# Interjurisdictional Collaboration in Water Resource Management

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*Abstract* — **Current concerns regarding an efficient water resource management have highlighted the necessity of top-down and bottom-up interjurisdictional alliances that aim to collectively improve the status of the watershed and the search for sustainable solutions. Acute problems are triggered by direct (land use change) or indirect (climate change, legislation) human interventions in the natural systems within which we live. Water resources management requires the processing of a huge amount of information with different levels of accessibility and availability and in various formats. Often, the data acquisition needs to be acquired, transmitted and accessed in real time. Equally important is to have access to historical data for calibration and validation of the models. Effective watershed management requires information-rich communication among central and local authorities, private industry, citizens, and academia. Effective watershed planning, regulation and management also require timely conveyance of information to agency staff, decision makers, and the public. Customized Decision Support Systems (DSS) are required for this purpose, to provide wide access to workflows to query, visualization, and compare vital information. DSS can use basically the same information for strategic or emergency planning if the access to the data, simulations, and workflow operation can be done in real-time. It is the duty of public and private sectors to determine how to effectively support the decision-making process without neglecting the appropriate amount of evaluation and the inclusion of stakeholders in the process.**

**The paper presents a concept for interjurisdictional collaboration in water resources management, using a DSS platform that integrates the data and information needed to support short- and long-term watershed actions. The focus of the paper is on describing an ontological framework which combines representative actors/stakeholders, hydrologic concepts and relationships with elements of offering an integrated approach to complex water related processes.**

***Keywords—interjurisdictional collaboration; water resource management; decision support systems***

## I. INTRODUCTION

Currently, the decision-making processes in water resources management is undergoing major transformations during its transition from the sectoral approaches of the past (e.g., water use for only irrigation, hydropower, or navigation) to contemporary ones that are integrative and comprehensive approaching watersheds as complex system with interrelated processes surrounding the water cycle. This transformation comes at a time when acute problems are rising in water resources by direct (land use change) or indirect (climate change) human interventions in the natural systems within which we live. Among the most obvious example of extreme events related to water are floods, droughts, excessive pollutant in streams, and an increasing demand of fresh water to sustain economic and social needs.

The new management approaches require processing of a huge amount of information with different levels of accessibility and availability and in various formats (from digital to hardcopy formats) from various points of the complex hydrologic cycle (Figure 1). Given the relevance of the data for practice, often the data acquisition needs to be acquired, transmitted and accessed in real time. Not all the required data neither is critical nor of equal quality, therefore screening and conditioning has to also be conducted in real time. Equally important is to have access to historical data (raw, statistics and post-processed) for calibration and validation of the models. With regard to the accessibility of stakeholders to information, there are as well different situations.

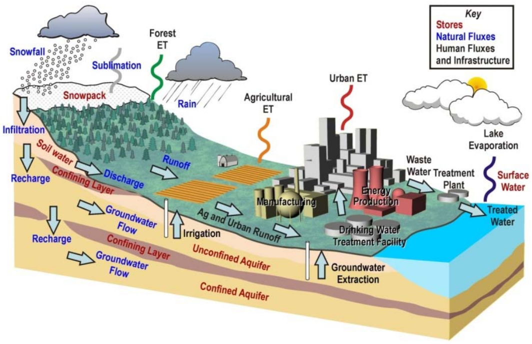


Fig. 1 Schematic of the hydrologic cycle [29]

The complexity of research related to water resources management is extremely high and requires deep expertise in several ICT-related research domains such as: Big Data and Smart Data; semantic Internet of Things; context-aware and event-based systems; Cloud computing; Web services; and social Web. The dynamics of water and the role of humans in the water cycle are not well understood largely because environmental and socio-economic analyses have traditionally been performed separately; and the methods, tools, and data needed for multidisciplinary work are not yet at the required level to satisfactory address problems posed in managing resources in aquatic environments.

