DISSERTATION

MULTICRITERIA DECISION SUPPORT SYSTEM TO DELINEATE WATER RESOURCES PLANNING AND MANAGEMENT REGIONS

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY ANA CAROLINA PINTO COELHO MARAN GONCALVES ENTITLED MULTICRITERIA DECISION SUPPORT SYSTEM TO DELINEATE WATER RESOURCES PLANNING AND MANAGEMENT REGIONS BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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ABSTRACT OF DISSERTATION

MULTICRITERIA DECISION SUPPORT SYSTEM TO DELINEATE WATER RESOURCES PLANNING AND MANAGEMENT REGIONS

The lack of uniform and integrated water resources regions that support sustainable water management within river basins is a critical issue. Overlapping and redundant efforts in planning and management result from conflicting water resources regions, which hamper Integrated Water Resources Management (IWRM). In addition, the process of delineating these regions has often been executed without sufficient scientific support or a commonly agreed upon approach, usually resulting from political and historical circumstances. In spite of this, it is possible to improve the results by using knowledge gained from prior experiences, employing modern techniques, improving decision support systems (DSS), and also by taking into account multiple stakeholders' interests. In order to harmonize multiple objectives, promote good governance practices and reflect the linkages between environmental, socioeconomic, political and historical aspects, it is imperative to define appropriate territorial limits for water resources planning and management regions.

Given the presented problem, this study introduces an approach to support the process of delineating water resources regions based upon recognition of more comprehensive aspects and incorporation of these aspects into a DSS. A harmonized division of water resources regions, agreed upon between stakeholders, is the first step to promoting IWRM, furthering cross-boundary cooperation and preventing conflicts. The proposed Water Resources Planning and Management Regions (WARPLAM) DSS is designed to be used by federal and state governments, international commissions and water councils. Although river basins are considered to be the most suitable boundaries to attain IWRM goals, the proposed DSS simulation model

offers the option for decision makers to include socioeconomic, political and environmental aspects into the analysis. Its main goals are to promote a common approach relating to the reasoning used in this process and to reinforce the principles of IWRM. It is based upon the use of geographic information systems (GIS), knowledge-based systems (KBS) and multi-criteria decision analysis (MCDA) combined with cluster analysis, dynamic programming (DP) and fuzzy analysis. WARPLAM DSS is also a flexible solution to support the delineation of regions in multiple levels of subsidiarity and to be adaptable to regional characteristics.

The process of developing WARPLAM DSS can be summarized into the following three main phases: Phase 1) Evaluating the aspects related to the delineation of water resources planning and management regions through a comparative analysis in eleven different countries; Phase 2) Building the DSS through the definition of a suitable approach utilizing the aspects identified in Phase 1; and Phase 3) Demonstrating the capability of WARPLAM DSS through a case study in Brazil.

The results of the study illustrate the potential for exploring different options for defining water resources regions depending upon the water resources management objectives and priorities. It is demonstrated that additional aspects, beyond solely river basin limits are being adopted in several countries. In addition, the results show that WARPLAM DSS provides a multi-faceted and comprehensive solution to the complex issue of delineating water resources regions. The proposed DSS can also support multiple interests and multiple users; capacity building and access to knowledge from prior experiences; human judgment, intuition, experience and preferences; and flexibility. The building and operating of the DSS into an integrated system between ArcGIS and Excel is an adequate solution to address the user-end focus. Moreover, the combination of GIS with Cluster Analysis and DP in an adequate approach to address the presented needs. Finally, it is expected that WARPLAM DSS will improve the chances of successful IWRM practices, help lessen the boundary effects and promote cross-boundary cooperation, as well as support future decision-making processes and facilitate multiple stakeholders' involvement .

Key Terms: water resources planning and management, institutional framework, IWRM, decision support systems, GIS, cluster analysis, dynamic programming.

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1. INTRODUCTION

The lack of integrated water resources regions is a critical issue. Overlapping and redundant efforts in planning and management result from conflicting water resources regions, which hamper Integrated Water Resources Management (IWRM). In addition, the process of delineating these regions has often been executed without sufficient scientific support or a commonly agreed upon approach, usually resulting from political and historical circumstances. In spite of this, it is possible to improve the results by using knowledge gained from prior experiences, employing modern techniques, improving decision support systems (DSS), and also by taking into account multiple stakeholders' interests. In order to harmonize multiple objectives and better represent the interaction between environmental, socioeconomic, political and historical aspects, it is imperative to define appropriate territorial limits for water resources planning and management that reflect multiple interests.

Conflicts over water allocation result because of different management practices adopted in distinct parts of the same river basin, or general management actions enforced in specific river basins. The fact that several different governmental institutions may be responsible for tasks related to water resources planning and management also contributes to the problem, especially in transboundary water regions and federative countries. Another relevant aspect is the existence of different boundaries in other policy sectors that are closely related to the water sector, such as navigation, spatial planning and energy. In addition, some existing regions may reflect historical interests of dominant sectors instead of multiple interests.

Water resources regions are considered in this study as the geographical territory adopted for the organization of water resources planning and management. It is expected that these regions have an organizational structure responsible for the execution of the related actions. It implies that the definition of water resources planning and management regions is directly related to the existence of respective institutional frameworks, such as River Basin Committees, Water Councils, Watershed Commissions, Water Courts, or Advisory Boards.

Given the presented problem, this study introduces an approach to support the process of delineating water resources regions based upon recognition of more comprehensive aspects and incorporation of these aspects into a DSS. A harmonized division of water resources regions, agreed upon between stakeholders, is the first step to promoting IWRM, furthering cross-boundary cooperation and preventing conflicts. The proposed Water Resources Planning and Management Regions (WARPLAM) DSS is designed to be used by federal and state governments, international commissions and water councils. Although river basins are considered to be the most suitable boundaries to attain IWRM goals, the proposed DSS simulation model offers the option for decision makers to include socioeconomic, political and environmental aspects into the analysis. Its main goals are to promote a common approach relating to the reasoning used in this process and to reinforce the principles of IWRM. It is based upon the use of geographic information systems (GIS), knowledge-based systems (KBS) and multi-criteria decision analysis (MCDA) combined with cluster analysis, dynamic programming (DP) and fuzzy analysis. WARPLAM DSS is also a flexible solution to support the delineation of regions in multiple levels of subsidiarity and to be adaptable to regional characteristics.

The process of developing WARPLAM DSS can be summarized into the following three main phases: Phase 1) Evaluating the aspects related to the delineation of water resources planning and management regions through a comparative analysis in eleven different countries; Phase 2) Building the DSS through the definition of a suitable approach utilizing the aspects identified in Phase 1; and Phase 3) Demonstrating the capability of WARPLAM DSS through a case study in Brazil.

The first phase, referred to as the definition, establishes the fundamentals of the problem in order to emphasize the recognition of more comprehensive aspects that should be considered in the delineation of water resources regions. A qualitative comparative analysis, using a simple theoretical framework, is performed. This analysis focuses on adopted water resources regions and their respective institutional frameworks in different countries on the European and American continents. The process of defining the boundaries of such regions is subjective, and decision makers do not have, in general, relevant references or a common agreed upon approach to support their decisions. Therefore, this analysis intends to further the understanding of important aspects related to the delineation of water resources regions, including the identification of new insights and heuristic knowledge used by experts when defining such regions. In summary, this part presents a brief overview of what is being established in terms of water resources regions in some countries, and based upon this information, suggests some important criteria to be included in the analysis, other than solely river basin limits.

The second phase, referred to as the modeling, describes how the proposed DSS is developed, including a general overview of its main components, structure, procedures and model design. It also describes how GIS and Excel are used as the basis for the development of the proposed DSS, combined with cluster analysis, MCDA, KBS and optimization techniques. There is also a detailed description of the algorithm, including the reasoning associated with the combination of Cluster Analysis and DP.

The third phase, referred to as findings, is the application of the proposed approach in a case study, given as an empirical analysis to illustrate the proposed methodology and to demonstrate its eventual value from a practical point of view. The selected case study uses actual data to evaluate ideal water resources regions in the Tocantins-Araguaia Region—in Brazil.

The present study is, then, organized into three main parts, subsequent to discussing the review of the current state-of-the-art literature, which reflects the interaction between the presented problem and the proposed solution. Finally, conclusions and general recommendations are given, addressing the main hypotheses presented throughout the study: 1) whether river basins limits are, solely, the best geographic territory for water resources planning and management; 2) whether other relevant IWRM aspects should be considered when delineating these regions, such as historical development, cultural and environmental aspects, strategic water uses or political boundaries; 3) whether is possible to integrate the boundaries of other closely related policy sectors with the boundaries of the water resources sector; and, 4) whether potential transboundary conflicts can be identified and considered in the process of establishing water resources planning and management regions.

2. LITERATURE REVIEW

2.1. Boundaries: concepts and trends

The concepts of *boundaries* can be vast and complex to describe. They vary from sociological and anthropological dimensions to political and historical, and even religious dimensions. Boundaries indeed represent complexity and uncertainty. Starting with the basic definition (Random House, 2010), a boundary is "something that indicates bounds or limits"; is the "sense of that which divides one entity or political unit from another"; and also "refers to a physical feature that marks the agreed-upon line separating two political units" such as a river. The terms *border* and *frontier* are often used in reference to a boundary. A border is the geographic boundary set by governments. In this sense, there is a political entity or legal jurisdictional authority as the central unit.

Buchanan and Moore (2003) and Newman (1999) agree that despite the increasing complexity of the current age and the existence of a 'borderless world' in the economy and information technology sectors, functional roles of boundaries are still really important in the globalized world. Buchanan and Moore (2003) also affirm that "the interrelationship between ethical traditions and political boundaries—which is often not coincident—is particularly interesting and complex". The relationship between territory, governance and sovereignty is also highlighted by the authors as an important aspect consideration in describing boundaries. Globalization also includes new concepts, functions and meanings for classical national borders. According to L'Estrange and O'Dowd (2008), there is a "new bordering strategy for the global economy", including new forms of governance such as the large geo-economic blocs of the North American Free Trade Area (NAFTA), the European Union (EU) and the *Mercosul* (Common Market of the South). Dimitrovova (2008) highlights the current challenge in Europe involving the "transformation of the EU's external boundaries into zones of interactions, opportunities and exchanges, where the emphasis is on transcendence of boundaries".

Lorberbaum (2003) introduces the complexity of the boundaries in the Jewish tradition. The author avers that there is a relationship with land changes in different nations and indigenous populations, for example, and presents some contrasts between the definition of the *State of Israel* and the *Land of Israel*, where it is possible to have a political entity no matter its territorial location. The Confusius and Mencius theory, as cited by Bell (2003), defends the ideal world as having no territorial boundaries between states. Buchanan (2003) also distinguishes the concepts of *territory* and *land*. The first is described as geographical jurisdiction or the area defined by the limits of political units, and is treated as a political and juridical concept. On the other hand, land is a geographical concept. Hurrell (2003) highlights the importance of establishing borders that are agreed among all parties involved. According to the author, this affirmation is true in many different time periods, places and cultures, and is especially true at the international level. He also mentions the goal of coexistence in the European system as one fundamental factor in defining boundaries and limits to sovereignty. Moore (2003) states that people need to agree with the approaches used to define or redefine boundaries "regardless of whether boundaries are viewed as mere administrative conveniences or as having some intrinsic moral value".

Interpretations and definitions of boundaries also involve conquests and settlements, including the history of innumerous wars that were motivated by territory limits. As proven in recent history, boundaries are not static; they are in constant transformation, and they can dissolve depending on many different situations. At some point though, "like cities and metropolitan areas, eventually we must agree on some form of political definition so we can draw lines for policy planning" (Ruhl, 1999). Mapping technologies, such as GIS tools, are also presented by Wood (2000) as an important advancement in the process of establishing or reviewing boundaries.

The advocacy coalition concept also has influence over the concept of boundaries. Sabatier (1998) defines an advocacy coalition as a group of people—such as agency officials, researchers and interest group leaders—who have a common belief system regarding basic values, assumptions and problem perceptions, and who have coordinated action over time. In this context, Lopez-Gunn (2009b) asserts that spaces of control, which also reflect the concept of territoriality whereby an action influences an area and controls people and resources in a geographic area, constitute a demonstration of power. Therefore, different coalitions appropriate different territorial limits. According to the author, water is the dominant object of appropriation in relation to territory, and has recurrently been used in politics.

In the water resources field, the concept of boundaries is being recognized as a strategic factor for successful practices, resulting in important contributions to the study of boundaries. The IWRM movement introduces the ecological river basin as the ideal limits for water resources planning and management practices. River basin limits are not static, however; they have different scales, levels and interdependencies with political, social and historical aspects. In addition, concepts such as *groundwater limits and transboundary aquifers* are more recently being emphasized. Puri (2009) contends that aquifers have no boundaries or, at most, have blurred limits and smooth transitions, resulting in either cooperative or conflicting situations. Climate change will impose even more challenges in defining of boundaries and responsibilities across borders.

Mostert et al. (2008) affirm that boundaries have a central importance in water management. According to the authors, these boundaries can be: 1) physical, considering aspects such as surface and groundwater, quantity and quality, coastal water and different geographical scales; 2) political-administrative; 3) social, considering different social and economic groups; and 4) cognitive, considering different disciplines. Mostert et al. define *social learning* as an approach for cooperation across boundaries and better harmonization of multiple interests in water management, including improved institutions. The key concept of the proposed approach is to define the stakeholders to be involved, considering that not all can be included at the same time. Therefore, the authors suggest that multiple levels of integration be developed, as well as the necessary connections among them. The next topic will introduce the complexity and uncertainty associated with adopting river basin limits as the ideal units for IWRM.

2.2. Water Resources Planning and Management and IWRM

Water resources planning and management are historically traditional activities. Dzurik (2003) states that river basin planning may have more than 9000 years of history dating back to the development along the Indus River, and the Tigris and Euphrates Rivers.

In order to clarify the understanding about water resources planning and management, some definitions were adopted for this study. Water resources management is the process of creating and implementing water resources plans, programs and projects, including the evaluation of current decisions and their impact in the future. Water resources planning, as defined by Dzurik (2003), is the logical and organized way to think about the future, considering the following stages: problem identification, data collection and analysis, goals and objectives, problem diagnosis, formulation of alternatives, analysis of alternatives, evaluation and recommendation, implementation, surveillance and monitoring. By reducing risk and uncertainty, planning allows for better decisions (Dzurik 2003).

The dynamics and unpredictably of the present era requires planning to accommodate new visions and ideals. Ringland (1998) maintains that planning needs to incorporate foresight and reflect strategic planning interests rather than constitute a rigid process. Vlachos et al. (2000) believe planning needs to focus on anticipatory actions and risk management in order to cope with uncertainty. Azevedo et al. (2000) also highlight the importance of strategic planning and the necessity for innovative and holistic approaches. Based upon that, the current trends in planning, according to Dzurik (2003), are to focus on executive planning and policy orientation, to understand the limits, to truly and comprehensively understand the facts, and to recognize the complexity and dynamic changing of the environment.

Adaptive management is another example of current planning practices. According to Rosa (2008), it means learning through experience in order to integrate "values and perceptions of communities". Dzurik (2003) affirms that it encourages learning from mistakes, allows flexibility and helps to build a better base of understanding, especially for long range planning. Postel and Richter (2003) also encourage 'learning by doing', or the incremental learning approach.

The most important concept to be considered in this context is IWRM. It 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 whereby all relevant objectives and multiple interests 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 represent the interaction between environment, society and technology. Grigg (2008) presents the *1917 U.S. Flood Control Act* as one antecedent of the IWRM concepts. Dzurik (2003) also includes the Rational Planning model in the 1940s, the *Water Resources Planning Act* in 1965, the *National Environmental Policy Act* (NEPA) in 1969, the Principles and Standards formulated by the Water Resources Council in 1973, and the Principles and Guidelines in 1983 as good examples of comprehensive planning and evolution of the IWRM concept.

Meire et al. (2008) contend that the IWRM concept originated at the first United Nations (UN) conference on the human environment in Stockholm in 1972. According to Porto and Porto (2008), the Dublin Principles and the 1992 UN Summit at Rio de Janeiro reinforced this concept through the Agenda 21's principles. Chapter 18 of Agenda 21 states: "IWRM is based upon the perception of water as an integral part of the ecosystem, a natural resource of social and economic good". Grigg (2008) describes IWRM as "a conceptual framework that is meant to describe the complexity of water decisions and the importance of balancing stakeholder viewpoints". According to Hajkowicz and Collins (2007), the sustainability context—related to IWRM principles—requires multiple objectives, especially in water resources management. Mitchell (1990) presents three aspects that should be considered in order to have integrated water management: 1) the dimensions of the water, including surface and groundwater as well as quantity and quality; 2) the interactions of the water with land and the environment; and, 3) the development of socioeconomic aspects.

The Global Water Partnership (GWP) also plays a most important role in tackling the principles and concepts of IWRM. According to Bonell (2008), the GWP published a manual regarding IWRM principles in 2000. The GWP's IWRM Toolbox is a reference set of good practices for water resources management at local, national, regional and global levels (GWP, 2009).

In this study, IWRM is defined as the integration of water resources planning and management developed at three stages. The first stage is the integration among policy sectors that are closely related to the water resources sector, including agricultural, energy, transportation, urban supply, sanitation, environmental and industries, among others. The second stage is the integration among different administrative levels, from the very local organization to the central government. The third stage is the integration among planning and management activities themselves, including mechanisms to promote an effective transition from planning to management and vice-versa.

The concept of IWRM is also related to the concept of systems analysis. According to Mostert (2006), IWRM can be defined by two concepts: systems analysis and an ecological approach. The analysis of the system from a holistic perspective is also an important step in IWRM. In both cases, the boundaries of a water system should be defined considering morphological, ecological, and functional relationships.

Institutional obstacles are presented by Grigg (2008) as one reason for difficulties in implementing IWRM. Vlachos et al. (2000) and Mylopoulus et al. (2008) maintain that the institutional jurisdiction over water resources at different levels of government and sectors is fragmented. Also, according to Dzurik (2003), additional barriers to IWRM are that it takes time and money, and it requires compromised solutions and trade-offs.

Kidd and Shaw (2007) discuss the various dimensions of integration necessary for appropriate institutional arrangements for IWRM. Grigg (2008) proposes eight areas of integration as part of IWRM goals: integration across policy sectors; integration across water sectors;

geographic units; integration across government units at national, regional and local levels, and at the same levels; organizational levels; functions of management; phases of management; and, disciplines and professions. GWP (as cited by Margeli et al., 2008) has identified 13 areas organized into these three factors: 1) favorable environment, including policies, legislation and grants; 2) institutional structure; and, 3) management tools. The concept of *integration across geographic units* is presented by Grigg (2008) as a special challenge for IWRM. Geographic integration is an important aspect since it reflects a wide range of activities, such as planning, management, controlling, data organization, monitoring, and water allocation (Grigg, 2005).

