

DELINEATION OF WATER RESOURCES UNITS TO PROMOTE IWRM AND FACILITATE TRANSBOUNDARY WATER CONFLICTS RESOLUTION

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Integrated Water Resources Management (IWRM) is a relatively recent practice being adopted by water managers because it reflects the necessity of planning and management of water systems in a way that all relevant objectives are harmonized (Grigg 2005). According to Vlachos (2008), the term appeared early in the 1930s as a new paradigm that reinforces the importance of considering the world's complexities, including new approaches for planning and organizational structures that represents the interaction between environment, society and technology. In this context, geographic integration is an important area since it reflects a wide range of activities, such as: planning, management, controlling, data organization, monitoring, and water allocation.

Many authors consider river basins the most suitable geographic unit for IWRM. Dourojeanni et. al. (2002) justify the use of river basins as they correspond to the: 1) principal terrestrial form of the hydrologic cycle; 2) interrelationship and interdependence between water uses and users; and 3) region where water and physical and biotic systems interact, including the socioeconomic system. Therefore, some countries define their water resources units using solely river basin classification based on topological relationships, such as proposed by Pfafstetter (1989). Most recently, however, different countries are aggregating other criteria for defining IWRM units, including historic development, cultural and environmental aspects and strategic water uses, representing the "problemshed" concept, as defined by Vlachos (2000) and Allan (2005).

Additionally, an important aspect to be considered is the fact that political boundaries, which are generally not coincident with the hydrological limits, can represent a strong barrier to using river basin areas as territorial units for IWRM. Those political boundaries can be characterized not only by international limits but also by boundaries between different regions in the same country (Ganoulis et. al. 1996) Matthews and Germain (2007) affirm that political limits, depending on the degree of permeability, can constitute a unifying influence or an obstacle to IWRM, depending on their scale and jurisdictional power over water. Internal issues within national borders and external issues between riparian countries regarding water sharing (Ganoulis et. al. 1996) can be reduced by defining IWRM units and respective comprehensive institutional structure (Waterstone 1996) with sufficient power to lessen the boundary effects.

In order to deal with such a complex and ill-structured problem, this study introduces an approach to support the delineation of water resources planning and management units to promote IWRM and facilitate the resolution of transboundary water conflicts. This approach is based on the development of a decision support system (DSS), to be used by National Water Councils or International River Basin Commissions, as a way to promote the necessary understanding about IWRM units, as well as to address the process of delineating those units and incorporating important related aspects and different stakeholders' interests. The Water Resources Planning and Management Units Delineation Decision Support System (WARPLAM DSS) is a proposed model based on the application of expert systems (ES) and multi-criteria decision analysis (MCDA) combined with geographic information systems (GIS) and cluster analysis.

A DSS is defined by Klein and Methlie (1995) as a "computer information system that provides information in a given domain of application by means of analytical decision models and access to databases, in order to support a decision maker in making decisions effectively in complex and ill-structured tasks". The use of DSS and

Expert Systems has been increasingly recognized as a way to combine scientific understanding of the natural world processes with the heuristic rules developed by managers through observation, experience, intuition, judgment and behavior (Bonczek et. al. 1987; Turban, 1998). Labadie (2007) presents the value of DSS as a way to increase the quality and efficiency of decision-making through easy identification of the problems, rapid assimilation through graphical display, comparison of alternatives, cost reduction and clear documentation. Also, because water resources problems are frequently complex and multi-faceted, MCDA approaches can be used to address these problems in a synthesized and integrated manner. According to Shrier et. al. (2008), MCDA approaches help to organize the decision analysis process and can be integrated with expert systems to incorporate expert knowledge with respect to criteria and ratings. Among multivariable analytical techniques, MOPU (1984) described cluster analysis as the structuring of a set of units in groups, by an initial distance matrix, considering that the best result is the one that maximizes the inter-group difference and minimizes the intra-group difference. According to Coelho (2004), GIS constitutes a broad analysis tool, which permits many criteria to be overlaid and synthesized. GIS also represents an intelligence environment that supports the management and decision process, allowing the integration of multiple uses and interdisciplinary thinking.

