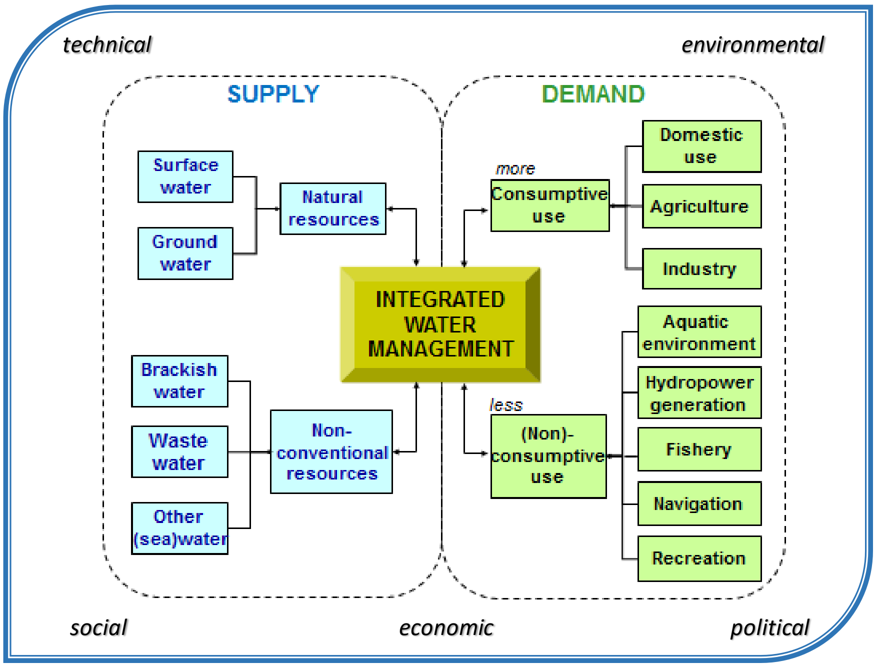

Figure 2. Integrated water management concept: a balance between water demand and supply equations (Todorovic, 2018)

The overall objective of water management is to balance water demand with water supply over time within a specific management unit, and among them whenever the transfer of resources is possible. In many water-scarce regions, this means the consideration of non-conventional water resources (treated wastewater, brackish water, etc.) and other marginal water use sectors like fishery, navigation and recreation. In this context, it is important to address properly the water quality issues and to distinguish between more and less water consumptive sectors.

AGRICULTURAL WATER MANAGEMENT

In the years to come, the demand for water in agriculture will continue to raise to meet the growth in food needs for an ever-increasing world population. Moreover, the impact of climate change and variability on agricultural production will enhance, which will trigger additional water needs in agricultural sector and possible extension of irrigated land. However, freshwater resources are limited especially in irrigated, usually arid and semi-arid regions. Moreover, the water demand of other sectors (domestic, industrial, environment, etc.) is expected to increase. Hence, a more efficient water use in agriculture should be based on the sustainable and integrated water management that includes agronomic and engineering aspects as well as environmental, social and economic factors.
Hence, the water management in agriculture should be seen in the same perspective of integration and consider different interests of stakeholders across administrative, hydrological and management scales (Todorovic, 2018).
Agricultural water management is a dynamic process inside the IWRM and represents a loop of mutually dependent issues (Fig. 3).

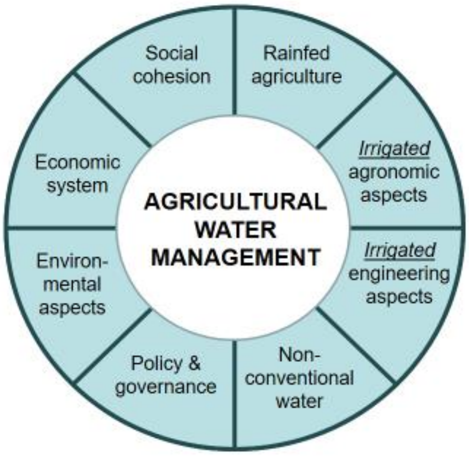

Figure 3. Agricultural water management loop: interdependence of various issues for sustainable development (Todorovic, 2018)

The agricultural water management requires the analysis and enhancement of the rainfed agricultural system (i.e., “green” water use) and its perspectives, the identification and use of additional water sources (i.e., “blue” water), the design and construction of the irrigation network and on-farm/plot irrigation systems, the establishment of a management body (e.g., water users association), planning/optimization of activities, monitoring, operation, maintenance and collection of fees. Thus, it requires strong collaboration between farmers, agro-meteorologists, hydrologists, soil experts, agronomists, engineers, economists, environmentalists, social-science experts and politicians since the beginning of the irrigation project preparation. Moreover, sustainable agricultural water management strategies should consider the use of non-conventional water resources as treated waste effluent, brackish and saline water and construction of adequate drainage system (Pereira, 2002). The interaction between the specific issues across different scales is presented graphically in Fig. 4.