Many authors consider ecological river basin limits as the most suitable geographic unit for integrated water resources planning and management (Draper, 2006; Postel and Richter, 2003; Wegerich, 2008; Turton, 2008; Falkenmark, 2004; Montgomery et al., 1995; Fontane, 2000; Kauffman, 2002; Ruhl, 1999; CEC, 2007; Iza and Stein, 2009). The concept of *river basin limits* is directly related to the drainage basin. It represents the area where water from rainfall or snow melting drains into a body of water, including the streams and rivers that carry the water, and the land surfaces. Similarly, *watershed* is defined as the region draining into a water body (Kauffman, 2002). In this study, the same concept is also applied to other terms such as catchment *areas* and *water basin*. Texas Water (2008) suggests there is a scale factor related to the definition of these terms, beginning with catchment as the smaller units, then watershed and river basin. No such notion is being considered in this study.

Agenda 21 calls for IWRM at river basin levels (Bonell, 2008) as river basins are generally accepted as the natural unit to manage water resources because they are coherent entities in a hydrological context. Dourojeanni et al. (2002) justify the use of river basins as they correspond to: 1) the principal terrestrial form of the hydrologic cycle; 2) the interrelationship and interdependence between water uses and users; and, 3) the region where water and physical and biotic systems interact, including the socioeconomic system. Therefore, some countries define their water resources region of management using solely river basin classification based upon topological relationships, such as the one proposed by Pfafstetter (1989) and described by

Furnans and Olivera (2001) ,or the one derived from one of the many consistent and feasible topographical models available (EC, 2002).

Most recently, however, some countries are aggregating other criteria for defining integrated water resources regions, including historical development, cultural and environmental aspects, and strategic water uses. Kliot et al. (2001) recommends that joint management of water resources should go beyond flood and pollution control. Jansky et al. (2005) suggest that the growth of population and urbanization are becoming important pressures to be considered. Transboundary flows or water transfers, for example, represent the need for a broader geographic scope. The authors assert that some dimensions of groundwater have been neglected historically when considering solely river basin limits for management of water resources. Postel and Richter (2003) also believe it is necessary to consider new development patterns in a way that sustains the environment. Tortajada (2001) affirms that river basins limits are not the most effective and operational institutional arrangements. Wegerich (2008) also questions the determination of hydrological boundaries and asserts that the process is highly influenced by political pressures. Mostert (2006) states that IWRM is context specific. According to the author, although the IWRM reinforces the necessity to consider all aspects and all functions of water, it does not assume that political priorities are defined. In this sense, Mostert defends an alternative approach to IWRM: having flexible water boundaries, according to relevant functional relationships.

For that reason, the first 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. These political boundaries can be characterized not only by international limits but also by boundaries between different sovereign 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, according to Ganoulis et al. (1996) and Waterstone (1996), can be reduced by defining integrated water resources regions and respective comprehensive institutional structure that have sufficient power to lessen the boundary effects.

Additional aspects to be considered need to reinforce the IWRM approaches as they approximate to socioeconomic interests and reflect environmental needs. Jansky et al. (2005) affirm that many water decisions are being made without the necessary understanding of the interrelation among these aspects. Bonell (2008) suggests that environmental, socio-cultural and socioeconomic aspects are important when implementing IWRM in river basin areas. Ringland (1998) discusses the complex interaction of technological, social, political, economic and environmental aspects, and suggests scenario planning as an approach to help address the uncertainty associated with that.

For example, water quality and quantity aspects needs to treated jointly in order to promote IWRM. Azevedo et al., 2000 affirm that water quality aspects are becoming increasingly important. In this case, not only water quantity aspects (e.g. the location and areas of influence from reservoir, dams, water transfers) but also, water quality aspects (e.g. the area of influence from stormwater and sources of non-point pollution) must be considered. The delineation of regions for water resources planning and management needs to reflect this integration as well as the integration between groundwater and surface water. (Tal, 2007; Environment Agency, 2008a; Jansky et al., 2005; Wheater and Peach, 2004). Coordination is required if shared groundwater is assigned to one region.

Coastal areas also need to be analyzed when delineating these regions. According to Margeta (2000), wetlands, estuary and administrative boundaries provide a complex environment for water resources management, and in some cases, it is difficult to determine the exact watershed boundaries. In addition, generally these watersheds are so small that they may be grouped into one region. In such a case, aggregation criteria need to be defined.

Another aspect to be considered is climate change and its possible impacts over water resources regions. According to Binder and Lara (2006), in order to build an adaptive capacity, watershed planning units are being defined to assess the potential climate impacts at the local level, as has been done in Washington State's delineated Water Resource Inventory Areas (WRIAs).

Additionally, environmental necessities and 'ecosystem services' according to Postel and Richter (2003), need to be considered, based upon the concept of *sustainability boundary*. For example, environmental conservation areas, such as forests and parks, should be included in the analysis. In contrast, it is necessary to consider artificial permanent infrastructure and developments because prior natural watersheds boundaries may not represent the real drainage area anymore (Loras, 2008; Barnes, 2003; Environment Agency, 2008a). It includes some structures created for navigation purposes—water supply, water transfers, artificial channels, etc.—that represent consolidated needs.

Regarding the legal framework, Bogardi (1996) affirms that conflicts may exist as a result of different water management criteria established in the same river basin area. According to Draper (2006), different water rights over the same water sources may generate disputes and ineffective allocation. In such cases, the definition of integrated regions may increase the chances of having harmonized water management criteria and policies. In addition, it is important to relate water resources policies to land use polices. Kliot et al. (2001) asserts that due to its moving nature, water resources need to be treated differently than land resources. Adequate integration, however, is still needed. According to Kidd and Shaw (2007), the example of spatial planning in England is well established and should be strongly considered when trying to impose regions for water resources planning and management. In this case, since spatial planning systems have implementation authority and community recognition, it is important to incorporate the established powers into the water resources planning and management system, instead of designating parallel structures.

Regarding data management, when water resources regions are well defined (Fontane, 2000), it is much easier to establish an organized system of information control and sharing policies. This also influences the level of integration between different organizations. Draper

(2006) contends that reliable data reduces uncertainty and are the key to effective water planning and management.

One last aspect to be considered in this analysis is the level and size of water resources planning and management regions. Regions can be defined for the entire river basin, some subbasins or tributaries, or a group of neighboring river basins. According to Berelson et al. (2004), any point in a stream can define a watershed, but deciding where to locate this point, how large it should be, and where to split it can be complex and subject to different interpretations. According to EC (2002):

> "if a river basin is sufficiently large and adjacent to other similarly large river basins, it is likely to be designated as a stand-alone individual river basin district. (...) In the case of small river basins, adjacent to larger ones, or of several neighboring small basins, it will be worth considering combining or joining them to form river basin districts, provided that their geographical size and functional characteristics do not hinder the development of efficient water management" (p.55).

Therefore, even if river basin limits are adopted as the best unit for water resources planning and management, there is still the necessity to define the adequate level and the aggregation criteria for the small units. According to Wegerich (2008), the definition of regions can expand or limit the area for agreements, including or excluding some stakeholders. Texas Water (2008) affirms that the size of the watershed may influence the roles of the stakeholders. One example is presented by Arabi et al. (2006) regarding the role of watershed subdivision on modeling best management practices. Additionally, the selection of an adequate level and respective organizational structures is closely related to the *subsidiarity* concept and how decentralization of powers affects water resources planning and management (Barraqué, 2000a; Barraqué, 2003; Costa, 2000).

Some important aspects beyond river basin limits—such as: political boundaries; integration between water quality and quantity, and between surface water and groundwater; costal areas; climate change impacts; environmental needs and conservation areas; man-made structures; legal frameworks; data management; and subsidiarity levels—were described in this analysis as examples of multiple criteria that should be considered when delineating regions for water resources planning and management. According to EC (2000), similar conditions favor the delineation of regions because of the "synergies emerging from existing similar problems". Historically, the process of delineating water resources regions has been influenced by the dominant sectors' interests, such as hydroelectric power generation. Falkenmark (2004) contends that several of today's approaches are still single-component. Therefore, it is important to define criteria that represent socioeconomic, hydro-environmental, historical, cultural and political aspects in order to delineate integrated water resources regions, and depending on the particular case, consider which of these criteria may be more important. As a result, conflicts of interests between ministers and water use sectors will be reduced.

Additionally, the concept of *problemshed* needs to be incorporated in this analysis. *Problemshed* is defined by Allan (2009, 2005a, 1999) as an answer to problems of a local watershed with limited water resources. Turton (2008) states that it is the "conceptual unit in which the remedy for a problem can be found". The intention is that the management of water resources should go beyond the consideration of the limits of the watershed by shifting from a 'hydro-centric' focus to a comprehensive approach. It allows decision makers to look for a viable coping strategy outside of the watershed limits where more options become available. It is related to environmental determinism and how communities react to resource scarcity. Allan (2005b) and Vlachos et al. (2000) indicate the solution to water problems may be outside the watershed. Loras (2008) claims that water problems take place irregularly through the territory. Turton (2008) suggests that if a problem occurs at a local level, the solution may be at the regional level. Porto and Porto (2008) affirm that the ideal watershed scale to be adopted depends on the incorporation of the necessary problems to be considered. USBR (2008) asserts that it is important to understand the context of the problem, considering multiple aspects: geographical, social, economic, cultural, biological, hydrologic, etc. In such a case, the area needs to be wide enough to include the *problemshed*, but narrow enough to solve the problem effectively.

Analysis of the related organization framework is also valuable in this process. Matthews and Germain (2007) suggest that the key to reducing transboundary conflicts is the creation of comprehensive administrative structures specifically for IWRM that are a powerful means of lessening the boundary effect. Chitale (1995) contends that the Agenda 21 "recognizes the need for new water related institutions at appropriate levels". The first organizational task is the definition of clear boundaries and consequent stakeholders. A harmonized distribution of regions and better-organized institutions avoid the proliferation of organizations and duplication of efforts, including overlapping water resources plans (Draper, 2006). Ruhl (1999) recommends that the geographic unit for IWRM be determined first, derived from the appropriate unit of governmental authority.

Regarding river basin organizations, Tortajada (2001) believes that traditional river basin organizations are not always necessary. In some cases, an efficient organization structure focused on solving specific water problems of a specific region is sufficient. It is important to analyze what is the best region for an efficient river basin organization. On the other hand, Kliot et al. (2001) avers that it is dangerous to create an organization framework for only a portion of the river basin because water is constantly in motion and equal distribution of benefits should be maintained. In both situations, the existing basin organization needs to consider the most important issues and the necessary integration with existing institutions and stakeholders. In addition, Chitale (1995) suggests that it is not possible to have a single standard model for all river basin organizations because they have different phases according to the rising needs. Many different organizations will exist, focusing on different issues and peculiarities. Tortajada (2001) reinforces this hypothesis and affirms that a single model is "highly unlikely to be equal applicable in all the countries". Barraqué (2000c) affirms that "new forms of government allow stakeholders, experts and policy makers to build up meaningful knowledge and appropriate strategies at the same time".

Regarding the definition of organizational design principles to promote effective management of the resources, to better organize groups of stakeholders and to govern the mutual interest resources, Ostrom (1990) and Freeman (1989) present some important factors. Ostrom (1990) emphasizes the necessity of clearly defined boundaries for common-pool resources management. For successful organizations, the author recommends that rules governing the use of resources be matched to local needs and conditions. It is important that most of the affected individuals participate in the process, and for external authorities to respect the decisions made by the organization. In addition, Ostrom (1990) proposes a monitoring system and the establishment of sanctions to prevent free riding, as well as low cost conflict resolution mechanisms. Freeman (1989) also presents some design principles that contribute to the success of local organizations. The author believes the source of leadership recruitment should be local, including management staff. In addition, the distributional share system should remove upstream and downstream distinctions to water rights, and the control should be given to members of the organization. The organization should also provide opportunities for participation, play the intermediary role between central state bureaucracies and local citizens, and provide space to integrate nomothetic and idiographic knowledge. Tortajada (2001) suggests more decentralization of authority and resources to enhance the institutional capacities, and avers that financial and human resources are the strategic aspects to be considered when defining decentralized river basin organizations.

Tortajada (2001) concludes that most of the river basin organizations in Latin America are still ineffective units for water resources management and planning. Grigg (2008) presents them as current examples to prove the potential of water resources planning and management at the river basin level. The current challenge is how to promote the necessary evolution.

Participation also needs to be analyzed, considering the proposed model is going to be used by multiple users and needs to reflect multiple interests. Staes et al. (2008) suggest that it can be used to explore different opinions and believe that it is necessary if the objective is to promote IWRM. Van Ast et al. (2008) asserts that the stakeholders must participate in the decision making, taking into account the territorial levels and subsidiarity principle. Jansky (2005) contends that the capacity of the participatory process depends directly on the scale of the region in the analysis. Postel and Richter (2003) recognize public participation as a strategic way to have a legitimate process, creating a more democratic environment and a multidisciplinary analysis that may offer innovative solutions. Mylopoulus et al. (2008) assert that participation increases the quality of decisions and promotes involvement, legitimacy and a shared role of responsibility.

As an example of a process of delineating water resources regions, the Tocantins State Water Resources Plan (SEINF, 2008), in Brazil, contains a regionalization study that aims to understand territorial dynamics in terms of public and sectoral policies and regional development. This study is presented as the initial step to subsidizing water resources planning. The proposed strategy overcomes the traditional regionalization method that considers the most developed cities as the main focus for regional planning. Instead, the innovative regionalization process intends to maximize socioeconomic benefits, for the whole area in general. The proposed approach is based on the necessity of harmonizing the political-administrative situation with the river basin regions. In addition, there are different territorial bases for water resources, established in different periods of times at the Tocantins State, including a different division at the Paraguai and Paraná Rivers. In order to address the presented issues, the State Water Resources Plan has adopted small catchment areas as aggregation units, instead of municipalities, in order to define homogeneous strategic water resources management regions. The aggregation factors are demographic density, agriculture and livestock production, hydroelectricity generation, industrial grow, conservation units and protected native population areas. The strategic water resources management regions support the establishment of specific licensing criteria in different regions, according to the projected water demand expansion for each type of use, and motivate the creation of river basin committees or new institutional models, especially in critical areas.

2.3. Transboundary Conflicts: concepts and examples

Ganoulis et al. (1996) state that 50 percent of the land in the world is composed of more than 200 international river basins that are home to 40 percent of the world's population. According to a recent update by Kliot et al. (2001), there are 261 transboundary river basins covering 45 percent of the land. Margeli et al. (2008) affirm that Africa has 59 transboundary river basins that hold 80 percent of its available water resources. Ganoulis (2000) highlights the complexity of transboundary water resources as it pertains to inequalities between riparian countries. Gleick (1998) contends that water-related disputes may constitute roots of conflict between countries. Vlachos et al. (2000) reinforce the idea that the transboundary crisis represents not only international frontiers, but also "intra-national transfer across administrative boundaries".

According to Ganoulis (1996), the basic elements to consider in transboundary water resources management are the technical, physical, social, stakeholders, institutions and administrative procedures. All these elements can be better integrated when the established water resources regions respect and reflect them in their management, and the respective relevance of each element is accorded between riparian countries or states. The decision-making process should also be agreed upon, and the goals of the individual country or state need to be in accordance with regional goals. According to Draper (2006), four principles are important to ensure effective transboundary water management: "coordination and cooperation; interdisciplinary analysis; watershed and river basin planning; adaptative management". In consideration of these principles, it is clear that transboundary conflicts constitute an important part of this analysis; thus, some examples are presented.

The first example is the transboundary joint management practice in the River Contract between France and Belgium at the Semois-Semoy basin. According to Rosillon and Lobet (2008), the objective is to restore the river basin's water resources. To accomplish this, a river basin committee was created in order to represent multiple interests. Also, according to the authors, the application in both countries differs because of their respective local dynamics, such as disparate management units. In France, the region is subdivided by the subdrainage basin, a portion of subdrainage basin or embayment. In Belgium, only the subdrainage basin is considered.

Another important example in transboundary water resources management is the collapse of the Soviet Union resulting in the political and economic separation of countries (Shutter, 2008). Due to the absence of established regions, data became unavailable (Campana et al., 2008). In addition, new international basins were delineated and the need for new rules and agreements was established. New regions for international agreements and cooperation on water resources management must be defined. In Armenia, Azerbaijan and Georgia, water institutions are being established and river basin management selected as an important step for transboundary water management.

According to Brilly et al. (2000), the Sava River, a tributary of the Danube River, was the largest national river basin in the former Yugoslavia. With the division of Yugoslavia into several countries, the basin became international, with resources shared by four countries in 2000: Slovenia, Croatia, Bosnia and Herzegovina and the Federal Republic of Yugoslavia. Later, continued division occurred, with Serbia, Montenegro and Kosovo becoming independent states, with each having its own agenda for the reform. All these new 'countries' need to agree now on new management systems, including regions for planning and management of water resources.

Another case is the Lowlands of the Amu Darya and the Syr Darya Rivers, known as the Fergana Valley. The region is shared by three republics—Kyrgyzstan, Tajikistan and Uzbekistan—which emerged from the break-up of the Soviet Union. According to Dukhovn and Horst (2008), the Valley has high demographic pressures and a limited irrigated area, resulting in complex social issues. In the proposed project it was decided that management should be based upon hydrographic units, and coordination between different stakeholders and organizations should be promoted. The need for integration at both the country and the basin levels was identified. Finally, in order to have IWRM, it was necessary to create management systems for the entire river basin, beginning with the valley. The expansion from the valley to the entire river basin was based upon the selection of priority actions over time. This is one example of how the potential of the proposed DSS can be applied to help delineate the region over time and to help organize different groups, interests and organizations. Water allocations are being questioned, and no firm treaty has been signed (O'Hara, 2000). According to O'Hara (2000), the implications for the water resources planning and management regions are significant, and there is not a consensus about how water should be managed and maintained. Wegerich (2008) also discusses the importance of water resources in the lower Amu Darya basin.

The Pecos River Interstate Compact is a good example of water resources management among Federative Units. Grigg (2008) uses this example as an illustration of the fragmented situation caused by the decentralization of water resources management in the U.S. This has resulted in required formal intergovernmental agreements; and lawsuits often exist. Between 1973 and 1988, the compact among Texas State and New Mexico State was under lawsuit in the Supreme Court. The author concludes if integrated water resources planning and management at the river basin level had occurred, the lawsuit would not be necessary.