ICT can contribute to several areas of research such as better understanding of coupled human-natural system dynamics; finding risk mitigation measures for the unintended consequences and side effects like water scarcity, increased pollution, unreasonable use of water, flood, food prices; and can contribute to the development of strategies for efficient use of water resources. There are situations when information is to be accessed only by designated stakeholders, but there is a huge amount of information that is, and should be handled, as public information. There are already regulations, at national, European or international level, that oblige decision making actors related to water resource management, to ensure the access of the population at certain types of information.

In the last time, there is an increased awareness that the water resource (quantity, quality, ecological status) is influenced by the joint action of stakeholders involved in various water related processes. Criteria for the assessment of the sustainability of the management process from participation perspectives are outlined in [10]. This sustainability cannot be expected to occur spontaneously, unless citizens play an active role (both as planners and executors) in the management of land and water resources in their watersheds. One of the most active initiative for sustainable actions for water management is the Global Water Partnership - GWP, that has the vision of a water secure world. Its mission is to advance governance and management of water resources for sustainable and equitable development [33].

## II. INTEGRATED APPROACHES FOR WATERSHED MANAGEMENT

In contrast with the traditional one-sectoral approach to water management, the integrated approaches recognize the fundamental linkages between water uses (e.g., agriculture, water supply, navigation, hydropower, environment, recreation) and their impact on the watershed resources viewed as a system [21]. The most widely used frameworks for integrative and adaptive management are Integrated Water Resource Management (IWRM) and Adaptive Management (AM). Both, IWRM and AM recognize the need for coordinated action among multiple users of water resources [2] and the systematic use of scientific methods to help decision making [18], respectively. The integrative nature of the approaches is not limited to water uses. According to [6], it implies: spatial integration, institutional integration, temporal integration, as well as the integration of tools used for sustainable water management (data and numerical models, middleware, workflows, operational management and public engagement). Figure 2 shows a graphical representation of the multiple integrative nature of IWRM. Integration is most often partial [6] and goal-directed (any goal from agricultural development to improve human welfare) but not tied to a single goal. The process is adaptive and iterative enabling the inclusion of additional activities and investigations as the watershed evolves over time.

There are various definitions for IWRM ([3], [5], [30]) and AM ([20]). IWRM is a participatory planning and implementation process, based on sound scientific, which brings together stakeholders to determine how to meet society's long-term needs for water resources while maintaining essential ecological services and economic benefits. In addition of these fundamental features, the Global Water Partnership (GWP) focuses on the importance of the IWRM in addressing the issues of poverty reduction and sustainable development in the context of the less-developed countries.

According to GWP ([8]), IWRM is a stakeholder-driven process for promoting coordinated activities in the pursuit of common goals for multiple objective development and sustainable water resources management. IWRM addresses the full range of physical, biological, and socioeconomic variables related to land and water resources within a watershed. Therefore IWRM supersedes traditional multi-purpose natural resources management (such as the multi-sectoral approached by Tennessee Valley Authority in early 1950s) by explicitly combining societal goals and ecosystem functions [1].