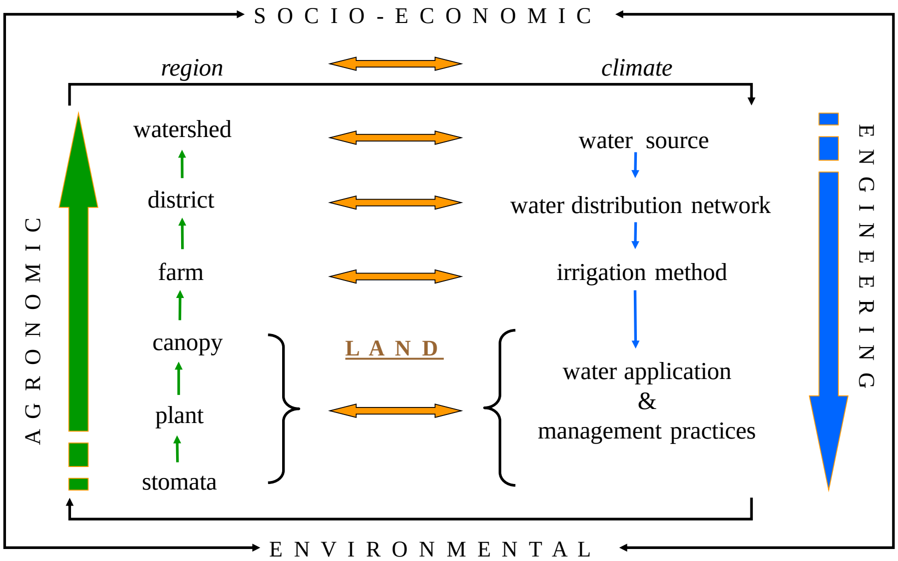

Figure 4. Interaction between specific issues and scales in crop growth modelling

ECO-EFFICIENCY CONCEPT IN AGRICULTURAL WATER MANAGEMENT

The modern regional strategies for sustainable water management in the agricultural sector aim to optimize the use of resources while respecting the interest of numerous stakeholders in a complex context of interactions, overlapping of responsibilities, policies and legislation (EC, 2013; EC, 2014b; OECD, 2010).

The concept of eco-efficiency offers the opportunity to establish a new conceptual framework for the evaluation of the performance of agricultural water management that is based on the overall economic benefits of irrigation and the corresponding environmental impact.

The concept of eco-efficiency provides the opportunity to upgrade the set of common indicators for the assessment of agricultural water management and to introduce a new conceptual frame that evaluates the performance of irrigation schemes and adopted management practices in a more comprehensive way. Eco-efficiency has not a specific spatial and temporal context. Instead, it is a concept of global interest, and it is spreading independently across the hydrological scales and water management units. The eco-efficiency aims to bridge the gap towards the effective implementation of IWRM at different scales since it contemplates, in a consistent and rational way, technical, environmental, social and economic aspects of water management.

The eco-efficiency concept may be used to assess the adoption of technological achievements in agricultural water management to attain economic and environmental progress through more efficient uses of resources and lower pollution. In the context of infrastructure development, the eco-efficiency approach represents an effort to promote design, construction, operation and maintenance and to maximize the value and/or function of sustainable water services. This concept can be applied in different water and other sectors and at different management levels and spatial scales (plot, farm, irrigation district, irrigation consortia and watershed).

A novel approach to the meso-level eco-efficiency indicators for technology assessment and promotion of stakeholder participation in water management was developed by EcoWater project (EcoWater, 2014). The meso-level assessment focuses on the interconnection between micro and macro level to address the dynamic behaviour of a product/service system for support policies towards sustainable water management and agricultural production. It is based on the Life Cycle Assessment (LCA), and the valuation of Life Cycle Costing (LCC). The methodological approach for the eco-efficiency assessment of agricultural water systems was described by Todorovic et al. (2016), Mehmeti et al. (2016), Canaj et al. (2021), and others.

The eco-efficiency concept of agricultural water use is developed on a system-based approach that interweaves among heterogeneous stakeholders across the entire value chain of a production/service process, as is agricultural water management (Fig. 5). Therefore, it includes managers of irrigation infrastructures, farmers, agricultural extension staff, environmental authorities and decision makers.

Eco-efficiency embraces all management activities, on a plot/farm/district level, which contribute to the farming process accomplishment, i.e., including water management as well as the use of energy, application of nutrients and agro-chemicals and adoption of land management and other farming practices necessary for crop cultivation and harvesting. In agricultural water management, eco-efficiency considers the entire water chain from its origin (source), where it is extracted as a natural resource, to the final use in agricultural fields and encompasses actions (processes) related to the creation of the economic value from the commercialization of the final product (yield) and other (any) by-products (Fig. 5). Accordingly, at each stage of the water chain (withdrawal, storage, conveyance, delivery, distribution and irrigation) the relevant stakeholders responsible for management decisions and actions, which affect the overall performance of the system, are identified.