Regarding International Treaties, Porto and Porto (2008) give these examples: 1616 Danube River, 1851 Amazon River between Brazil and Peru, and 1928 Prata River. According to Tal (2007), international conventions help to influence initiatives at national levels, and promote equitable and reasonable use of the water resources between riparian countries. Examples are: the *UN Vienna Convention on the Law of Treaties in 1969*, the *Helsinki* Rules on the uses of the waters of International Rivers in 1966, *the UN Convention on the Law of the Non-navigational Uses of International Watercourses* in 1997 and the *Bellagio Draft Treaty on Transboundary Groundwaters* in 1989. In addition, the *EU's Water Framework Directive* (WFD) illustrates another example of an international treaty that requires all member states to have a single river basin management plan for an international river basin district with subbasin management plans for supplementation. The WFD is a new ecological and transboundary approach to encourage IWRM. Its purpose is to promote the preservation and improvement of water quality of inland surface waters, transitional, coastal and ground waters.

Many principles and tools developed by the EU in implementing the WFD are considered in this study. One of the DSS purposes is to be able to 'transfer' these principles to other regions of the world according to regional particularities, or at least, to make decision makers aware of these principles and their applicability in order to support the decision process. Tortajada (2001) suggests that the European experiences should be carefully analyzed to confirm if the established regions are the optimal units for water resources planning and management, and to verify their applicability in Latin America.

Finally, *hydrodiplomacy* is presented by Spring (2007), Vlachos et al. (2000), Mylopoulos and Kolokytha (2008b), Vlachos (1996) and Draper (2006) as an important concept to be considered in the negotiation process at international, national, regional and local levels. Mutually beneficial agreements and cooperation among sovereign parties are needed, and all important aspects to be considered in the negotiation process should be included.

2.4. Decision Support Systems: concepts and techniques

In order to deal with complex and ill-structured problems, uncertainty and imprecise objectives, DSS are highly recommended. In this study's context, DSS can provide the necessary understanding about integrated water resources regions and related important aspects, as well as address the process of delineating these regions and incorporating different stakeholders' interests. Andreu et al. (2008) affirm that DSS are the best way to convey knowledge to decision makers, which often cannot generate and understand the necessary information.

According to Turban (1998), it is practically impossible for a person to make completely rational decisions because the "human rationality is bounded by its inability to obtain all the information needed due to economic, technological, political and time pressures". In consideration of this, the DSS can help decision makers to analyze multiple aspects during a decision analysis process, increasing the chances of successful decisions. According to Bonnel (2008), the use of DSS is a new way to apply the IWRM concepts beyond conceptual ideas.

The use of DSS 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., 1981; Turban, 1998). According to Sprague and Carlson (1982), and Turban (1998), the first time DSS' concepts were articulated was in the early 1970's, called *management decision systems*. It initially focused on upper level decisions, especially management information systems, another term used before the introduction of the term DSS for the solution of managerial problems.

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". Salewicz (2005) defines it as a: "Set of computer based tools that provide decision makers with interactive capabilities to enhance their understanding and information basis of the decision problem under consideration through which allows decisions to be reached by combining personal judgment, with the information provided by these tools". Turban (1998) presents the DSS as a way to improve the quality of decisions and address unexpected problems, including the ability to provide new insights and support group decisions. Labadie (2007) presents the value of DSS as a way to increase the quality and efficiency of decision analysis through easy identification of the problems, rapid assimilation through graphical display, comparison of alternatives, cost reduction, and clear documentation and communication. Salewicz (2005) reinforces the DSS as a learning process and a way to improve knowledge understanding and mutual perception of the problem.

Considering the values and applications of DSS, it is important to describe the difference between a structured problem and an unstructured problem. According to Turban (1998), the procedures for obtaining the optimal solution are easily known for structured problems. On the other hand, for unstructured problems, human intuition is generally necessary for the decision making. In this case, heuristics provide the rules of thumb.

Additionally, when dealing with DSS, it is important to describe the difference between simulation and optimization models. A simulation model is a descriptive model, ideal for *what if* questions (Labadie, 2008). In this case, the decision variables are usually selected by trial and error, and the optimum is generally not guaranteed. It runs with different scenarios or alternatives, but not all of them are tested (Turban, 1998). According to Dzurik (2003), it is a cause-effect model that allows flexibility. Simulation is usually related to the concept of 'satisficing' or good enough. On the other hand, optimization models, prescriptive models or normative models are used for more structured problems (Turban, 1998). According to Labadie (2008), the decision variables are being optimized through search procedures. It is mathematically and computationally more difficult, but the best alternative or optimum solution is guaranteed. Andreu et al. (2008) contend that optimization is not the best option when creating a prescriptive tool. The authors defend the combination of simulation and optimization techniques as the best way to improve policy making.

Regarding the phases of the decision process, Turban (1998) suggests intelligence, design, choice and implementation. The intelligence phase is related to the conceptualization of the problem and its decomposition. The design phase is the analysis of the possible courses of action, defining the assumptions and testing the solutions. The choice phase is the evaluation and recommendation of an adequate solution.

Sprague and Carlson (1982), and Turban (1998), specify the three important parts of a DSS: dialog or user interface, model and database. The dialog needs to collect user input, to support communication and knowledge, and to provide the representation of the results through a user-friendly interface. The database needs to organize, store and manage the data structure, supporting the intelligence phase of the decision analysis process. The model needs to give the ability to comprehensively analyze the problem, to provide a flexible and adaptive model support, and to convert the ill structure problem into a well-structured problem.

Regarding required characteristics, Sprague and Carlson (1982) suggest that it is important to specify when the DSS is going to be used, by whom, the nature and purpose, its objectives, if it is going to be used one or many times, the necessary knowledge required from the decision maker, and the responsibility associated with the decision to be made. The authors also suggest the DSS needs to have an iterative design to cope with the rapidity of changes and complexity of today's environment. It should have the necessary flexibility to integrate new applications, and to adapt and easily accommodate changes. It needs to be able to incorporate what is learned and evolve from its initial design through sufficient feedback. Turban (1998) avers that as the decision maker learns more about the problem, the DSS needs to evolve and reflect the necessary advance, including functional requirements not planned in advance.

In order to address some of these requirements, DSS are being supported by Expert Systems (ES). ES is a way to reproduce the knowledge from experts and understand some of the key factors to be considered. According to Turban (1998), ES are computerized advisory programs that attempt to imitate the reasoning process and knowledge from experts. In this study, the ES may provide detailed information regarding the aspects to be considered when dealing with the delineation of water resources planning and management regions.

Turban (1998) affirms that the complexity inherent in some problems require specific expertise in order to solve them. This expertise may be part of an additional KBS used to enhance the DSS operation. Some of the aspects that cannot be expressed in technical terms may be based upon experience to provide meaningful answers. Usually, this knowledge is not found in documented sources. In this case, heuristics is used in order to cope with the complexity of real world.

According to Turban (1998), ES enclose acquisition, representation, inference, and transference of expertise. The inference engine is the rule interpreter. In addition, ES should represent the different ways people reason—formal (logical deduction), heuristic, common sense, division, parallelism, representation, analogy, synergy and serendipity—and it should show the logic behind the conclusions through explanation capability. The author affirms that many ES are rule-based, meaning the "knowledge is represented as a series of production rules". Some possible deficiencies of rule induction are: it is difficult to validate; sometimes the expert cannot explain the reasoning process; and, occasionally there is weak correlation between verbal reports and mental behavior.

Turban (1998) presents some benefits of ES, to:

> "increase output and productivity; increase quality; reduce downtime; capture scarce expertise; flexibility; easier equipment operation; eliminate the need for expensive equipment; operate in hazardous environments; accessibility to knowledge and help desks; improve computer time; simple to understand; help arrive at feasible and 'good enough' solutions; make expert knowledge and experience more widely available; include undocumented sources, mind, emotion, common sense and intuition" (pp.490-491).

KBS or knowledge-based expert systems (KBES), in contrast, are a set of predetermined rules that describe actions to be performed based on captured heuristic knowledge. KBS were introduced in the early 1990s and are comprised of artificial intelligence tools to support justification of decisions, documentation of knowledge, learning and reasoning, according to knowledge representation rules. These rules, according to Dym and Levitt (1991), are fired according to the sequence defined by an inference engine, and may lead to several actions or no action. This set of rules includes heuristics and rules of thumb accumulated by experience. Gonzales and Dankel (1993) affirm that KBS are the most successful field of artificial intelligence in terms of practical applications. KBS applications are illustrated by Klein and Methlie (1995) and Shrier et al. (2008).

Finally, the author stressed that KBES, ES and DSS in general are not created to be a substitute for decision makers, but to provide as much information as possible in order to improve the quality of the decisions. It helps the decision makers to learn from other experiences, and how to act in similar situations. The final choice is made by the decision maker and is political in nature. Stewart (2000) reinforces that the decision environment should be improved in order to reduce conflicts among political players, which result in obstacles to the use of scientific predictions because of their inherent uncertainty. According to the author, this uncertainty cannot be eliminated, but it can be reduced by supporting the judgment process, and making use of every tool that can evaluate and cope with it.

Many DSS and ES are being developed using GIS. GIS have proven to be a valuable tool in the evaluation and analyses of natural resources problems, which often involve spatial relationships. It helps promote IWRM because it improves the decision analysis process (Jansky, 2005) by helping with knowledge acquisition, providing better information (Colaceci, 2008) and facilitating the evaluation of environmental aspects and watershed characteristics (Dzurik, 2003)

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 users and interdisciplinary thinking.

Colaceci et al. (2008) defines GIS as a "complex collection of information processes allowed by a great number of hardware, software and communication technologies". The authors also consider GIS to be a strategic mechanism to implement many decision problems because it facilitates the graphic visualization of the information into a user-friendly interface. Turban (1998) avers that the design of the user interface is one of the most important aspects in DSS. Staes et al. (2008) affirm that spatial databases help evaluate multiple interests and enhance participation. Territory assessment is important in decision systems, especially in planning problems, when IWRM is the goal (Colaceci, 2008).

Considering the importance of the utilization of GIS into the decision process and the easy involvement of the decision makers through the Internet, Dymond (2004) presents an interdisciplinary spatial DSS to watershed management that is available online. The user can straightforwardly analyze which is the most suitable scenario, and the results are demonstrated automatically. Considering its advantages, this DSS facilitates interdisciplinary comprehension of the problem because it promotes multiple user access and interaction. Among other applications, many authors (Store and Kangas, 2001; Fontane, 2007; and Malczewski, 2006) describe the integration of GIS and MCDA.

According to Hajkowicz and Collins (2007), MCDA was first used as a decision analysis methodology in the 1960s and 1970s, and in the early 1990s, there was a growth in MCDA publications because of the adoption of *sustainability* concepts. The authors describe multiple criteria analysis as a "framework for ranking or scoring the overall performance of alternative decision options against multiple objectives". Also, MCDA corresponds to "a body of techniques potentially capable of improving the transparency, auditability and analytic rigor of the decisions made". According to Fontane et al. (1997), a "multicriterion rating scale measures the degree of satisfaction of an alternative compared to a specific criterion".

Since 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) and Fontane (2007), MCDA approaches help to organize the decision analysis process, and can be integrated with ES to incorporate expert knowledge with respect to criteria and ratings.

According to Hajkowicz and Collins (2007) the terms MCA (*multi-criteria analysis*), MODS (*multiple objective decision support*), MADM (*multi-attribute decision making*) and MCDA have the same theoretical basis and represent the same concept in this study. The authors also affirm that there are diverse MCDA approaches such as weighted summation and weighted multiplication multi-criteria value functions, distance to ideal point or compromise programming, PROMETHEE and ELECTRE outranking approaches, pairwise comparisons and fuzzy set analysis. Also, it is important to highlight the compromise programming approach as one of the approaches that has the ability to fully integrate the different elements dimensions into a common framework.

MCDA focuses on discrete or prior articulated alternatives whereas multiobjective optimization (MO) deals with continuous decision variables to be ranked. Both methods include a set of evaluation criteria and respective weights according to its importance, and a set of performance measures. According to Azevedo et al. (2000), some measures may be used to evaluate and compare alternatives in MCDA such as reliability, vulnerability and total resiliency. Hajkowicz and Collins (2007) stress that it is important to perform sensitivity analysis as part of the MCDA process in order to test the strength of the results.

MOPU (1984) emphasizes the difficulty of establishing weights. As an important piece of this process, MOPU stresses the tendency of counting on public opinion in valuing techniques and weight establishment. According to Hajkowicz and Collins (2007), the harmonization of multiple stakeholders' interests and public participation are supported by the adoption of MDCA approaches.

Regarding MCDA application examples, Hyde (2004) proposes a method for water resources analysis that allows the decision maker to examine the solution and to decide with more certainty what is the best chosen alternative among the probable circumstances. Francisco and Ali (2006) present the application of multiple objective programming into an economic analysis of a peri-urban vegetable production using cluster analysis and compromise programming. Ruhl (1999) describe multivariate clustering as a method for delineating ecosystem boundaries.

Among multivariable analytical techniques, MOPU (1984) introduces cluster analysis as the structuring of a set of elements into groups, considering that the best result is the one that maximizes the inter-group difference and minimizes the intra-group difference. Kaufman and Rousseeuw (1990) describe cluster analysis as the classification of similar objects into different groups or partitioning of data into subsets or clusters. It may be used to identify a structure already present or to impose a new structure on a dataset. Aldenderfer and Blashfield (1984) contend that this analysis encompasses many procedures used to create classification and reorganize data into homogeneous groups. It is also called numerical taxonomy or automatic data classification.

The *distance matrix* or *similarity matrix* is the concept related to the relative distance measure between elements to be grouped. It represents the similarities or dissimilarities between clusters and the analysis of these values usually derives a numerical measure of homogeneity (Bellman, 1973; Bellman and Zadeh, 1970). According to Aldenderfer and Blashfield (1984) and Bellman (1973), this limit can be the average distance between elements of each cluster within a given level of similarity, or the minimum distance between these elements, or the size of the interval, or the minimum level of variance for the new potential cluster, or the lower level of complete linkage required for all links between the existing cluster and the new potential member. In addition, according to Aldenderfer and Blashfield (1984), the selection of adequate criteria to represent the distance measure is the most critical step in cluster analysis. This distance measure can be calculated using different methods such as compromise programming.

Kaufman and Rousseeuw (1990), and Aldenderfer and Blashfield (1984) avers that clustering techniques are being applied in many domains such as artificial intelligence, pattern recognition, geographic classification, data mining, image analysis, bioinformatics, machine learning, biology, medicine, market research, social analysis, geology, anthropology, psychology, political sciences, and chemistry.

The most common cluster analysis methods are the hierarchical method and the partitioning method. The first one can be agglomerative when it begins with every element as a separate cluster, or dissociative when it begins with all elements grouped in one cluster. The choice of the cluster method, according to Kaufman and Rousseeuw (1990), depends on the type of data and purposes of the grouping process. Different methods usually produce different results.

Kaufman and Rousseeuw (1990) maintain that the hierarchical method is conceptually simple and deals with different numbers of groups in a run-chaining effect. This method shows different stages of agglomeration of units and requires a stop criterion, e.g. an ideal number of groups. It finds successive clusters using previously established clusters, and is efficient in terms of computer time. Aldenderfer and Blashfield (1984) affirm that just one distance link is necessary to group two clusters based upon the highest level of proximity. The dendogram tree illustrates the hierarchical relation. The hierarchical method's drawback is caused by the fact the initial decision to group one element is definitive, and cannot be repaired in the future if a cluster formed along the way is not necessarily the best option. Aldenderfer and Blashfield (1984) emphasize that the method passes only once through the data and, therefore, decisions cannot be changed later. As a consequence, the methods' tendency is to create elongated groups. Regarding the two different hierarchical approaches, the divisive approach is more advantageous than the agglomerative approach because it starts with few larger clusters and fewer steps may be necessary to reach the final desired groups. As a result, chances of having bad decisions are smaller.

Kaufman and Rousseeuw (1990) point out that the partitioning, or k-means method, consists of defining K groups, in which each group contains at least one object and each object belongs to one group. This method, which is widely applied (Painho and Bação, 2000), tries to select the best cluster with K groups, and makes more than one pass through the data, assigning each element to the nearest cluster center. According to Aldenderfer and Blashfield (1984), this property can compensate for an initial poor division. Additionally, heuristics can be applied to define this initial division. The definition of K is important since not all values result in 'natural' clustering. Final results may depend on the initial solution given. In addition, this method allows for the representation of the results using fuzzy logic. For example, using the concept of membership coefficients or degree of belonging, one element may belong 90 percent to cluster #1 and 10 percent to cluster #2.

Again, according to Kaufman and Rousseeuw (1990), data need to be pre-processed in order to be used in cluster analysis, especially when different measurement units are being used. Pre-processing may involve weighting or standardization. The authors also affirm that most of the statistical packages do not have the most modern methods of cluster analysis. Therefore, it is necessary to develop new algorithms, which are becoming more potent with the advances in computer power.

Aldenderfer and Blashfield (1984) state that the "key to using cluster analysis is knowing when these groups are *real* and not merely imposed on the data by the method". In this sense, the ideal number of clusters may be determined using the elbow criterion. Hanusch and Pyka (2006) write that this is a common employed measure used to define the optimal number of different classes. In this method, after the ideal number of groups is reached, adding another cluster will not add information. This can be verified by the percentage of variance explained by the clusters. According to Aldenderfer and Blashfield (1984), this is a complex procedure considering the nature of multivariate sampling distribution. In addition, the authors suggest that some validations techniques need to be evidenced in order to evaluate how the clusters created actually represent the pattern of similarity between the elements.

Among optimization techniques, combinations of artificial neural networks, fuzzy logic, DP, and genetic algorithms (GA) have important applications in classification and clustering (Izquierdo, 2008). Fuzzy clustering is presented by Kaufman and Rousseeuw (1990) as a generalization of the partitioning method in which the objects are spread out over different clusters, with various degrees of belonging, representing the data ambiguity. DP and cluster analysis are being applied jointly in many examples. Esogbue (1986) avers that combining these methods is an excellent approach. Liua and Gader (2002) present a segmentation and DP-based handwritten word recognition system. Brailovsky (1992) presents the application of multi-stage cluster analysis to perform image segmentation. Mishalani and Koutsopoulos (2002) developed a methodology based upon nonparametric cluster analysis and DP for the analysis of the deterioration of infrastructure condition in order to identify optimal spatial regions within which behavior is uniform. Esogbue (1986), Esogbue and Bellman (1984), Bellman and Zadeh (1970) and Bellman (1973) discuss a DP formulation of a clustering problem. The problem is divided into two parts: 1) division of the set of alternatives into K groups according to the relative distance between alternatives, and 2) determination of the optimal value of K according to some 'cost' criteria, and then the optimal subdivision.