The process of developing the WARPLAM DSS can be summarized in three main phases: Phase 1 – Understanding the important aspects related to the delineation of water resources planning and management geographic units; Phase 2 – Building the DSS through the definition of suitable approach; and Phase 3 – Validating the system through the application in a study case region. Phase 1 refers to the conceptualization of the problem. Based on a comparison among water resources geographic units adopted in different countries, the analysis resulted in the identification of criteria to be incorporated into the DSS. Heuristic knowledge, used from experts in decision-making processes related to the definition of those units, was identified and incorporated into the model, in order to increase the quality of future decision-making processes.

Phase 2 can be summarized into five steps that represent the adopted approach to analyze the problem. The first step was the generation of a consistent basis over which to develop an aggregation process, considering natural drainage area limits into the smallest possible level. The second step was the incorporation of related criteria, beyond river basin boundaries, that reflect the main aspects related to IWRM purposes. The third step was the combination of selected criteria and the generated basis. Each pair of adjacent units contained in the basis constitutes one alternative. The ‘measurement of closeness’ for each alternative was defined taking into account overlaying area values of criteria. The fourth step was the application of Compromise Programming (CP) to sum all criteria values for each alternative, considering the different scale range or space dimensions of the criteria’ values. The fifth step was the application of Cluster Analysis to the alternatives to define different groups of basis’ units. Different grouping results were generated using different sets of weights and different L norms of CP, representing the ‘ideal’ IWRM units.

Phase 3 refers to model validation. The study case area adopted in the analysis is the Brazilian territory. The river basin area is recognized by the Law #9433/97 as the territorial unit for the implementation of the Water Resources National Policy (PNRH). However, this law did not expressly define "river basin" and, considering the huge extension of country’s drainage network, the scale needs to be better defined. The Federal Government established twelve national hydrographic regions, representing the recognition of the necessity to establish regional policies for the country, considering its hydrologic, environment, institutional, political, social, economic and cultural diversities. However, the suitable scale for an effective IWRM has not yet been reached. Furthermore, taking into consideration water resources are under a double domain, as established by the Brazil Federative Republic’s Constitution from 1988, some subdivisions are being randomly established by the States (Figure 1). Therefore, the advancement of PNRH is dependent on treaties between Federal and States Governments, which

Figure 1. Map of Brazilian Water Resources Units established by Federal and State Governments



This paper details the Phase 1 of the WARPLAM DSS development. The most important recognized aspects were incorporated into the DSS as the knowledge base of the Expert System. For that, a comparative analysis was executed based on the adopted water resources units in different countries in the European and the American Continents.

The USA selected four levels of hydrologic units in 1987, after a long period of disagreement about subdivisions of the Federal, State, and local agencies. These agencies had been using incompatible criteria for names, codes and river basins boundaries, strengthening transboundary water conflicts. The four levels of units were delimited considering drainage area of major rivers or a combination of small drainage areas, hydrograph characteristics, culture, and political boundaries (Seaber et. al. 1987).

In Mexico, thirteen hydrologic-administrative regions were established as Regional Management Units by the National Water Council in 1998. The division is based on hydrologic and administrative aspects, having coincident limits with one or more river basins, according to regional characteristics of water resources. The actuation area of those regions, through the creation of River Basin Organisms, is correspondent to the limits of the municipalities contained in each region (CNA 2007).

The European Union, through the Water Framework Directive (WFD), requires all Member States to identify River Basin Districts (RBDs) as the main areas for IWRM (UK Environment Agency 2005). According to guidelines provided by the EU (2005), the districts are made up of main river basins or groups of small river basins considering climatic, environmental, socio-economic and administrative aspects, weighted based on particular characteristics of the Member States. For example, France, including its colonies, is divided into 14 units, based on administrative and hydrologic aspects, adopting the lines corresponding to the delimitation of the communes' territories – which are the smaller administrative unit – closest to river basins or groups of river basins (MED 2003). In case of transboundary river basin districts, coordinated planning and management must be ensured (EU, 2005).

Those and further included examples demonstrate that some aspects, other than solely river basin limits, are being aggregated in order to define integrated water resources planning and management units, such as political-administrative, cultural, environmental and socio-economic aspects. As a result, in order to help future decision-making processes and facilitate stakeholders' involvement, the aspects, that represent IWRM and were identified as criteria to be incorporated into the DSS, are described in more detail in this paper.

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