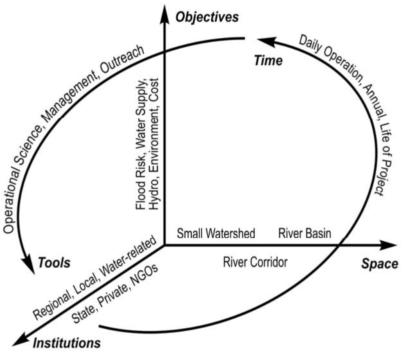


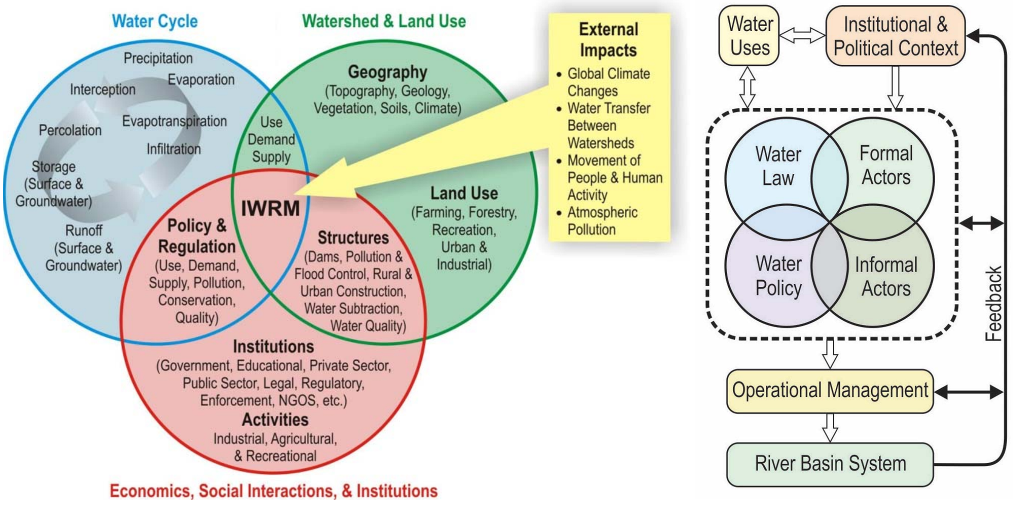
Figure 2. Multi-dimensional aspects of IWRM integrative nature (adapted from [6])

AM, as a concept, has been designed primarily to support managers in dealing with uncertainties inherent in complex ecological system required to meet multiple objectives. AM combines multidisciplinary scientific research, policy development, and local practice in a cyclic learning process aimed at leading to more effective decision making and enhanced environmental, social, and economic benefits [31].

According to [31], AM is a systematic approach for improving resource management by learning from management outcomes. AM is a process of sequential activities that include: exploration of alternative ways to meet management objectives, predicting the outcomes of alternatives based on the current state of knowledge, implementing one or more of these alternatives, monitoring the impacts of management actions, and finally adjusting the management actions based on the knowledge inferred from the monitoring results [17]. AM is emphasizes learning and adaptation, through partnerships of managers, scientists, and other stakeholders who work together to devise ways for creating and maintaining sustainable resource systems. Adaptive management does not represent an end in itself, but rather a means to more effective decisions and enhanced benefits. Its true measure is in how successful it is in helping to meet environmental, social, and economic goals; to increase scientific knowledge; and to reduce tensions among stakeholders.

AM origin can be traced back to ideas of scientific management pioneered by Frederick Taylor in the early 1900s [9]. Various perspectives on adaptive management are rooted in similar concepts found in areas such business, experimental science, systems theory, and industrial ecology [31]. The concept has attracted attention as a means of linking learning with policy and implementation. Although the idea of learning from experience and modifying subsequent behavior in light of that experience has long been reported in the literature, the specific concept of adaptive management as a strategy for natural resource management can be traced to the seminal work of [12], [28], and [14].

Both IWRM and AM target the same overarching goal and they are similar in many essential respects, as illustrated in Figures 3, a and b. Their common goal is to attain the sustainable development and use of the natural resources. Of the two approaches, IWRM has a broader scope by addressing watershed resources from a holistic, integrated and comprehensive watershed system perspective [21]. It also emphasizes the necessity of implementing IWRM through a watershed approach, with watershed defined closely to its hydrologic definition: an area of land within which all surface waters flow to a single point. The systemic approach is applied in practice through integration of the management of the physical environment within that of the broader socio-economic and political framework. Effective and efficient IWRM outcomes are considered those that deliver water services through coordination and balance of various water-using sectors and establish adaptable governance mechanisms capable of coping with evolving environmental, economical and social circumstances [8].



a) IWRM (http://wvlc.uwaterloo.ca)  b) AM (adapted from [26])

Figure 3. Components of the integrative approaches:

Despite their similarity in scope and components, Medema & Jeffrey [16] found slight differentiation between the two approaches by observing that IWRM is a strategy for pursuing the goal, while AM is the necessary management process to realize the goal. Similarly, Timmerman et al. [27] advocate that AM is a timely extension of IWRM to cope with the uncertainties and lack of information and technical knowledge involved in IWRM implementation. Both integrative management approaches have become popular in recent decades as they are easy to understand at a conceptual level, at least at a first glance [4]. The frameworks can be found in various stages of their implementation, even though in many situations they cannot be implemented immediately or at all because of various obstacles. This does not imply that IWRM or AM cannot be applied in basins with a minimum of elements in place. Their implementation performance in any stage is typically measured by way of rather broad indicators that track general environmental, social, and economic development goals with practical appearance in reduced tensions among watershed stakeholders..

## III. INFORMATION-CENTRIC SYSTEMS (ICS) FOR WATERSHED INVESTIGATION AND MANAGEMENT

Recent advances in information science and cyber-infrastructure have set the stage for a new information-knowledge generation technology that can facilitate an "information-centric" approach for watershed investigation and management that capitalizes on observations and their interpretation [15]. This new approach differs fundamentally from the "observation-centric" and "model-centric" strategies of the past, whereby water cycle components were viewed independently and uncorrelated with the bio-geo-chemical processes supported by it. Systematic integration of the water-relevant data into a dedicated system allows to uniquely couple hydroscience information with other water-allied disciplines, such as economics, political and social sciences, in a common information system ([28], [13]) and management practice. These integrative systems enhance the understanding of ecosystems and the management of the natural and built environment through a participatory approach that ensures continuous stakeholder involvement.

The wide variety of users and associated interests and some of the tools for handling data and information to support management and policy developments during IWRM implementation are illustrated in Figure 6. At this time, there is no unified vision on the components, their role and functions, and the enabling technologies to accomplish integrative management approaches. Moreover, there is no guidance of what components should be developed first and in what integration order. It is emphasized herein, that IWRM is not just a conceptual and academic exercise and it can be only attained by giving proper consideration to the nature of information requirements to support IWRM and by identifying the "enabling technology" to fulfill those requirements as one of the first priority. The need to set data and information for supporting IWRM as a high priority was clearly documented in [19]. It can be said that the lack of progress in informatics-related aspects of IWRM may be part of the slow implementation pace perceived by some of its critics. Overlooking of the above aspects contrasts with the considerable intellectual and financial efforts carried out to clarify IWRM concepts and functions and for putting in place the necessary political structure and institutional framework for IWRM implementation. It is quite obvious that the fully integrated water resources management is not limited by a lack of conceptual framework, but because the operational problems have not received sufficient attention in the past.

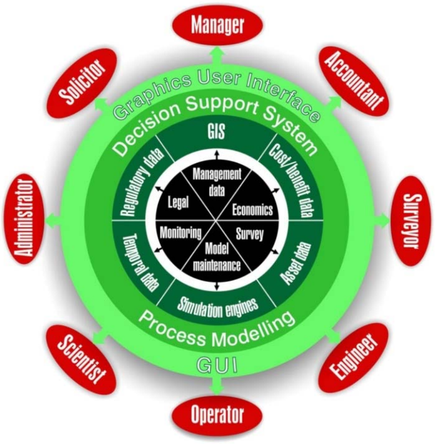


Figure 4. The actors in IWRM - users, tools and activities ([24])

Hydroinformatics-based systems are computer-centered platforms quasi-equivalent to CI-based ones focused on water related problems in the environment, therefore the terms are interchangeable. These integrate CI tools and methods in a digital environment that facilitates the conversion of the data into information and subsequently into knowledge through customized workflows.