The term *dynamic programming* was first coined by Richard Bellman in the 1950s (Dreyfus, 2002). Bellman (1963) defines DP as the "mathematical theory devoted to the study of multistage decision processes" or sequential decision process. This method is used to efficiently solve problems that present overlapping and optimal substructure properties. According to Bellman, there are many applications in engineering, economics, operations research, physics and mathematics. Bellman's Principle of Optimality, as presented by Labadie (2008), states: "no matter what the initial state and stage of a sequential decision process, there exists an optimal policy from that state and stage to the end". This is an important principle used to evaluate the different problems that may be solved using DP and to indirectly comprehend how to restate an optimization problem in recursive form. Dreyfus and Law (1977) affirms that "a major part of the art of DP is the appropriate choice of the subproblems that must be solved in order to solve the given problem".

Bellman (1954) introduces certain classes of problems related to the control of a physical system over a time interval, and how the theory of DP can be used to solve them. In that this is a huge contribution to the method's equation, it is known as 'Bellman equation'. Also, according to Bellman (1956), there are two different functional equations used in dynamic decision problems—one for discrete intervals and another for continuous processes. Another aspect to be considered when dealing with DP application is the 'curse of dimensionality'. Bellman (1957) describes it as the existing limitation to be considered when multiple space dimensions are necessary, resulting in an exponential increase in computer time. Labadie (2008) presents the advantages of DP: a) the method is ideal for non-linear problems and highly regulated systems; b) it decomposes large-scale problems into a sequence of smaller problems; c) it provides feedback rules; and d) it allows explicit stochastic optimization and analysis of risk.

Regarding additional DP application examples, fuzzy DP is presented by Fontane et al. (1997) for planning reservoirs with imprecise objectives. In this example, the goals and the constraints were associated with linguistic descriptions. The objectives were subjective and vague, including both qualitative and quantitative aspects. As a result of the presented aspects, an implicit stochastic approach was used, applying the fuzzy dynamic recursion relation. This way, the "perceptions of degrees of satisfaction of linguistically described reservoir objectives were modeled as fuzzy membership functions". The authors state that the use of fuzzy sets provides "a mechanism to represent the degree of satisfaction of reservoir objectives" and "address the problem of subjective and noncommensurable objectives" and qualitative judgments.

The theory of fuzzy sets was first developed by Zadeh (1965). According to the author, a "fuzzy set is a class of objects with a continuum of grades of membership". Bellman and Zadeh (1970) describe a fuzzy set as "a class of objects in which there is no sharp boundary between those objects that belong to the class and those that do not". Fontane et al. (1997) avers that the use of fuzzy sets "allows a gradual transition from a situation that completely fulfills a concept to a situation that does not". Turban (1998) suggests that fuzzy sets may represent the gray areas and the term 'maybe'. Zadeh (1965) writes that "a fuzzy set A in X is characterized by a membership function which associates with each point in X a real number in the interval [0,1]". Esogbue (1986) claims that a fuzzy set is especially suited for qualitative aspects, or when the classification may be influenced by emotion or imprecise knowledge.

Hajkowicz and Collins (2007) aver that the fuzzy set theory is appropriate to handle the uncertainty inherent in ill-structured problems. Probability theory also deals with uncertainty, but fuzzy sets constitute a 'nonfrequentist' approach used to describe imprecision or vagueness (Labadie, 2007; Shrestha et al.,1995). Bellman and Zadeh (1970) define the decision analysis process in a fuzzy environment as "a decision process in which the goals and/or the constraints, but not necessarily the system under control, are fuzzy in nature". In such a case, goals and constraints do not have sharply defined boundaries and the solution is the alternative at which the membership function of a fuzzy decision has the maximum or the minimum value. The authors compare this methodology to conventional approaches using Lagrangian Multipliers and Penalty Functions. In both cases, the goal and the constraint functions are treated identically in the formulation, considering the intersection of the goals and constraints.

Bellman and Zadeh (1970) question the assumption of equating imprecision with randomness, using, for instance, probability theory. The authors describe the difference between randomness and fuzziness. Randomness is the assumption of crisp boundaries between classes that separate objects and is related to the uncertainty of membership to those classes. Fontane et al. (1997) affirm that "a classical crisp set is a collection of elements for which any given element under consideration can be classified as a member or not a member". Fuzziness is a type of imprecision that assumes "there is no sharp transition from membership to non-membership"; instead, there may be 'grades of membership'. Zadeh (1965) adds that "the classes of objects encountered in the real physical world do not have precisely defined criteria of membership". Examples of fuzzy characteristics are large, small, colors, significant, approximate, close, etc. The author also describes the notions of inclusion, union, intersection and convexity, applied to fuzzy sets.

Bellman and Zadeh (1970) believe that fuzzy analysis is the best way to demonstrate the difference between human intelligence and machine ability. Also, the authors affirm that it is simpler and generally more advantageous to deal with fuzzy sets than probability theory. Turban (1998) states that the use of fuzzy sets provides flexibility and "frees the imagination". Regarding additional fuzzy application examples, Shrestha et al. (1995) describe a fuzzy rule-based model used for multipurpose reservoir operation. Esogbue (1986) presents the fuzzy multi-stage decision analysis process and builds a fuzzy DP algorithm for cluster analysis. The results from this author's analysis indicate that this algorithm is the most stable compared to other algorithms and concludes that this is an effective tool for clustering fuzzy data. DP ensures optimality, especially considering that this is a one-dimensional problem. The author describes fuzzy DP as a way to incorporate fuzzy set theory into the optimization of imprecise processes. Additionally, in the presented problem, G 'closely related' alternatives need to be optimally clustered into K groups. The term *closely related* illustrates the imprecise aspect that represents fuzziness. It means the relative distance is fuzzy and, consequently, the alternatives will be grouped into fuzzy groups.

Another concept related to DP is the optimal stopping (OS) concept. Esogbue and Bellman (1984) present an example using fuzzy DP with terminal times. According to Tsitsiklis and Roy (1999), the OS problem is to determine the right time to finish a procedure in order to maximize the return benefit. The authors introduce a set of complex OS problems and a theory characterizing OS times for discrete-time ergodic Markov processes with discounted rewards as well as a computational systematic method for approximating solutions. Krichen and Abdelaziz (2007) investigate a conflicting OS problem with two decision makers having the task to accept one single offer and stop the selection process, or get a new offer. In this case, a stopping rule for the group must be defined. Yoshida (1994) deals with fuzzy DP with OS times and with general state spaces and action spaces, considering Snell's OS problem for the Markov fuzzy system. In this problem, the objective is to find paths and stopping times to maximize the grade of fuzzy sets. Stein (1980) presents an approach, using DP, to control and stop a deterministic or a stochastic system in a fuzzy constraints and goal environment. The objective is to maximize the membership function based on the optimal sequence of controls and a set of possible stopping times.

In addition, GA and cluster analysis are also being applied jointly in several attempts (Levine, 1994; Lorena and Furtado, 2001; Cowgill and Harvey, 1999; Paterlini and Krink, 2006; Painho and Bação, 2000). GA was introduced by Goldberg (1953) as a stochastic search algorithm inspired by the natural selection process and genetics. It is a feasible optimization method that is being applied in several fields, from political science to medicine and engineering. In this method, the transition rules are probabilistic, while other methods have deterministic transition rules. New search points are speculated based on historical information, and the optimal solution is found with a relatively large number of populations and subpopulations, after a predefined number of generations. Levine (1994) presents the utilization of GA to optimize flight crew scheduling, which is a difficult combinatorial partitioning problem and affirms that there is a limitation on solving highly constrained problems. Lorena and Furtado (2001) aver that GA is considered a powerful optimization method and illustrate its application in some clustering problems in graphs. Cowgill and Harvey (1999) propose a GA clustering technique, to maximize a variance-ratio (within-cluster cohesion and external cluster isolation), that works toward the global maximum for a specific number of clusters more efficiently than the hierarchical agglomerative and the k-means partitioning methods. The authors assert that clustering is a difficult combinatorial problem due to the large number of possible group assignments that exist, making an exhaustive search unreasonable. Therefore, Cowgill and Harvey recognize the importance of additional clustering methods, especially considering that GA approaches can benefit from parallel computing hardware. Painho and Bação (2000) present GA as a flexible and powerful method that performs a global search for problems with local suboptima, such as the problem of minimizing the within cluster variance and in geographical clustering problems. Paterlini and Krink (2006) compare the use of GA, particle swarm optimization (PSO), and differential evolution (DE) to solve partitional clustering problems. According to the authors, DE is easy to implement and requires less effort than GAs and PSOs, considering that a "clustering algorithm should be simple, efficient and capable of dealing with large data sets." Also, the authors recommend the use of statistical criteria that represent the intra and inter cluster measure of homogeneity to quantify the goodness of the partitions.

Regarding general examples of DSS dealing with the planning and management of water resources, Cameron (2002) presents the Regional Integrated Management Information System (RIMIS), which has an objective to provide planners and decision makers of different areas and organizations with an information infra-structure in order to permit a broader and more integrated investigation of socioeconomic and water quality questions involved in decision processes.

Considering the difficulty of interaction between policies and the scientific environment on water resources management, Falkenmark (2004) proposes the utilization of the HELP program—Hydrology for Environment, Life and Policy. This program intends to create a scientific method to watershed integrated management and particularly, to facilitate the dialog between scientists, decision makers and stakeholders. According to Falkenmark (2004), the challenge to sustainable management is to find the balance between human development and the impacts over ecosystems. As a result of this premise, the task proposed in the model is to develop a management system where decision makers can interact with the scientific community members, users and other decision makers, intending to harmonize water uses in a watershed.

Another similar example—CATCH: support decision model to watershed management—is presented by Collentine (2002), having the objective of promoting the discussion and deliberation among decision maker groups through the definition of relevant socioeconomic parameters and their inter-relations. It also helps to structure the participation of decision makers at the watershed level.

Baltar (2003) tackles the complexity of water resources problem analysis and, consequently, the importance of DSS. The author describes some important aspects to be considered in the process of creating and implementing these systems: 1) clarity on the definition of the objectives and functions, broad discussion and synchrony among decision makers and the technical team; 2) flexibility of the DSS; 3) organization, treating and updating of available information; 4) efficiency of the analysis resources; and, 5) good results' communication.

According to the CWRRI (2005), a DSS was developed for the South Platte Basin to support water resources management. The decision process involved the Water Institutes from Nebraska, Wyoming and Colorado. Some objectives of the research were: 1) to summarize water resources modeling in the basin; 2) to organize the discussions between stakeholders; 3) to register the questions faced by the users; 4) to define the requirements for a decision support model; and, 5) to develop a network of water managers of the basin.

According to the literature review presented here, the outline of the proposed approach is envisaged as a way to provide the necessary support for the delimitation of water resources planning and management regions through experience and common sense. The most important element to be emphasized is that the *decision support system* is not a *decision making system.* This approach seeks to formulate a process technically consistent, politically appropriate and legally relevant, in a way that promotes IWRM, multiple stakeholders' participation, and decentralized decision making.

3. FUNDAMENTALS OF THE PROBLEM: EVALUATING THE ASPECTS RELATED TO THE DELINEATION OF WATER RESOURCES REGIONS

As described above, the process of developing WARPLAM DSS can be summarized in three main phases, as illustrated in Figure 3.1: Phase 1) Evaluating the aspects related to the delineation of water resources planning and management regions through a comparative analysis in eleven different countries; Phase 2) Building the DSS through the definition of a suitable approach utilizing the aspects identified in Phase 1; and Phase 3) Demonstrating the capability of WARPLAM DSS through a case study in Brazil.

This chapter outlines Phase 1, fundamentals of the problem. The methodology used for this phase is a qualitative comparative analysis using a simple theoretical framework.

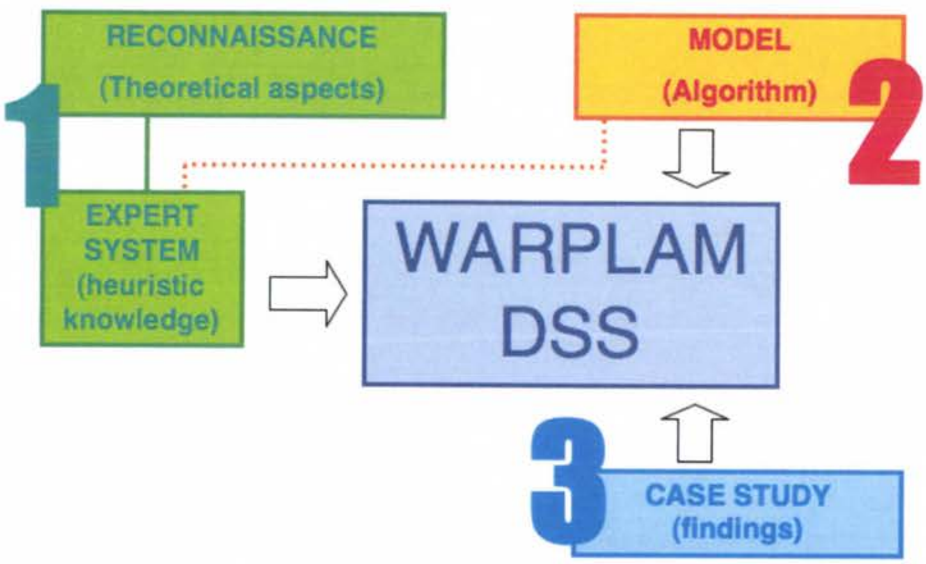


Figure 3.1. WARPLAM DSS Developing Phases

The main objective of the analysis is to recognize more comprehensive aspects related to the process of delineating water resources planning and management regions. The analysis focuses on existing water resources regions and their respective institutional frameworks, as well as on evaluating the aspects considered when establishing these regions at regional, national, and international levels. It aims to identify if river basin limits and socioeconomic, political, and environmental aspects are considered when delineating regions for planning and management of water resources and how, in practice, these regions promote IWRM. Heuristic knowledge, used by experts, in decision-making processes related to the definition of these regions, is also analyzed. The most important aspects recognized in this phase will be included in the DSS as the KBS in order to increase the quality of future decision-making processes.

The final list of selected countries was chosen based upon the information available at each step of the process. The list constitutes a broad selection of countries on two different continents—Europe and Americas, including examples from different types of political systems, such as unitary governments and federal governments. Despite the relatively large number of countries selected, the examples are not exhaustive. Considering the variety of cases included in the study, it is assumed that the analysis of the selected countries represents unbiased results, with negligible gaps, which leads to valid key messages and general lessons.

The information necessary for the analysis was obtained in three steps based upon a qualitative approach. These steps include: 1) the analysis of documented sources; 2) administration of an online survey; and, 3) personal interviews with experts. The analysis of documented sources was based upon existing legislation, treaties, and agency reports. However, it was not sufficient to evaluate the wide range of aspects related to the definition of water resources regions. This is a specific topic, which is usually not documented. Therefore, an online survey was administered and follow up personal interviews were conducted as a secondary analysis to complement the documented sources' analysis.

According to Fontane et al. (1997) surveys need to be cautiously planned, executed, and interpreted in order to provide effective information, especially when dealing with qualitative data. An online survey was prepared considering the authors' suggestions, and sent to experts for feedback (Appendix 1). These experts where selected according to their experience in the field of water resources planning and management. Together with the questionnaire, some pre-collected data was also sent to the experts in order to illustrate the information needed, such as existing water resources regions, related institutional framework, and criteria considered when defining these regions. The experts were encouraged to include, in their answers, their personal experience in dealing with the delineation of water resources regions, according to each country's particularities. Finally, a structured personal follow up interview was planned as a goal-oriented process in order to reduce interpretation problems and address some conflicting information. A random sample of experts was selected from the online survey process respondents, to allow them to elaborate on their arguments and to acquire additional relevant information.

As a result, about 160 documented sources were analyzed; approximately 40 specialists answered the online survey; and 25 experts went through a face-to-face question and answer structured process that was intended to track their reasoning processes. The complete list of specialists is located in Appendix 2. The following tables (Table 3.1 to 3.3) present, as an example, the results obtained in Portugal, Netherlands and Brazil. The general overview of the results of the comparison analysis, including the complete list of the 11 countries analyzed (Portugal, Spain, Greece, England and Wales, the Netherlands, Germany, France, the United States, Colombia, Mexico, and Brazil) is included in Appendix 3. The information is organized under seven topics: 1) form and system of government in each selected country; 2) existing water resources regions and respective level and sublevels; 3) main purposes of the existing regions in relation to planning and management aspects; 4) main criteria considered when delineating these regions in relation to hydrologic, social, economic, and environmental aspects; 5) existence of river basin committees respective to these established water resources regions; 6) existence of real planning and/or management at the river basin level at established water resources regions; and 7) existence of international river basin commissions respective to established water resources regions.

Table 3.1. Analysis of Water Resources Planning and Management Regions in Portugal

	**PORTUGAL**
Form / System of Government	Unitary Republic Parliamentary
Water Resources Regions	Ten River Basin Districts (RBDs), Under WFD (eight continental including groundwater and adjacent costal waters and two regional archipelagos including groundwater and costal waters in all islands)—RH1: Minho and Lima; RH2: Cávado, Ave, Leça and Ribeiras da Costa; RH3: Douro; RH4: Vouga, Mondego, Lis and Ribeiras do Oeste; RH5: Tejo; RH6: Sado and Mira; RH7: Guadiana; RH8: Ribeiras do Algarve; RH9: Açores; RH10: Madeira
Purposes	Mainly planning according to the WFD strategy.
Criteria considered when delineating water resources regions	Mainly Hydrographic Political: consideration of transboundary river basins (international x national). The corresponding international RBDs are in accordance with the Spanish ones. Historical: Portugal has a long tradition in water resources planning and management. Prior planning processes: Fifteen river basin plans were defined by law in 1994 and approved in 2000 and 2001. The bidding process was organized in order to group some smaller river basins. In cases where the river basin was national, the plan was elaborated by the respective regional entity; if international, the plan was elaborated by the INAG. Size: combination of smaller river basins, according to WFD strategy.
Other Established Regions	Five Hydrographic Region Administrations—ARH (continental): ARH-Norte (embracing RH1, RH2 and RH3), ARH-Centro (RH4), ARH-Tejo (RH 5), ARH-Alentejo (embracing RH6 and RH7), ARH-Algarve (RH8). The two Portuguese autonomous regions—archipelago of Azores and Madeira—do not follow this model because they are under the jurisdiction of regional governments, and their territory is composed of relatively small islands. They were established in 2008 as the water resources competencies were separated from the Regional Development Coordination Commissions—CCDRs structure—in order to empower the regional water resources management process at the river basin level.
Purposes	Management and Planning The ARHs are responsible for water quality, data management, licensing, supervision, water use charges (including economic analysis), monitoring, planning (execution of river basin plans and specific plans for water management), river basin organizations and applying the program of measures established at the planning process (implementation). They are also responsible for coastal water and groundwater management. In cases where there is a common aquifer, the responsibility is shared among the ARHs. The dominant responsible party is the ARH where the aquifer is under pressure and affects considerably the superficial water resources. In addition, the ARH has the important task of harmonizing and coordinating the general environmental information exchange between the CCDR under their respective territories. For example, the ARH-Tejo has three different CCDRs in its territory, representing the most significant case that justifies the importance of the ARH.
Criteria	Mainly Hydrographic, including the RBDs delimitation established for the WFD. Political Jurisdictions: transboundary basins and municipal councils that are significant. Historical: Algarve, for example, is historically well delineated. Prior Plans: the 2002 National Water Plan has important references on regional organization.