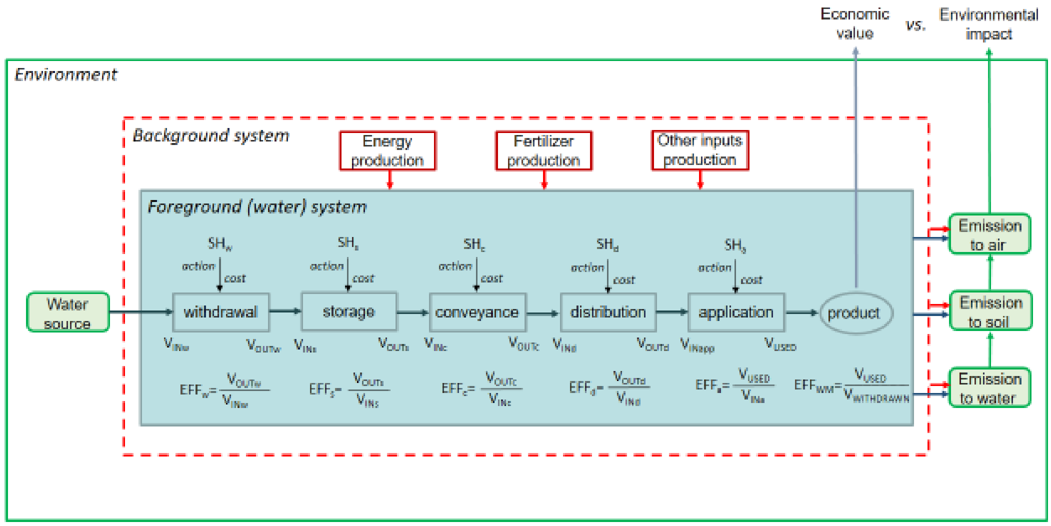

Figure 5. Value chain of water from the source (where it is withdrawn) to the plot (where it is used for irrigation). V indicates water volumes – inflows and outflows for different stages indicated as w (withdrawal), s (storage), c (conveyance), d (distribution), a (application). SH and EFF indicate the corresponding stakeholders and water management efficiencies, respectively.

Eco-efficiency overcomes the specificity of other water performance indicators since it includes the overall economic benefits (of all production outputs) and different environmental burdens. Therefore, it makes possible to shift from a specific ratio (e.g., yield or biomass vs. crop evapotranspiration or irrigation supply) to a more comprehensive approach that integrates the appropriateness and interaction of different management practices and inputs (e.g., water, fertilizer, energy, etc.), overall benefits of stakeholders and various environmental impacts. This is of importance at all hydrological and management scales.

PROSPECTS FOR THE FUTURE

Nowadays, the unceasing challenge is to embrace, in a comprehensive way, the numerous technical, socio-economic and environmental factors, institutional settings and stakeholders' interests interplaying throughout the scales in the water management process. In the agricultural sector, it is particularly important the consideration of new challenges related to climate change and increased frequency of extreme events (heat, drought, floods), land/water/energy/food insecurity and a common need to achieve the sustainable development goals. The primary aim is to implement effective water management platforms and information systems that contain historical, real time and forecasting data about water availability and demand of different sectors (WWAP, 2009) and within specific sectors as it is agriculture. This calls for the application of modern technological solutions for big data acquisition, transfer and elaboration. The research should focus on the adoption of blockchain approach and development of modern monitoring tools and technologies (Internet of Things, remote sensing), data assessment techniques, integrated and smart modelling software and real-time management solutions (Abi Saab et al., 2019; Abi Saab et al., 2021). The overall aim should be the consolidation of a mutual link between the biophysical and technical factors, on one side, and social, economic, environmental and policy issues on the other. The focus should be on a more efficient use of water in agriculture (Levidow et al., 2014).

Communication, understanding of data and consequences of each specific water management action should be upgraded to enhance awareness and involvement of the whole society and of different stakeholders in the water management process. Transparency and trust are the keys to success. Research should focus on the improvement of weather forecasting tools and identification of the most suitable proactive management options to adapt to both droughts and floods. Hence, a setup of modern early warning systems and new regional/watershed management plans is needed to attenuate the vulnerability of water systems and of the society to climate change and extreme weather events.

The adoption of innovations, based on green technologies, should be guided at all hydrological and administrative management scales in a concerted manner. A matrix for the adoption of water management solutions on the ground should be adaptive and inclusive. The priorities for actions and interventions could vary for different scenarios, locations, and water sectors. However, they should be agreed jointly among all stakeholders considering the risk of not acting, the overall benefits of specific water users and of the society, the costs and attenuation of ecosystem vulnerability.

The eco-efficiency concept might be among the top approaches and indicators for the evaluation of the performance of water systems and especially of agricultural water management. However, further research is needed to develop more complete procedures and detailed databases that support the assessment of eco-efficiency at different scales.

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