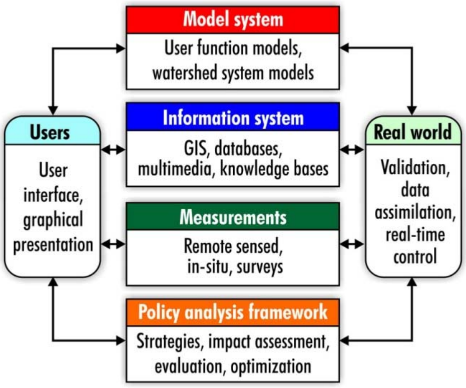


Figure 5. The information flow for decision making (adapted from [34])

The fusion of data and numerical simulation is the most powerful tool to generate information that managers use to monitor, predict, and warn the public in extreme events. Recently, data-driven modeling is increasingly used for the same purposes ([7]). Engineers continue to have important responsibilities to build, calibrate, verify, validate and apply models. Collaborative models are also used for prediction, assessments of alternative scenarios, and multi-criteria indicators that are also used for the decision-making process.

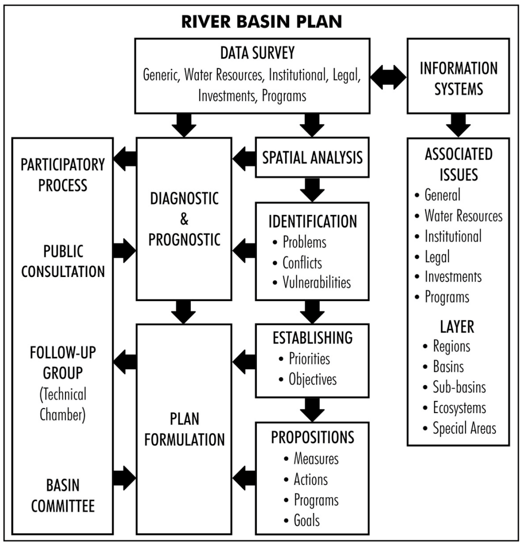


Figure 6. Data and information flow for end-to-end IWRM implementation ([16])

There are various perspectives of the IWRM-based decision support system highlighting the importance of data and information and their integration in a watershed-focused information system. Figure 4 presents the actor based perspective, while figure 5 presents the information flow for decision making perspective, that enables the interjurisdictional collaboration in water resource management. Figure 6 depicts the data information flow for implementation of IWRM.

## IV. ICS CONTRIBUTIONS TO SUSTAINABLE MANAGEMENT OF WATERSHEDS

In the last two decades, the decision-making in water resources systems management has been influenced by the introduction of the sustainability paradigm [26]. Savenije and Hoekstra [25] indicate that the watershed sustainability is only accomplished when the resource base and water use are each sustainable. The first aspect is accomplished by closing of the water, nutrient, soil and energy cycles, building up societal assets (know-how, knowledge, technology, infrastructure welfare, civic society, educational and legislative capacity). The second one is reached by imposing zero tolerance on pollution, complete recycling (agriculture, industry, household), water conservation and retention, water sector reform (good governance and institutional framework, education, participation).

***Improvement of the information services***. Information services are the prerequisite for providing basic data and information that allow an understanding of the environmental, economic, social, and cultural interactions over a range of various spatial and temporal scales.

Today, the U.S. government and other data collection agencies are increasingly making their information available through web-based systems. The European Union is also concerned about the increased availability and interoperability of structured information and services and initiated the INSPIRE directive that aims to create a common European spatial data infrastructure. This will enable the sharing of environmental spatial information among public sector organizations and better facilitate public access to spatial information across Europe [32]. A European Spatial Data Infrastructure will assist policy-making across boundaries. Therefore the spatial information considered under the directive is extensive and includes a great variety of topical and technical themes.