	**PORTUGAL**
Criteria (cont.)	Administrative/Institutional: consideration of prior institutional structures. In 1886, there were four hydraulic divisions: North until Douro, Douro to Lis, Lis to Tejo, and Tejo until South. In 1892 there were only two subdivisions: North until Lis, Lis until South. Then, from 1949 until 1992, there were five Hydraulic Services Regional Directions: Douro, Mondego, Tejo, Sul e Algarve. Later, five CCDRs—Norte, Centro, Lisboa, Alentejo, Algarve—become responsible for the environment and spatial planning, including water resources. The CCDRs, however, do not have the river basin concept, and the water resources were not the focus of their competencies. Therefore, the ARHs resumed the specific water focus, largely based upon the river basin concept and adopting divisions that are similar to the 1949—1992 ones, representing historical aspects. Financial Efficacy: Avoid excessive institutional structures that may result in additional costs. Hydraulic Connectivity: some river basins depend on each other for water resources planning and management. For example, the Alqueva Reservoir connects Guadiana River Basin with Sado River Basin. Water Quantity and Quality aspects: recognizes the territory asymmetry in terms of spatial and temporal variability of water quantity and quality. Similar Kinds of Problems: Problems occur, for example, when two adjacent small river basins suffer from drought events. It is related to the concept of *problemshed*. Many times the problems are not distributed harmoniously within the population or natural regions. Social: similar human occupation process, for instance at the three RBDs of ARH-Norte. Geological/Geomorphological: similar characteristics, for instance Mira and Sado. Economical: similar conditions, for instance, Mira and Sado have traditional agriculture activity, rural areas not well developed, and suffer tourism pressures in the coastal area. Regional Planning Regions and the Territorial Units for Statistical Purposes—NUTs: the second level (NUTII) was considered when defining the ARHs. They represent similar socioeconomic profiles, corresponding to the CCDRs, and are used for macro planning purposes. Geographical Distances: According to the *2005 Water Law*, Tejo RBD does not include the Ribeiras do Oeste region, which is part of the Lis/Mondego/Vouga RBD. However, water resources planning and management of this region—Ribeiras do Oeste—is part of the ARH Tejo by delegation of the ARH Centro, which is responsible for the Lis/Mondego/Vouga RBD. Ribeiras do Oeste region is more centrally located within the Tejo RBD than the Lis/Mondego/Vouga RBD. It represents the Atlantic border of the Tejo River Basin and has much more adjacency to it than to Lis/Mondego/Vouga RBD. The population living in this area has a greater proximity to Lisboa, where the coordination of ARH Tejo is located. One justification for the fact that the Ribeiras do Oeste region is not included in Tejo RBD is that Tejo River Basin is international. A similar arrangement occurs at the Algarve Region, in which two important tributaries of the Guadiana RBD (RH7) are administered by the ARH-Algarve. The possibility of delegation is considered in the legislation in order to accommodate some singularities and allows flexibility. Communication Distances: reinforces the geographical distance criteria
Committees	RBD Councils are the consultative bodies of the ARH, comprised of public administrators, municipalities, users, and other technical, scientific and non-governmental authorities. They support the elaboration of river basin plans and discuss main water issues in each RBD included in their territories.

	**PORTUGAL**
Public Participation	Yes, through the RBD Councils and also during the river basin plans elaboration process (public participation happens six months before the final report of the plans). Local authorities (Municipal Councils and Municipal Assemblies) are also very vocal, politically influential, and considered to be very representative of the citizens. These institutions are active in all water related matters and participate in the RBD Councils.
Real Planning and/or Management at River Basin Level	Yes, despite the fact that Portugal has a strong tradition of centralized administration and decision-making processes. Despite the conviction that they will be effective, the existence of the ARHs is recent; therefore, more experience is necessary in order to evaluate the real planning and management efforts at the river basin level.
International River Basin Commissions	The Albufeira Agreement is the most recent bilateral agreement between Portugal and Spain, signed in 1998 and effective in 2000. It supports coordination at the four international river basins, including superficial and groundwater: Minho-Lima, Douro, Guadiana and Tejo. It establishes, also, a Commission for the Implementation and Development of the Agreement (CADC), under the dependence of the Foreign Affaires Ministry but with participation of INAG and ARH, which is responsible for coordinating the information change process, evaluating projects that may cause impacts for any side, helping to implement the WFD, overseeing the program of measures implementation process, and maintaining the minimum flows regime. Both countries have agreed on RBDs and corresponding competent authorities—ARHs in Portugal and *Confederaciones Hidrograficas* in Spain—to put the WFD into practice. The first planning process for the WFD is being performed separately in these international RBDs. Some decision makers believe that the second planning process should be performed jointly, having one single plan for each of the four RBDs, although this is controversial for political reasons. There is a debate between *joint planning* versus *coordinated planning*, with the later prevailing.
General Comments and Questions	It is important to emphasize that Portugal and Spain have a long tradition of international collaboration and signed agreements in water resources issues, dating back to 1864. The Water Institute (INAG) is the national water authority, responsible for water resources planning and management at the national level, coordinating and harmonizing procedures, guaranteeing the effective implementation of the water law, ensuring the execution of the national policies, and dealing with international questions as the EC interlocutor. The National Water Council is the consultative body of the government for water resources issues that promotes the integration of sectors' interests through it representatives. There is a significant effort to integrate spatial planning into water resources planning and management in Portugal, as this is considered essential to the implementation of effective policies. The *2005 Water Law* is the most updated legislation dealing with water resources in Portugal and represents the transposition of WFD principles to Portuguese legislation. It establishes an important institutional reform, ensuring the integration of management and planning is performed throughout the different levels, from the regional to the national level. This law has also grouped the 15 existing river basins into eight RBDs. The prior 15 river basin plans are being considered as the basis for the preparation of the new plans, in accordance with the WFD strategy.

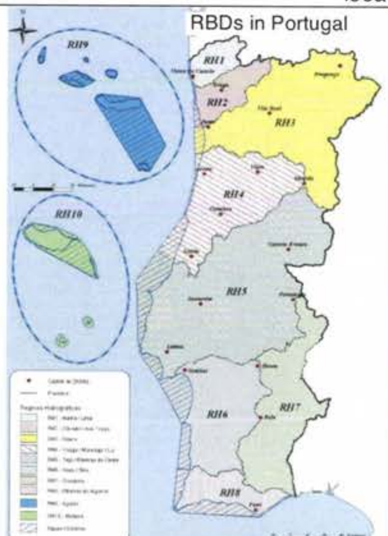
	**PORTUGAL**
General Comments and Questions (cont.)	ARHs have financial independence because they are in charge of water use fees. However, these fees may be too low in some ARHs to promote solid independence. ARHs can create regional departments with a specific council to focus on more problematic subbasins; for example, the Aveeiro River and the Ria de Aveiro (lagoon). For that, they should develop a specific water management plan, as established in the *2005 Water Law*. ARHs need to work in agreement with CCDRs in order to promote the necessary integration with environmental and spatial planning components. Depending on a specific situation, one ARH can delegate all water resources management functions, in a specific region, to another ARH. This is the case of two tributaries of the Guadiana River Basin, located in the territory assigned to the Alentejo ARH, but belonging to the Algarve Region. This river basin has been historically administrated by the Algarve Regional Authorities. The Algarve region also utilizes the water resources of those tributaries of the Guadiana River Basin on a large scale, including some existing water transfer infrastructure and an interconnected drainage system. The problems are similar between those two tributaries and the other rivers in the Algarve, included in the Algarve ARH, including droughts and floods. There is also a greater proximity of the population to this ARH than is the case with the Alentejo. Ribeiras do Oeste is another example of delegation that brings some flexibility to a hydrographic criteria. It is a group of small rivers that are included in ARH-Centro in strict hydrographic terms, but it would be completely artificial to have water users dealing with the administration in Coimbra instead of Lisbon where ARH-Tejo is located.
Map of the Water Resources Regions	 
References	Correia, 2000; EC, 2002; MAIA, 2003; CNA, 2005; INAG, 2005; Silva, 2005; Brito, 2007; INAG, 2007; MAOTDR, 2007a & 2007b; INAG, 2008; MAOTDR, 2008a, 2008b & 2008c; MFAP and MAOTDR, 2008; Rodrigues, 2008; ARH Alentejo, 2009a; ARH Alentejo, 2009b; ARH Norte, 2009; Brito, 2009; Correia, 2009; EC, 2009b; Eira Leitão, 2009; Maia, 2009; Matoso, 2009; MCOTA, 2002; Mendes, 2009; Pio, 2009; Rocha, 2009; Saraiva, 2009.

Table 3.2. Analysis of Water Resources Planning and Management Regions in Netherlands

	**NETHERLANDS**
Form / System of Government	Unitary (National, provincial and municipal level) Monarchy (Constitutional) Parliamentary
Water Resources Regions	Four International RBDs under WFD: Ems, Rhine, Meuse and the Schelde basins (designated on the basis of the *Water Management Act*). The Dutch part of the Rhine RBD is subdivided into four areas for practical purposes. Within these areas there is cooperation among state agencies, provinces, water boards, and some municipalities.
Purposes	Mainly Planning (mostly cooperation/coordination because they have no authority)
Criteria	Hydrographic
Other Established Regions	Twenty-six Water Boards (*Waterschappen*) are bottom-up governmental institutions that are elected/appointed by the main water user categories, levy their own taxes, and have legal and administrative powers.
Purposes	Management (planning is mainly carried out at the Provincial level) The first water boards (*Waterschap*) were created in the twelfth and thirteenth centuries, During the Middle Ages, farmers began to organize themselves at a local level to improve the management of dikes and polders. The Dutch *Constitution of 1848* introduced the term *Waterschap*. Only in the Twentieth Century was the whole country divided into water resources regions. The first water boards were responsible only for dikes and drainage. Collection and treatment systems are more recent tasks. Some of the water boards carried out several water management tasks. Currently, all the water boards incorporate the full scope of water management, including water quality, operational management plans and regional surface waters management, as well as regulating most groundwater abstractions. More specifically, their tasks include policy development, local and regional quantitative and qualitative water management, data management, monitoring, flood risk management, treating urban wastewater, granting water permits and establishing usage charges. Regarding land use planning and management, water boards act as advisors. They are not active in the environmental field in general, only when water is related, for instance, in water emissions. The water boards have a constitutional position equivalent to municipalities but are under the supervision of the regional provinces and the central government. The Dutch Association of Water Boards—*Unie van Waterschappen*—was created in 1927 to promote the water boards' interests at national, and later, at international levels.
Criteria	Mainly Hydrographic. Because The Netherlands is a hydrologically complex area, the concept of a river basin might be adapted. Half of the country is a single water system according to system analysis and 60 percent of the land is below sea level. The dike rings are areas with risk of inundation protected by a ring of dikes and also by higher grounds. The Netherlands can be subdivided into five areas according to hydrological aspects: coastal, rivers, lake, higher parts, and lower parts. The areas for water management up to 800 A.D. were divided In: peat reclamation area, the Schelde delta, the area of the rivers and the tidal salt marsh area in the north. From 800 to 1250 A.D., there were no separate governing bodies; local governments were responsible for water management and drainage while some regional water boards were being defined. From 1250 to about 1600 A.D., the organization of the water boards was part of the governmental structure in many districts; this is

	**NETHERLANDS**
Criteria (cont.)	reflected in the 20th Century model. From 1600 to about 1800 A.D., the provincial government was becoming increasingly responsible for water management. Between 1800 and 1950 A.D., The Netherlands had thousands of water boards. From 1800 to the present, the country has been divided into five districts that represent the regional directorates and the basis of the organization of the central government. The water boards are primarily determined by hydraulic aspects such as subcatchment basins and water systems or groups of water systems, for instance, dike rings, pumping and storage areas, polders or drainage basins. They are also partly based upon river basins, combined with administrative regions. Many existing water boards are inter-provincial. Coordination is guaranteed at the river basin level, especially through the WFD international RBDs. Some additional aspects considered include: coastal water and estuaries; groundwater; artificial structures such as reservoirs, channels, and water transfers projects; climatic characteristics; environmental protection areas; socioeconomic areas and agriculture lands; political jurisdictions; metropolitan regions; geographic features; census divisions; historical development and cultural factors; size and distance limits; and pragmatic considerations. The wide range of criteria being considered for defining regions leads to a good level of integration with other public fields, such as environment and spatial planning. After 1950, a transformation in the water board model started to happen. On February 1st 1953, there was a large tidal flood disaster that accelerated the process of administrative concentration of the water boards. Lack of central coordination and the need for a broader scope were the leading motivation factors. Many clustering of small and middle-sized water boards started to take place. From 1950 onwards, an increasing number of water boards got water quality management as a task, which required more specialized expertise. In such a case, bigger water boards could attract personnel with this expertise. In addition, the government policy of implementing IWRM started in 1985, and especially the integration of water quality and quantity management into the water boards resulted in a significant decrease in numbers and increase in size of these water boards. The need for expertise resulted in an increase in financial need, which also contributed to the process. Furthermore, in 1996, the Association of Water Boards took an official position in favor of the integration. More recently, the main principles of the WFD have influenced the delineation of water boards. In 1985, there were 255 water boards. In 2004, there were 56 water boards. In the time between 1950 and now, the total number of water boards decreased from more than 2600 to 26. Changes also included the organization of tasks, funding, and composition and election of the boards. The boards became modern professional organizations with an important role in regional water management. It is possible that further reduction in the number is necessary, getting closer to the twenty water authorities predicted by the Water Authorities Research Committee in 1974 and seventeen administrative river basins envisaged by the Committee for Water Management in 2000. Moreover, the water boards may lose their independence and become branches of provincial government, according to the program of several political parties that want to abolish them in order to simplify water management, increase municipal and provincial integration, and reduce costs.
Committees	The water boards might be considered committees, considering that different representatives are elected once every four years, having legal responsibilities for water management.
Public Participation	Yes. Similar to other governments, the water boards have formal consultation processes. Their representatives are directly elected or appointed by user groups, and many also organize more active forms of participation.

	**NETHERLANDS**
Public Participation (cont.)	According to the principle of 'the unity of pay, say and interest', these stakeholders that have an interest in water management pay for the operational costs of the water authorities and compose its board. In the beginning, the interest was linked to land property, and the boards were dominated by landowners. Currently, it is related to a wider variety of aspects and regulations, including several stakeholders in this process, which are democratically elected and can be involved in the decision-making process at early stages.
Real Planning and/or Management at River Basin Level	Yes. The Netherlands is, in legal terms, a 'decentralized unitary state', and this is especially reflected in water management. Cooperation between different water authorities at river basin level is considered relatively effective; cooperation between the water authorities and other policy sectors, such as agriculture and special planning, is more problematic. The WFD implementation process has been reinforcing the management process at the river basin level. For most areas, there are still a couple of water policy plans, a couple of water management plans, some land use plans, environmental plans and so on. Despite the fact that there are different plans on different levels, there is a structure designed to reach integration and coordination of water management.
International River Basin Commissions	International Commissions for the Protection of the Rhine, Meuse, Sheldt and Ems. They have limited competencies and instead have a coordinating function and knowledge exchange. In addition, there are smaller not so active commissions for some small transboundary rivers.
General Comments and Questions	The Netherlands is known for its public water management and its water board system. In addition to the water boards, twelve provinces are responsible for regional water management plans and environmental and land use plans; supervision of local water and wastewater management; licensing groundwater abstractions; and formulation of strategic water management policy. The central government—State Water Management Agency (*Rijkswaterstaat*)—is responsible for the strategic national water management plan and for the management of the main water system in the country. Water policies and legislation are the responsibility of the Minister of Transport, Public Works and Water Management, including coordinating river basin management plans, submitting information and reports for the WFD, and integrating water boards with RBDs. The Water Boards' model is considered relatively compatible with the WFD objectives, regarding its similarity to the RBD model, its appropriate field of public participation, and its adequate institutional structure. However, to reach good chemical and ecological status of water, as required by the WFD, it is necessary to develop the necessary coordination among water boards and the agricultural sector, which is responsible for the diffuse pollution, one of the main current problems in the Netherlands. Another issue is related to the morphological changes and need for more natural ecosystems that are required by the WFD. Considering that heavily modified bodies are the vast majority of the bodies in the Netherlands, additional space is necessary to address this issue. Therefore, better coordination among the water boards and the spatial planning sector is also necessary.

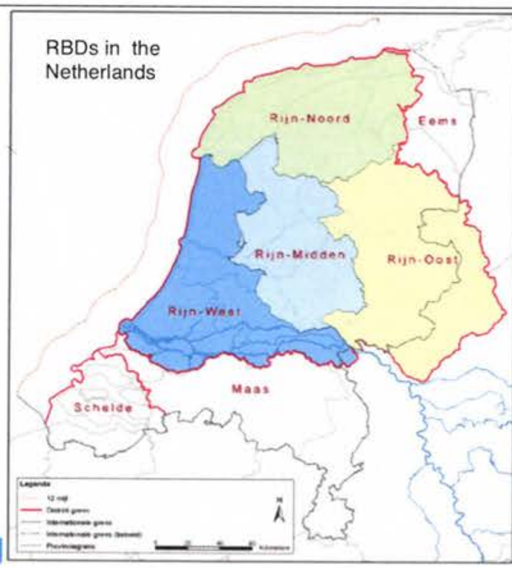
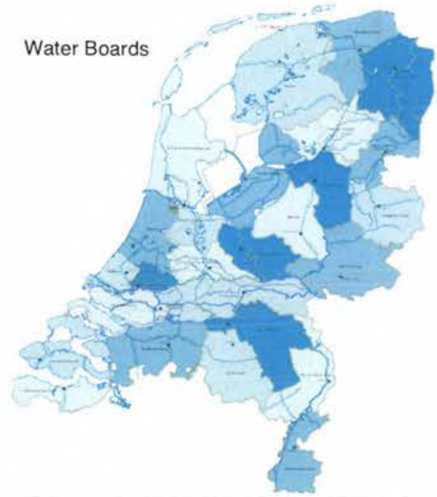
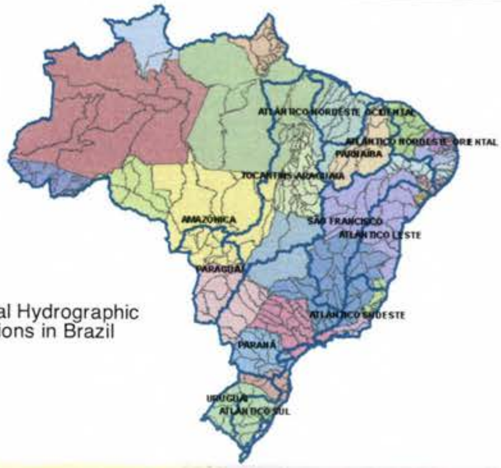
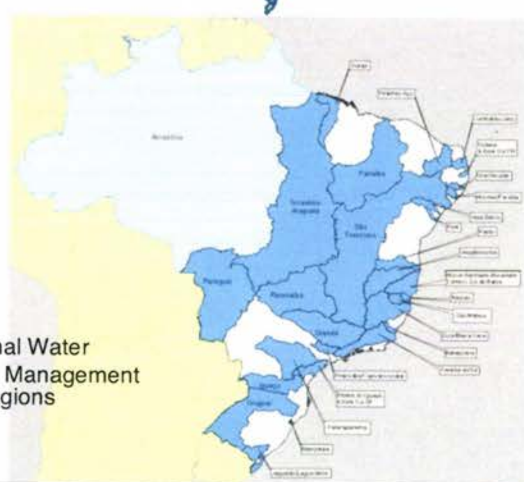
	**NETHERLANDS**
Map of the Water Resources Regions	 
References	Grijp and Oslthoorn, 2001; Brugge and Rotmans, 2007; Rijswick, 2004; Mostert, 2000b; EC, 2002; Aerts, 2009; Havekes, 2009; Mostert, 2009; Ven, 2004; Havekes et al., 2008; Mostert, 2006; Havekes, 2008; Ministry of Transport, Public Works and Water Management, 2009; Kuks, 2004; Uitenboogaart, 2009; Junier, 2009.

Table 3.3. Analysis of Water Resources Planning and Management Regions in Brazil

	**BRAZIL**
Form / System of Government	Federalism
	Republic
	Executive
Water Resources Regions	Twelve National Hydrographic Regions: 1) Amazonian; 2) Tocantins-Araguaia; 3) Western Northeast Atlantic; 4) Parnaiba; 5) Eastern Northeast Atlantic; 6) Sao Francisco; 7) East Atlantic; 8) Southeastern Atlantic; 9) Parana; 10) Uruguay; 11) South Atlantic and 12) Paraguay. Brazil's territorial base, at the national level, was established by *Resolution #32* of the Water Resources National Council in 2003.
Purposes	Allows guidance for water resources planning and management at the National Water Resources Plan level. The federal government established national hydrographic regions, recognizing the importance of establishing regional policies for the country at the river basin level.
Criteria considered when delineating water resources regions	Mainly Hydrographic. The National Hydrographic Regions are defined based upon river basin limits or groups of river basins, including socioeconomic, cultural, environmental, institutional, political, and regional aspects. Prior subdivisions of Brazil's territory present three regional committees and eight Hydrographic Region Councils. These and additional aspects were considered in some studies developed prior to the establishment of the national hydrographic regions. In the first study, selected aspects include hydrographic, main urban centers, climatic conditions, ecosystems, hydrogeology potential, water quality and quantity, predominant uses, political-institutional and socioeconomic conditions. In the second study, selected aspects include hydro-environmental (scarcity, pollution, flooding, conflict and protection of natural ecosystems) and strategic factors (related sectors' policies, governmental programs, management institutionalization stage and sensitivity of the interested parts).
Other Established Regions	More than 400 Federal and State Water Resources Regions. In these regions, there are 161 River Basin Committees installed at the state level and seven River Basin Committees installed at the federal level. The National Water Resources Plan established 56 planning units. At São Francisco River Basin Plan, for instance, four subdivisions were also established. Furthermore, there are divisions established by important sectors, such as hydroelectricity and transportation.
Purposes	Planning and Management, in general, including, river basin committees, licensing abstraction, controlling, and monitoring. They vary among states.
Criteria	Mainly Hydrographic. However, the criteria used to define water resources regions vary among states, as demonstrated by some studies on the definition of territorial boundaries for water resources planning and management. In São Paulo, 22 territorial units were established in 1991, considering historical (i.e., 1972 DAEE subdivision into 18 units), physical (geomorphology, geology, regional hydrology, and hydrogeology), political (compatibility with neighbor's regions, up to 50 municipalities per unit), and socioeconomic aspects (size limits, road distances). In Minas Gerais, 34 territorial units were defined considering physical (climate, hydroelectricity potential, hydrogeology, pedology, and morphology), socioeconomic (IBGE mesoregions, up to 50 municipalities per unit, human occupation process, and existing social organization initiatives), and hydrographic aspects (river basin limits, water quality indicators). In Santa Catarina, the territory is divided into ten hydrographic regions in 1998, considering river basin limits as the basic units, reasonable level of homogeneity (physical and socioeconomic aspects) among these basic units, maximum of three river basins and 40 municipalities per region, existing inter-municipalities associations, and size limits.

	**BRAZIL**
Committees	In Brazil, river basin organizations are instituted by law. State and National River Basin Committees have been created in several regions according to existing social demands or political interests. However, they do not represent a uniform concept and are not present in the entire country. Legislation limits the creation of committees to the third level of tributary river basins; however, no additional guidelines are provided in order to promote better coordination.
Public Participation	Yes. Participation of governmental representatives, water users, and civil society is legally enforced, including deliberative power into River Basin Commissions. The representatives approve the River Basin Plan and propose the value to be paid for water use.
Real Planning and/or Management at River Basin Level	Yes, but not for the entire country. The 12 National Hydrographic Regions do not promote real and effective integrated water resources planning and management at the river basin level. Federal and State Water Resources Regions promote planning and management at the river basin level, but coordination must be improved in order to have IWRM.
International River Basin Commissions	Multi-lateral Agreements at La Plata Basin (Tratado da Bacia do Prata, 1969) and at Amazonas River Basin (Tratado de Cooperação Amazônica, 1978). There are several specific bilateral agreements also, for instance at Quaraí (1991) and Lagoa Mirim (1977) River Basins, between Brazil and Uruguai.
General Comments and Questions	Water legislation in Brazil was initiated with the institution of the Water Code in 1934. The political context at that time lead to the prioritization of the hydroelectric sector as the main user of water resources and the existence of water resources regions reflects hydroelectricity interests exclusively. On January 8, 1997, *Federal Law #9.433—Water Law*, established the National Water Resources Management System and introduced the National Water Resources Policy. On July 17, 2000, the Brazilian Water National Agency was charged by *Federal Law #9.984*, with the responsibility for the implementation of the *Water Law*. The *Water Law* defined river basin limits as the territorial unit for implementation of the policy and performance of the National System of Water Resources Management. However, this law did not expressly define *river basin* or *main course of the basin*. Considering the huge territorial extension of the country and its diverse drainage net, specific regulation regarding the most adequate scale and level of river basins for IWRM is necessary. For instance, river basins may include one to ten states, varying from small coastal watersheds (~50 km^2) to the Amazon River Basin (4 million km^2). In addition, article 20 of the *Brazil Federative Republic's Constitution*, from 1988, established the dual jurisdiction of Brazilian rivers, defining as the federal goods: lakes, rivers and other water flows in its lands of domain, or which flow through more than one state, are the boundaries with other countries, or flow to or come from foreign land, as well as marginal lands and river beaches. The advancement of the national policy is, therefore, dependent on agreements between federal and state governments, which should be based upon standard, widely accepted, and harmonized geographic regions that are not regulated yet. The legislation provides flexibility in the institutional solutions, foreseeing that the models would be negotiated between federal and state governments. True IWRM at the river basin level, instead of the river level, is the real challenge. Considering their legal authority, states also have their own water resources legislation, some prior to the federal government's legislation. Without the necessary guidelines from the central state, there are many existing obstacles to effective IWRM. For instance, the 12 National Hydrographic regions do not have appropriate scale for promoting water resources planning and management. There are several overlapping and disarticulated water resources regions and a high risk of extreme proliferation of river basin committees. For instance, 31 requests for the creation of Federal River Basin Committees (in river basins that

	**BRAZIL**
General Comments and Questions (cont.)	contain federal domain rivers) and only at Rio de Janeiro State, there are 25 federal domain rivers, with varied national and local relevance. The question of subsidiarity versus centralization is also important, given the dimension of Brazil's territory, regional differences, and the centralist tradition. For instance, a restricted analysis considering rivers as indivisible units should result mostly in water resources regions under the federal government domain. On the other hand, the extreme proliferation or water resources regions at very local levels, and respective river basin committees, may result in high financial costs for the system and lack of coordination. It is evidently the necessity of defining adequate criteria and appropriate levels for water resources planning and management regions, as well as the appropriate coordination among these levels. One step to address this issue was taken on April 13, 2010, when the National Water Resources Council approved *Resolution #109* that establishes the National Water Resources Management Regions at the federal domain rivers. It is expected that it provides better guidance on this process.
Map of the Water Resources Regions	 National Hydrographic Regions in Brazil  National Water Resources Management Regions
References	Barth, 2002; Kettekhut, 2000; DAEE, 1992; IGAM, 1999; Costa, 2003; Costa, 2000; Guimaraes and Magrini, 2008; Gontijo and Reis, 2008; Tortajada, 2001; Vasconcelos, 2006; Porto and Porto, 2008; Coelho et al., 2003; Sollero, 2003; Garrido and Freitas Jr, 2002; Braga, 2009; Lotufo, 2009; Flecha, 2009, Gontijo, 2009, Gondim, 2009; Costa, 2009; Braga and Lotufo, 2008; Silva, 2009.

3.1. Summary of the Comparative Analysis

The presented comparative analysis has contributed to a general understanding of the existing regions for planning and/or management of water resources in different countries and of the respective institutional frameworks. Margeli et al. (2008) affirms that the concept of the water resources planning and management regions is related to functional and administrative aspects. Political jurisdictions constitute forms of general territorial decentralization, and water authorities constitute a functional territorial decentralization. As illustrated in the analysis, there are a variety of functional territorial regions established in different geographical scopes and different institutional models, including several multi-level systems. Figure 3.2 presents a summary of the main aspects characterized in the comparative analysis.

As demonstrated above, several factors have significant influence over water management, such as historical aspects and different types of problems, their timing, and scale. Llamas (2000) affirms that water problems are complex and varied because of multiple uses, physical characteristics, and cultural values. Barraqué (1995) also states that water resources organizations are impacted by the transformation of the geographical scales of the problems due to the increase of water users in number and variety. As a result, complex water institutions, at multi-level governance systems, are necessary in order to address current society's needs and uncertainties and environmental demands. This is exactly what is observed in the examples presented above: different kinds of problems or prevailing focuses lead to different kinds of regions and different kinds of organization structures.

Establishing adequate water institutional organizations, among the various existing types, is important in order to accomplish IWRM goals. According to Iza and Stein (2009), water institutions are managed by the State in centralized governments and by public-private institutions in less centralized governments, enabling participation of multiple stakeholders. Decisions related to water resources planning and management are not made, usually, in a single institution. Therefore, coordination is necessary among river basin and multiple and cross-sectoral government levels in order to avoid overlapping structures and promote effective water management.

Water authorities have a long tradition and significant power in the course of history. A protest in Netherlands, for example, in 1795, dissolved all administrative bodies, but not the organizations supervising the dikes and hydraulic works (Ven, 2004). Because water is strategic in so many different sectors, water organizations may have strong powers and may directly compete with other established administrative organizations. As a result, water authorities have been created, dissolved, and re-created several times in history. Defining the exact amount of power, the right level and subsequent levels, and the adequate model of water organizations is not

COUNTRIES	**PORTUGAL**	**SPAIN**	**GREECE**	**ENGLAND AND WALES**	**NETHER-LANDS**	**GERMANY**	**FRANCE**	**UNITED STATES**	**COLOMBIA**	**MEXICO**	**BRAZIL**
Form / System of Government	Unitary Republic Parliamentary	Quasi-Federal Monarchy Parliamentary	Unitary Republic Parliamentary	Unitary Monarchy Parliamentary	Unitary Monarchy Parliamentary	Federalism Republic Parliamentary	Unitary Republic Executive & Parliamentary	Federalism Republic Executive	Unitary Republic Executive	Federalism Republic Executive	Federalism Republic Executive
Water Resources Regions	10 River Basin Districts Under WFD	25 River Basin Districts Under WFD	14 River Basin Districts Under WFD	11 River Basin Districts Under WFD	4 River Basin Districts Under WFD	10 River Basin Districts Under WFD	12 River Basin Districts Under WFD	21 Regions and 222 Sub-regions	33 CARs - Reg. Environ. Authorities	13 Administrative Basins	12 National Hydrographic Regions
Purposes	Mainly Planning	Planning and Management	Mainly Planning	Mainly Planning	Mainly Planning	Mainly Planning	Mainly Planning	Mainly Data Management	Management Mainly	Management Mainly	Limited Planning
Criteria considered when delineating those regions	Hydrographic, Political, Transboundary Basins, Historical, Prior Planning Processes, and Size Limits	Hydrographic, Historical, Political, Transboundary Basins	Hydrographic and Hydrogeology	Hydrographic	Hydrographic	Hydrographic, Ecoregions, Size Limits	Hydrographic /Administrative Mainly, Political, Geology, Historical, Socio-Economy, Geography, Finance, Culture, and Size Limits	Hydrographic, Political, Cultural	Biogeography, Hydro-geographic and Geopolitical	Hydrographic and Administrative	Hydrographic Mainly, socio economic, cultural, environmental, institutional, political, and regional
Other Established Regions	5 ARHs - Hydrographic Region Administrations	Sub-basins in each RBD.	13 Regional Water Directorates	129 CAMs and 8 Regions	26 Water Boards - Waterschappen	Sub-regions: Working Groups of State Water authorities	Sub-basins: Local Water Commissions, River Basin Territorial Public Establishments	Interstate Compacts + Several River Basin Commissions	-	102 sub-regions + 37 Hydrological Regions	Several Federal and State Water Resources Units
Purposes	Planning and Management	Planning and Management	Management	Planning and Management	Management	Management	Planning and management	Planning and management	-	Planning and Monitoring	Planning and Management
Criteria considered when delineating those regions	Hydrographic Mainly, Historical, Political, Prior Planning Processes, Transboundary Basins, Administrative/ Institutional, Financial Efficiency, Similar Problems, Water Quality, Socio-Economic, Size and Distance Limits	Hydrographic, Political, Administrative, Size Limits, Geographic Features, Territorial Organization, User Participation and Historic-Social Processes	Administrative Regions	Surface Water Catchments Mainly, Groundwater, Coastal Areas, Significant Abstractions and Water Transfers, Historical, Urban Limits, Size Limits, Administrative Structures Efficiency	Hydrographic Mainly, Politico-Administrative, Coastal Areas, Groundwater, Artificial Structures, Climate, Environment Protection, Socio-Economic, Geographic, Census, Historical, Culture, Size and Distance Limits.	Political-Administrative and Hydrographic	Hydrographic (Small River Basins) or Water Systems (Estuary, Aquifer, etc.)	Hydrographic (River Basin Limits in Critical Areas)	-	Political Jurisdictions and Hydrographic	Hydrographic, Administrative Regions, Socio-Political Aspects
Committees	River Basin Districts Councils at ARHs	Water Council + other boards in most RBDs	Regional Water Councils (not installed yet)	Liaison Panels at the River Basin Level	Water Boards	River Basin Communities in some Rivers	River Basin Authorities	Watershed Groups in some areas	No permanent River Basin Commissions	25 River Basin Councils	Several River Basin Committees
Real Planning and/or Management at River Basin Level	Yes. ARHs will reinforce this process.	Yes. Competent Water Authorities.	No. Carried out mainly along administrative boundaries.	Yes. It is being promoted by the WFD.	Yes. It is being reinforced by the WFD.	No. It is mostly performed by the Federal States.	Yes. Competent Water Authorities.	No. It is mostly conducted by State level.	No. There is a dispute among CARs and Municipalities.	Balanced among Central Government and regions.	Not for the entire country yet.
International River Basin Commissions	Albufeira Agreement with Spain at Mino-Lima, Douro, Guadiana and Tejo.	Albufeira Agreement with Portugal at Mino-Lima, Douro, Guadiana and Tejo.	Bi(multi)lateral Agreements: Aoos, Vardar/Axios, Strimon, Marits/Evros, Prespa, Nestos/Mesta	Cross-border arrangements between England and Wales (Dee; Severn).	International Commissions for the Protection of the Rhine, Meuse, Shelde and Ems.	International Commissions: Rhine, Elbe, Danube, Meuse, Mosel and Saar, Oder, Ems.	International Commissions: Garrone, Rhine, Meuse, Lake Geneva and Scheldt.	IBWC: Mexico and US; IJC: Canada and US; Columbia River Treaty; Great Lakes Commission	Organization of the Amazon Cooperation Treaty (OTCA)	IBWC: Mexico and US; IBWC: Guatemala, Belize and Mexico	Multi-lateral Agreements at La Plata and at Amazonas River Basin. Several specific bilateral agreements.

Figure 3.2. General Overview of the Comparative Analysis Results in Eleven Countries

an easy task. Water resources planning and management depends on how institutional organizations are developed. Having adequate autonomy and enough power to implement water resources planning and management actions is recognized as the best strategy to attain IWRM. Soronhenho-Marques (2007) supports *shared sovereignty* as the best way to deal with water issues, especially with the advent of climate change. The concept of shared sovereignty is related to the existence of organizations that have enough competences and independency to decide about water issues, beyond political boundaries. Lopez-Gunn (2009b) defends that the global trend towards decentralization and increased acceptance of subsidiarity needs to be reflected in the existing water authorities. Nevertheless, establishing a harmonized and efficient multi-level governance system may improve the chances of successful creation and continuous existence of water authorities. In this context, the comparative analysis focused on trying to understand how water authorities are established, what their relationship is to other levels of governance, and which aspect should be considered in order to define water resources regions and respective authorities more integrated with the existing administrative structures.