***Development of operational science for decision making***. NOAA (2009) defines operational science as the combination between the physical and social science aspects of a well-integrated water resources information system that is responsive to the needs of stakeholders. The operational science is focused more on science implementation and integration than on science development, recognizing that there is a large resource of mature science readily available. The physical science is concerned with estimation of past, current and future states of the water budget sampled with data collected at high spatial and temporal resolutions. Data alone cannot supply all the information required to support IWRM at all levels of governance. Analyses are needed to bring together disparate datasets and infer interactions, impacts, and broader context of the processes. Inferences are the results of specialized analyses, most of them available, but still needing varying degrees of work to implement and connect them into ICS. Data and their analyses are complemented by simulation models that are integrated both over the water cycle processes as well as over extraneous, yet related factors and variables associated with the natural environment. Additional expertise is required to implement and operate these models, to ingest sensed observations, and to produce meaningful information products and services from them.

ICSs can support the social science operations through their wide and user-friendly accessibility. Such platforms can be viewed on two levels [34]. The first level concerns decision-makers, politicians, water resource managers and project engineers, while the second level aims at analysts, software developers, software maintainers and also, to a certain extent, to project engineers.

***Enhancing the human dimension in the management process.*** One of the four major principles for IWRM implementation is to adopt a participatory approach in the decision-making process ([7]). Among the factors that underscore a participatory approach are: adequate funding or resources to support the process, the quality of communication and information exchange, team building, organization and leadership, and development of common goals and understanding, and building a knowledge base and technology for mobilizing for future action. The knowledge that needs representation is not limited to numerical format. It also includes knowledge that is represented in a qualitative form, such as linguistic descriptions of what a process is, what to do, or what information to use, and at what point in time.

***Supporting capacity building.*** Integrative approaches to the science and management of watersheds are new endeavors that will require ambitious developmental programs on many fronts, from elementary education to academia, to operations personnel and to the public. Few universities programs train "water scientists" in the many facets of science relater to water and in the multiple issues such as specialty entails.

The capabilities of ICS to gather in one place all watershed-related information makes them attractive to agencies that usually work independently. The Iowa DEOs recently developed for Iowa, were central pieces in the formation of inter-institutional alliances that could have not been conceived in the past. As a result, a basin-wide interagency coordination team was created for a Iowa-Cedar Basin that currently develops the capacity to work collaboratively and aggregate complementary expertise and resources in a joint effort (http://iowacedarbasin.org).

***Fostering institutional and governance adjustments***. The watershed systems have well-defined interconnections between their components (natural and human-impacted), yet these resources are administered separately in most cases [12]. Moreover, in many countries, the prevailing institutional perception is that data/information gives power and sharing is not favored, since its collection/production is associated with financial cost. While the goals of the individual institutions are very different in scope and extent, ICSs produce consistent water-related data services and information that is published uniformly, permanently, and eventually allows easy access through an ubiquitous web interface, by keeping the decision-making process transparent and opening venues to collaboration among concerned watershed stakeholders. The integrated resources as a whole are greater than the sum of their parts and can cater to multiple users ranging from climate scientists and hydrologists to decision makers and stakeholders. ICSs benefit all the partners making possible to engage the community through partnerships of data providers, developers and collaborators at a time when available funding is stretched under the ever-growing pressure of competing interests. Involving watershed stakeholders in all steps of the IWRM planning and implementation ensures that the research results are translated into political processes and, subsequently, into meaningful watershed management strategies and policies applied by progressive and adaptive legislation within institutional frameworks.

## V. CONCLUSIONS AND FURTHER WORK

The frameworks, concepts, and CI technologies described in this paper demonstrate that the actual implementation of the integrative management approaches has a great potential. The CI infrastructure embedded in ICS facilitates a cross-sectoral approach based on the analysis and implementation of multiple objective tradeoffs established through a multi-disciplinary and multi-participatory decision-making process. The ICS implementation cases illustrate that translation of the theoretical concepts into practice is achievable and it will lead to new, unprecedented perspectives to address the stresses of the watershed resources in a comprehensive manner, by educating and engaging all relevant stakeholders in the decision-making. These end-to-end engineering systems are bound to create a new paradigm for watershed science and management, enabling interdisciplinary teams to collaboratively understand and manage complex watershed issues with view to a long-term sustainability.

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