Mostert (2003) also studied the different types of water resources institutions around the world and concluded they have a wide variety in geographical scope, including river basins, lakes, or major subbasins, river only, main rivers and tributaries, and aquifers. Mostert (2000a) describes three models comparing the different national and international water resources management systems. The first one is the 'hydrologic model', in which the organizational structure for water management is based upon hydrologic limits, focusing on river basin planning. The second is the 'administrative model', in which water resources management is part of the environmental management system carried out by the provinces, municipalities, and other political institutions. The third is the 'cooperation model', in which the water management is not carried out by river basin authorities, but commissions of river basins, with coordination tasks, including strategic plans.

The analysis of water resources regions, presented above, recognizes some important aspects that were considered when establishing such regions. According to the Zaragoza

Declaration (Margeli et al., 2008), the river basin is the most suitable limit to address environmental challenges. The declaration affirms that despite municipal, provincial, state and other jurisdictional limits, the decisions made at the river basin level should be implemented in the whole river basin. However, the simple characterization of river basin limits is not enough to determine water resources regions. The selection of the appropriate level of river basin and grouping of smaller river basins, for instance, are performed considering important socioeconomic, political-administrative, environmental, cultural, and historical aspects. In addition to river basin limits, several aspects are also identified and valued according to IWRM principles. The recognition and harmonization with existing political, administrative and social structures, for instance, is necessary in order to have effective functional territorial division in water resources regions.

The selected examples confirm that additional aspects, beyond river basin limits, are being considered in order to define integrated water resources regions, such as political-administrative, socioeconomic, cultural, historical, physical, and environmental aspects. As observed, the sets of criteria vary among the examples illustrated. It is difficult to generalize one common set because it depends on the way the countries define their priorities in terms of river basin planning and management, and respective institutional frameworks. As a prevailing scheme, the examples from the EU demonstrate a deeper examination of the water resources regions, defined as RBDs. It is important to emphasize the value of the EU WFD in motivating EU member countries to delineate integrated water resources regions and promote the consideration of a broader scope. Significant progress, in terms of implementing more integrated water resources regions, as advocated by the WFD, is already noticed in the examples analyzed, and many RBDs are harmonized with previously established structures.

In order to address the challenges of IWRM and the complexities and uncertainties of the current era, including climate change adaptation needs, it is necessary to consider how to integrate the ecological approach to define river basins limits as the appropriate unit for water resources management with the existing political, cultural, and historical existing structures. In fact, as a general conclusion, it is imperative that more comprehensive aspects be incorporated into the decision-making process regarding water resources regions in order to promote IWRM and facilitate transboundary water conflict resolution. Recognizing these aspects leads to a good level of integration with other sectors, such as environment and spatial planning.

Regarding the examples presented, there are similarities among the American and European countries. The European examples, though, have more similarities among them than the American examples because of the EU guidelines. It is possible to observe, however, that there is a contrast between federative and unitary countries. The selected unitary countries—Portugal, Spain, Greece, the Netherlands, France, and Colombia—present a more homogeneous set of water resources regions, as expected. Piégay (2006) assumes that is comparatively easy to implement WFD in a country like France, for instance, where there are no administrative boundaries. Even though Spain, for instance, is considered a 'quasi-federal' state, decentralized into Autonomous Regions or Autonomous Communities, it is possible to observe a strong top-down influence from the central government in defining water resources regions throughout history. On the other hand, the examples of federative countries—Germany, the United States, Mexico, and Brazil, present significant differences among water resources regions. Intergovernmental relations, according to Wright (1978), is extremely complex, and intergovernmental achievements depend on managing this complexity, especially in Federative arenas. For example, in the United States, the states have their own legislation and limited effective integration at the river basin level. The models vary from the TVA, which has comprehensive powers across state boundaries to the Florida Water Management Districts, which have a unique institutional framework based upon the state's hydrologic boundaries. In Brazil, there are many different water resources regions established by the states. They vary in terms of size, level of integration with neighbor states, and aspects prioritized when delineating the regions. There is also a lack of integration among states' water resources regions and the central government's water resources regions that is comparable to the challenges existing in riparian countries. In Germany, there is an improved level of integration organized into four levels of water organizations (Iza and Stein, 2009). In each river basin, the Landers have created several sub-regions for coordinated water management. The Landers have also established cooperation procedures among them, for the purpose of coordinated river basin management, which occurs through the national river commissions and working groups on specific rivers. According to Iza and Stein (2009), Germany illustrates how a federative country can coordinate interests from different states and improve collaboration. The existence of traditional International River Basin Commissions, stakeholders' involvement, and guidelines provided by the EU WFD constitute decisive factors that contribute to the good level of integration among the Landers. It can be concluded, therefore, that despite the federative situation and complexity, it is possible to develop IWRM. Irujo and Hölling (2009) reinforce the discussion about the federative situation through a study about water resources management in selected federative countries. The authors affirm that water resources planning and management in decentralized countries is complex because of the need to harmonize the federative principle with the river basin level and to coordinate responsibilities among governments. There are many different organizations established at multiple levels as well as distinct criteria to define river basin limits. According to the authors, the adoption of river basin units, solely, does not generate homogenous solutions for water resources planning and management. In such cases, it is necessary to have an agreed upon common guideline to address these issues and promote IWRM.

In most of the selected countries—the Netherlands, Germany, Greece, the United States, Mexico, Colombia, and Brazil—regions for water resources planning and management are not integrated into one common territory limit. Different institutions are responsible for different responsibilities related to water resources planning and management in the same territory. The ideal scenario, for a more effective IWRM, is to have one region for both planning and management purposes, such as the ARHs in Portugal, *Confederaciones Hidrograficas* in Spain, and Water Agencies and Committees in France. It is important that the authority, which elaborates a river basin plan, be also responsible for its execution. The implementation process should follow the same logic and priorities established during the planning stage. This approach is also much more effective in terms of public participation, stakeholders' involvement and accomplishment of the plan.

On the American continent, the United States 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 areas of major rivers or a combination of small drainage areas, hydrograph characteristics, culture, and political boundaries (Seaber et al., 1987). In Mexico, 13 hydrologic-administrative regions were established as Regional Management Units by the National Water Council. The division is based upon hydrologic and administrative aspects, having coincident limits with one or more river basins, according to regional characteristics of water resources. The area of these regions, and respective River Basin Organisms, is corresponding to the limits of the municipalities contained in each region (CNA, 2007). In Colombia, 33 *Corporaciones Autonomas Regionales—CARs*—were established from 1954, following the U.S. TVA model, and influenced by the Spain's *Confederaciones Hidrograficas* model. CARs, in general, follow the hydrographic limits, in accordance with the regional department's boundaries. In addition, biogeography, hydro-geography and geopolitical aspects are considered, including political jurisdictions, administrative regions and environmental protection areas. In Brazil, the 12 National Hydrographic Regions are mainly based upon hydrographic aspects, and also consider socioeconomic, cultural, and regional aspects, especially at the smaller river basins groups. These national regions co-exist with several federal and state water resources regions, being created randomly around the country, following hydrological and socio-political aspects, in general. The U.S. regions and Brazil's National Hydrographic Regions do not have an institutional framework directly related to them.

On the European continent, Portugal has five hydrographic region administrations based mainly on hydrographic aspects. Some additional important criteria were also considered, such as political jurisdictions, including municipal, administrative regions and international boundaries;

historical aspects, including prior planning processes and prior institutional and administrative structures; financial efficacy; hydraulic connectivity, including water transfer projects; water quantity and quality aspects; similar kinds of problems and priorities; geological and geomorphologic characteristics; socioeconomic aspects, including the territorial units for statistical purposes; and geographical distances. France, including its colonies, is divided into 12 regions, based upon administrative and hydrologic aspects, adopting the lines corresponding to the delimitation of the communes' territories—which are the smaller administrative territorial unit—closest to river basins or groups of river basins. They correspond to the EU RBDs. Spain has 25 RBDs under the WFD. Some of the districts in Spain have a strong tradition in integrated water resources planning and management, dating from the creation of the *Confederaciones Hidrograficas*. Historical, political and hydrographic aspects are the leading criteria considered when delineating the water resources regions. The formal designation of RBDs and respective authorities is still being reviewed in Spain. In Greece, 14 RBDs were created, following WFD guidelines. In Spain and Greece, the second level of established regions described in the tables presented above do not correspond to sub levels, but to prior existing organizations, such as the *Confederaciones Hidrograficas*. The Netherlands' water boards are based upon water systems or groups of water systems, for instance, polders or drainage basins, combined with: administrative regions and political jurisdictions; coastal areas; groundwater limits; artificial structures, such as reservoirs, channels, and water transfers projects; climatic characteristics; environmental protection areas; socioeconomic areas, including agriculture lands; metropolitan regions; geographic features; census divisions; historical development and cultural factors; and size and distance limits. In England and Wales, there are 11 RBDs under the WFD and 129 Catchment Abstraction Management Strategies—CAMS. Mainly hydrographic aspects were considered, combined with coastal areas, urban areas, significant abstractions, historical aspects, large reservoirs, and artificial watersheds. In Germany, ten RBDs were created under WFD, according to hydrographic, ecoregions and size limit aspects.

All the examples from the European continent have RBDs because the EU, through the WFD, requires all member states to identify RBDs as the main area for IWRM (Environment Agency, 2004). The implementation process of the WFD is a complex process in which the institutional arrangements have to change from national geo-political entities into (cross-boundary) river basin management regimes, which constitute the basis for assigning the rights and responsibilities associated with water management (Giupponi et al., 2002). The identification of river basins as the main unit for water resources planning and management was the first task to be accomplished by the member states (JOCE, 2000). According to guidelines provided by the EC (2002), these districts are made up of main river basins or groups of small river basins, considering climatic, environmental, socioeconomic and administrative aspects, and weighted according to particular characteristics of the member states. Coastal waters, groundwater, estuaries (transitional waters) and artificial waters (such as canals) are assigned to the most appropriate districts. According to CEC (2007) there are 110 RBDs in the EU. From these, 40 are international RBDs, covering more than 60 percent of the territory of the EU. In cases of these transboundary RBDs, coordinated planning and management must be ensured (EC, 2005). In the future, it is expected that individual parts of transboundary basins will be managed as a single river basin. According to JOCE (2000), member states must define the proper organizational arrangement and competent water authority for each RBD and encourage the participation of all interested parties, especially during the execution of river basin management plans. Kolokytha (2008) defends that the WFD is strongly based upon the integration concept, present at the Helsinki Convention. Williams (2001) states that the "WFD requires monitoring and the establishment of programs at the river basin level, through either the imposition of a single authority or the coordination of administrative efforts among authorities". According to the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (2007), the concept of RBDs is flexible to react to future climate change adaptation needs.

Regarding the specific criteria considered when defining RBDs, the common implementation strategy (EC, 2002) includes the following steps and principles: 1) define river basin limits as the natural unit of the hydrologic cycle; 2) designate large river basins as individual RBDs; 3) group neighboring small river basins considering climatic, environmental, socioeconomic, and administrative similarities; 4) assign the main aquifers and shared groundwater to the proper RBD; 5) designate international river basins; and 6) identify competent water authorities. The climatic aspects are the degree of humidity, evapotranspiration, sunshine hours, and temperature. The environmental aspects are the bio-geographical regions. The socioeconomic aspects are population density, importance of the primary, secondary, or tertiary economic sectors, and linguistic and cultural differences. The administrative aspects are the regional, provincial, or local boundaries, and the established and consolidated structures. The definition of a small river basin is based upon tentative reference area values and respective percentile.

As a result of the proposed methodology, RBDs are mostly based on hydrogeographic boundaries (EC, 2007). WFD Article 3, which defines the grouping of smaller river basins into RBDs, has been effectively accomplished, in general, including the attribution of groundwater and coastal water, and especially in countries with several small coastal river basins, for instance, the United Kingdom, and in countries that contain numerous islands, for instance, Greece. In Italy, however, the delineation of RBDs is not in accordance with the WFD guidelines. Serchio RBD, for example, divides one RBD into two parts. The RBDs' sizes vary from small to large, and the assignment of competent authorities and new institutional arrangements is also diverse, ranging from simple to complex structures, as illustrated in the comparative analysis. Still, according to EC (2007), coordination mechanisms are limited. At the international river basin level, the most sophisticated arrangements occur at the Danube, Elbe, Meuse, Odra, Rhine and Scheldt river basins. Nevertheless, Nilsson et al. (2004) argue that the WFD serve only as an incentive for joint management, instead of implementing international management. As illustrated by two examples, WFD tolerates different interpretations about the identification and planning of RBDs. The authors consider the WFD requirements to be soft and affirm that they may weaken the goal of managing water resources at the river basin level. As a conclusion, it is possible to assume that the WFD still does not overcome the need for IWRM since it is difficult to reorganize the whole territory into river basin limit management strategies. However, it allows a wide discussion about how and what level of integration is necessary in multi-levels systems, and in a cross-sectoral environment, in order to harmonize the political-administrative scale and the water resources hydrological boundaries scale.

3.2. Summary of the Key Aspects

The following Table 3.4 presents the list of aspects identified in the comparative analysis. These aspects are organized into five categories: hydrographic, political-administrative, historical-cultural, socioeconomic and physical-environmental. There is a brief description of each aspect, followed by examples or more detailed information, and the respective regions that incorporated the corresponding aspect. If RBDs in Europe is indicated in the last column, it means every example in Europe has considered the aspect. In the sequence of the table, each aspect is discussed individually, in order to emphasize its importance.

Table 3.4 Aspects Considered to Delineate Integrated Water Resources Regions

Category	Description	Detail/Example	Regions
Hydrographic Aspects	River Basin Limits	River Basins, Subbasins, Watersheds, Catchments and Sub-catchments	RBDs in Europe, *Spain's Confederaciones Hidrograficas*, CAMS in England, Water Boards in Netherlands, U.S. Regions, CARs in Colombia, Administrative River Basins in Mexico, Hydrographic Regions in Brazil
	Hydraulic Connectivity	Water Transfers, Artificial Channels, Artificial Watersheds, Significant Abstractions	ARHs in Portugal, CAMS in England, Water Boards in Netherlands, U.S. Regions
	Large Reservoirs, Major Lakes	Integrated Projects, Artificial Structures	CAMS in England, Water Boards in the Netherlands, U.S. Regions
	Groundwater	Aquifer Limits	CAMS in England, Water Boards in the Netherlands, RBDs in France
	Coastal Waters, Bays, Coastal Islands	Tidal Waters, Estuary Regions, Marsh Areas (direction that water flows to the main river)	CAMS in England, Water Boards in the Netherlands, RBDs in Germany, RBDs in France, U.S. Regions
	Water Quality / Quantity / Gauging Stations	Critical spatial and temporal variability	ARHs in Portugal, U.S. Regions

Category	Description	Detail/Example	Regions
Hydrographic Aspects (cont.)	Flood Protection Areas	Dike rings, drainage, pumping and storage areas, polders	Water Boards in Netherlands
Political-Administrative Aspects	Municipal, State and Country Limits, Municipal Councils (administrative political / regions)	Regional, Provincial or Local Boundaries, Political Jurisdictions, Division of Powers, Transboundary Basins	RBDs and ARHs in Portugal, *Confederaciones Hidrograficas* in Spain, Water Boards in the Netherlands, Regions in Germany, RBDs in France, U.S. Regions, CARs in Colombia, Administrative River Basins in Mexico
	Administrative Organizations	Prior / Existing Institutional Structures	ARHs Portugal, Water Districts in Greece, CAMS in England, RBDs in Germany, RBDs in France, CARs in Colombia
	Financial and Institutional Efficiency	Reduce Institutional / Administrative Structures	ARHs Portugal, CAMS in England, Water Boards in the Netherlands
	Size Limits (Max/Min area or number of subbasins)	Combination of Small Regions, Scaling Up Power (financial and human resources)	RBDs in Europe *Confederaciones Hidrograficas* in Spain, CAMS in England, Water Boards in the Netherlands, RBDs in France, U.S. Regions
Historical-Cultural Aspects	Tradition in Water Resource Planning and Management	Prior Planning Processes	RBDs in Portugal
	Historical Conditions/Aspects	Traditional Region, Well Delineated	ARHs in Portugal, *Confederaciones Hidrograficas* in Spain, CAMS in England, Water Boards in the Netherlands, RBDs in Germany, RBDs in France
	Cultural Identity	Common Recognition, Linguistic Differences, Traditional Customs	Water Boards in the Netherlands, RBDs in France, U.S. Regions, Hydrographic Regions in Brazil
Socioeconomic Aspects	Human Occupation	Historical-social Processes, Regional Identities, Population Densities	*Confederaciones Hidrograficas* in Spain, ARHs Portugal, RBDs in France, Hydrographic Regions in Brazil
	Socioeconomic Areas/Sectors	Similar Economic Activities / Priorities (e.g., agricultural or industrial areas)	ARHs Portugal, Water Boards in Netherlands, RBDs in France, U.S. Regions, Hydrographic Regions in Brazil
	Problemshed	Similar kinds of Problems, Broader Scope	ARHs Portugal, Water Boards in the Netherlands, RBDs in Germany, RBDs in France, CARs in Colombia
	Macro-Planning Regions	Similar Regional Socioeconomic Profile	ARHs Portugal

Category	Description	Detail/Example	Regions
Socioeconomic Aspects (cont.)	Census Regions	Territorial Units for Statistical Purposes	ARHs Portugal, Water Boards in Netherlands, U.S.' Regions
	Geographic Distances (Strategic Centers)	Communication / Displacement Distances	ARHs Portugal, Water Boards in the Netherlands
	User's Territorial Organizations	Historical Allocation Processes among water users	*Confederaciones Hidrograficas* in Spain
	Metropolitan Regions or Large Cities	Large and Complex Urban Limits	CAMS in England, Water Boards in the Netherlands, U.S. Regions
Physical-Environmental Aspects	Geology / Hydrogeology / Geomorphology	Similar Characteristics, (e.g. sedimentary basins)	ARHs Portugal, Water Districts in Greece, RBDs in France
	Geographic Features / Geographic Regions	Similar Topography, Landscape, Biogeography, Hydrogeography, Ecoregions	RBDs in Europe, *Confederaciones Hidrograficas* in Spain, Water Boards in the Netherlands, CARs in Colombia
	Climatic Factors	Common Characteristics such as humidity, evapotranspiration, sunshine hours, and temperature	RBDs in Europe, Water Boards in the Netherlands
	Environmental Protection Areas	Land, Resources Conservation Areas	Water Boards in the Netherlands, U.S. Regions, CARs in Colombia

Among hydrographic aspects, river basin limits are considered in every studied region for water resources planning and/or management in the European and American examples, both in the creation and transformation of water resources regions. The RBDs in Europe are primarily based upon river basin limits. The *Confederaciones Hidrograficas* in Spain have a long tradition in using river basin limits to set up water resources planning and management organizations. The *Confederaciones Hidrograficas* greatly influenced the CARs in Colombia. Mexico and Brazil have also incorporated the concept of river basin limits into their water resources policy and organization.

Hydrographic aspects go beyond river basin limits. Hydraulic connectivity is one important aspect considered when defining water resources regions in the U.S., Portugal, England, and the Netherlands. Water transfers, significant abstractions and the infrastructure related, such as channels, are also important aspects to be considered. It is possible to have an artificial river basin established in some situations, which can have a big impact in defining water resources planning and management strategies. The linkage resulting from a water transfer, for instance, is an important factor to be recognized and that can group two regions together as one unit for water resources planning and management. In the Netherlands, for example, there are so many artificial structures that there is no sense to using river basin limits solely, considering what is happening to the water flow after all human interventions. Because the Netherlands is a hydrologically complex area, the concept of river basin might be adapted. England has also assumed that artificial structures and significant abstractions already affect the water flow significantly; therefore, they should be taken into account.

Large reservoir projects and major lakes also have a big impact over water resources. They usually affect the water users demands and availability, the stakeholders involved, and the priorities established for water resources planning and management. The connection between regions resulting from an integrated reservoir project must be considered. The water authority needs to harmonize the interests related to significant artificial structures. Among the studied countries, England, the Netherlands and the U.S. recognize reservoirs as an important aspect when defining water resources regions.

Groundwater has also a strong association with surface river basins. In some situations, it becomes strategic to consider aquifer limits in defining regions for IWRM. England, the Netherlands, and France recognize groundwater as an important integration factor. In England, the CAMS are being refined to represent the connection between surface water and groundwater.

IWRM also supports the integration between surface and coastal waters. The WFD requires coastal and transitional waters to be part of the RBDs, being managed jointly with river basins. England, the Netherlands, Germany, France and the U.S. give a special emphasis to considering coastal waters, for instance, tidal waters, estuary systems, marsh areas and the direction of water flowing to the main river, when defining integrated regions for water planning and management.

Spatial and temporal variability of both water quality and water quantity may determine critical regions that should be integrated for planning and management of water resources. A uniform pattern of water quality in one region, for instance, may facilitate the prioritization and implementation of programs and plans. Portugal and the U.S. recognized this aspect when defining their water resources regions. Another important approach related to water allocation is water footprints or the virtual water concept. This approach helps to analyze sectorial water uses and the level of exploitation of water resources in different regions (Casado et al., 2008). Depending on the degree of commitment, a higher proximity may exist between two areas.

As the last example among hydrological aspects, flood protection areas are also presented as an important integration factor. Dike rings, pumping and storage areas, polders and drainage areas were considered when defining the water boards in the Netherlands. They constitute one integrated system that must be managed jointly in order to reach IWRM goals.

Political-administrative Aspects constitute the next category. First, municipal, state and country limits are fundamental in establishing water public policies. Budgets and program implementation are organized following political boundaries. Thus, it is strategic to consider these limits as a way to promote integration for water resources planning and management practices. Political jurisdictions and the division of powers must be recognized when defining water resources regions. Among the examples, Portugal, Spain, the Netherlands, Germany, France, the U.S., Colombia and Mexico considered political boundaries as an important factor. Mexico highlighted that development planning, budgeting, and programs implementation have political boundaries, therefore, these should be combined with river basin limits. In international transboundary basins, it can be even more complex because the international border may impose an obstacle for IWRM. For instance, in Portugal and Spain, the consideration of transboundary river basins was an important aspect when defining RBDs, reflecting a strong political aspect.

The recognition of established and consolidated institutional structures and prior administrative organizations also play an important role in defining water resources regions. Portugal, Greece, England, Germany, France, and Colombia considered this aspect. The history of administrative organizations represents important relations between regions that need to be contemplated.

Another point that should be examined is the financial and institutional efficiency when establishing integrated water resources regions. There should be an ideal level for establishing administrative structures in order to avoid excessive expenditures. Portugal, England and the Netherlands considered this aspect when defining their water resources regions. Size limits are also related to this concept. In some situations, it is important to scale up, by combining small regions into a bigger one, in order to have sufficient resources to deal with the water resources challenges. Europe has recognized this in the WFD. Spain, England, the Netherlands and France also emphasize this aspect. The U.S. established a maximum number of subbasins present in one region.

The next category relates to the historical-cultural aspects. Traditional water resources planning and management practices need to be recognized. Historical conditions are considered in Portugal, Spain, England, the Netherlands, Germany and France. For instance, RBDs in Portugal are a result, in combination with other aspects, of prior planning processes that divided the country into regions for water resources planning. Cultural aspects such as cultural identity, linguistic differences, and traditional customs, are, as well, really important. A cultural identity is reflected in the water boards in the Netherlands, RBDs in France, the U.S. Regions and Hydrographic Regions in Brazil.

Next are the socioeconomic aspects. The historical-social human occupation processes also may represent important associations between regions. *Confederaciones Hidrograficas* in Spain, ARHs in Portugal, RBDs in France and Hydrographic Regions in Brazil seek to represent some socioeconomic regional identities established in terms of human occupation and population density in the course of history.

Similar socioeconomic areas also represent an important integration factor among regions. Priorities might be more easily agreed upon when similar economic activities, from the same primary, secondary or tertiary economic sectors, exist or have the same importance in one region. For instance, sugar cane production in Brazil is a current priority, and the expansion of the sugar cane crop is putting some pressure on some areas. Portugal, the Netherlands, France, the U.S. and Brazil incorporated this aspect in the definition of their water resources regions.

The recognition of similar kinds of problems represents a broader scope when defining integrated water resources regions. *Problemshed* is the concept being used to recognize common problems existing in a region, or similar kinds of problems that can approximate several regions. Allan (1999, 2004) affirms that available solutions in *problemshed* might be beyond local constraints or 'the watersheds of the water sector', so river basin limits could have minor importance. It is important to understand the broad context because limited analysis may lead to inexact conclusions. Drought events, for instance, occurring in a particular area, may help some regions to establish similar priorities in terms of water resources planning and management. Recognizing this aspect in defining water resources regions may lead to successful implementation practices. Portugal, the Netherlands, Germany, France and Colombia recognized this aspect when defining their regions.

Macro planning regions represent a similar regional socioeconomic profile. It was used to delineate water resources regions in Portugal. These regions reflect several aspects that represent multi-sector interests. If established water resources regions are harmonized with macro planning regions, the water sector is more integrated with other related sectors. The same affirmative can be used for the census regions or territorial units for statistical purposes. Census regions represent important integration factors that can be used to generate improved water resources regions. Portugal, the Netherlands and the U.S. recognized the census division in their water resources regions' delineation process.

Another socioeconomic aspect, geographic distance, might impose limits for communication and displacement. If public participation is emphasized, geographic distances must be considered. People usually have an established relationship with strategic centers, and this relationship cannot be disregarded. ARHs in Portugal and water boards in the Netherlands contemplated this factor as an important aspect to guarantee effective public participation and improved integrated water resources regions.

In order to improve public participation, it is also important to consider existing and historic user's territorial organizations. *Confederaciones Hidrograficas* in Spain recognized historical allocation processes among water users, at different geographic scales and different administrative boundaries. The economic distribution is related to water allocation distribution, in the course of history.

The last socioeconomic aspect that is recognized is the existence of metropolitan regions or large cities. England, the Netherlands, and the U.S. considered large and complex urban limits as an important integration factor. Around 50 percent of the world's population is now living in urban areas. Because water must be available at these urban areas, an increasingly complex system of water sources must be defined.

The next category of aspects is the physical-environmental aspects. First, geology is mentioned in the Portugal, Greece and France examples as an important aspect in defining water resources regions. Similar characteristics, for instance, a sedimentary basin, may contribute to defining one region for IWRM. Hydrogeology and geomorphology are also characteristics considered to determine these regions.

Geographic features, for instance, topography, slope, or landscape patterns, and ecoregions can also be used as important aspects to define integrated water resources regions. Spain, the Netherlands, Germany, France, and Colombia considered geographic features in order to define water resources regions. Biogeography and hydro-geography are also similar aspects.

Similar climatic characteristics, such as humidity, evapotranspiration and temperature, may also help to define regions for water resources planning and management purpose. Water boards in the Netherlands consider climatic aspects to define their boundaries.

Environmental Protection Areas constitute the last important integration factor listed in this study. Land and resources conservation areas might impose some restrictions on water use and allocation priorities. Therefore, the boundaries of such areas should be, preferably, contained in one region. Water boards in the Netherlands, U.S. Regions, and CARs in Colombia consider the boundaries of environmental protection areas to be harmonized with the limits of their water resources regions.

Furthermore, it is possible to consider also some aspects related to river basin subdivisions. Basically the same list of aspects presented above can be used for both merging or dividing units, in order to delineate water resources regions. For example, the Rhine River Basin is divided into four reaches, according to river ecosystems that represent significant spatial variation (Frijters and Leentvaar, 2003). The High Rhine is located mainly in Switzerland and is preserved for fish and birds. The Upper Rhine has similar slope patterns and a focus on rehabilitation and protection of the alluvial areas. Flood problems and consequent dams and dikes are present in this reach also. The Middle Rhine has similar landscape and slope patterns and is characterized by strong ecological importance. The Lower Rhine is the urbanized part of the river, where cities and industries are located. This delta is also subject to floods. In Portugal, the Rio Real is divided in three reaches according to basin characteristics (Natali et al., 2009). The lower reach is a broad floodplain, characterized by large irrigation projects, channels and water transfers projects. The middle part is more flat, has narrow levees, and is economically based upon pear orchards and vineyards. The upper reach has narrow channels, less flooding but erosion problems, and no levees.

The organization of criteria into the presented categories is subjective because some aspects fit in more than one category. For instance, hydrographic aspects are physical by nature. Therefore, this classification is flexible and subject to further adjustments, according to different interests.

In accordance with the above exposed, several factors beyond river basin limits have significant influence over water resources planning and management, such as political-administrative, historical-cultural, physical-environmental, socioeconomic and hydrographic characteristics. The recognition of more comprehensive aspects, as detailed in this chapter, reinforces the principles of IWRM. The presented comparative analysis promotes, in addition, a better understanding of the process of delineating water resources planning and management regions, based upon the examples of existing water resources regions in the selected countries. Considering that this is a subjective practice, heuristic knowledge has been identified and incorporated in the analysis. The suggested list of criteria, as well as the additional details of the selected examples in Europe and in America, provide, at least, reference material to future related processes. It is expected that the major aspects are covered, in general, in this analysis. Nevertheless, the consideration of further examples, for instance in Asia or Africa, might certainly include new factors.

Finally, it is important to emphasize that if all the aspects presented above are considered at once, water resources regions might become too centralized or they may not represent actual IWRM strategies. The idea of listing all aspects is to provide possible combinations of conditions to be considered according to a particular situation. At least, it demonstrates that river basin limits need to be harmonized with other hydrographic, socioeconomic, historical-cultural, political-administrative, and physical-environmental aspects. For that reason, each aspect should be weighted, according to the context specific priorities, regional circumstances and IWRM goals, as well as with multiple levels of subsidiarity and adaptive water management strategies.

As a decision support tool to help prioritizing these aspects and delineating water resources regions, WARPLAM is presented in the next chapter.

4. WARPLAM DSS: THE PROPOSED APPROACH TO ADDRESS THE PROBLEM

As described before, the process of developing WARPLAM DSS can be summarized in three main phases: Phase 1) Evaluating the aspects related to the delineation of water resources planning and management regions through a comparative analysis in eleven different countries; Phase 2) Building the DSS through the definition of a suitable approach utilizing the aspects identified in Phase 1; and Phase 3) Demonstrating the capability of WARPLAM DSS through a case study in Brazil.

This chapter outlines Phase 2, modeling of the problem. It presents the DSS and describes how it is developed, including a general overview of its main components, structure, procedures and model design. It also describes how GIS is used as the basis for the development of the proposed DSS, combined with cluster analysis, MCDA, KBS and optimization techniques.

Water Resources Planning and Management Regions Decision Support System is the proposed approach to address the issue of lack of uniform and integrated water resources regions. It constitutes a structured and instructive tool to help decision makers delineate water resources regions, which is usually an ill-structured task. Another important characteristic of the proposed approach is its ability to help balance multiple interests from different stakeholders. Indeed, the DSS supports the harmonization of river basin limits with other hydrographic, socioeconomic, cultural, historical, political-administrative, and environmental-physical aspects.

To describe the process of developing this approach, it is helpful to understand the main steps of the decision analysis process related to the delineation of water resources planning and management regions. In this study, the process is organized into five basic steps, as illustrated in Figure 4.1.

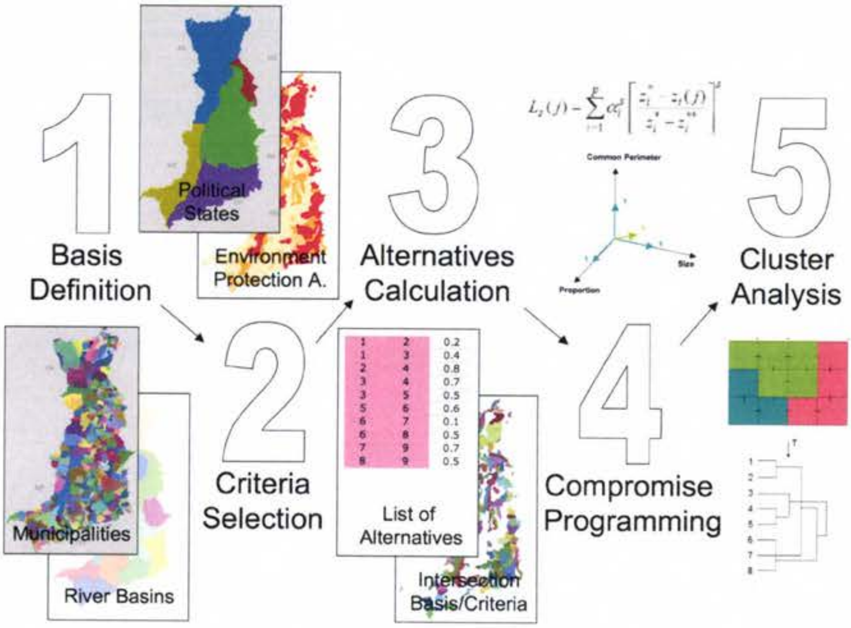


Figure 4.1. Five Steps of the Decision Analysis Process

The first step is the definition of a consistent territorial basis over which to develop an aggregation process. This is an important step because it represents the main aspect to be considered for the water resources regions. For example, the adoption of a consistent basis taking into account natural drainage area limits represents the consideration of watershed boundaries as the basis for the analysis. On the other hand, the adoption of municipalities represents the consideration of political-administrative boundaries as the basis for the analysis. From the grouping of smaller territorial units, such as natural drainage areas or municipalities, water resources planning and management regions will be created. The second step is the selection of criteria, beyond river basin boundaries, that reflect the main aspects related to IWRM principles, such as political-administrative, cultural, and environmental aspects. These criteria represent the recognition of more comprehensive objectives and multiple interests in the analysis. The comparative analysis, presented in the previous chapter, introduces a list of several aspects to be considered and weighted at this step. They should be available, preferably, in the spatial format, or as a constraint to the model. There are different ways to represent the aspects in the spatial format, as demonstrated in Chapter 5. These aspects constitute the DSS KBS, used to support the decision analysis process.

The third step is the combination of weighted criteria with the basis in order to define the 'measure of closeness' for each adjacent pair of territorial units contained in the basis. Each of these pairs constitutes one grouping alternative. The 'measurement of closeness' for each alternative is defined by taking into account overlapping area values of all the criteria. The fourth step is the application of the L2-norm subset of compromise programming to sum up all weighted criteria values for each alternative, considering the different scale range or space dimensions of the criteria' values. The fifth and last proposed step is the application of Cluster Analysis to define different grouping alternatives that represent 'ideal' integrated water resources regions.

The first and second steps of the decision analysis process are closely related to user preferences and the context of the case in analysis. It reflects the results obtained in Phase 1 of this study, which is the identification of important criteria to be considered when delineating regions for water resources planning and management. It constitutes a KBS that provides the necessary understanding about this process, based upon the heuristic rules derived in Phase 1 throughout the comparative analysis among selected countries, surveys, and interviews of experts. The process allows the user to learn from past experiences and decide based upon his/her preferences which of these aspects are important in the specific case.

The last three steps are part of the algorithm developed to model the process of delineating water resources regions. According to the input provided from the KBS, the algorithm performs the necessary agglomeration or clustering by combining weighted criteria and producing different grouping results. After considering the main steps of the decision analysis process, the approach and model outline are presented, followed by a description of the DSS procedures and structure and its components.

4.1. Approach and Model Outline

The model structure is comprised of the algorithm developed to address the delineation of water resources regions. It is divided into three main modules, corresponding to Step 3, Step 4 and Step 5 of the decision analysis process described above. The first module of the algorithm performs the intersection between selected criteria and the basis' units to be clustered according to the KBS rules and users' preferences. It also performs the polygon-to-line operation in ArcGIS, using the basis, in order to list all possible clustering alternatives or adjacent pairs. The criteria, as well as the basis, must be available in the format of spatial data, to be input in the model. The DSS Database Management System supports this step.

Immediately after the intersection and polygon-to-line operations, it is necessary to check for double values, especially because of the list of adjacent basis' units that should have unique alternatives. For instance, when calculating the common perimeter between each adjacent pair, it is possible to have two common lines (perimeter) between the same pair, as shown below (Figure 4.2). The first module of the algorithm sums up all these values. As a result, only unique alternatives are listed.

WS#	WS#	Length
1	2	0.55
1	2	0.32
1	3	0.61

Sum

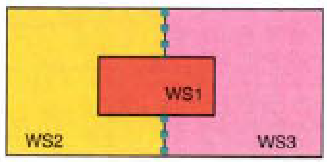


Figure 4.2. Illustration of common lines being shared by the same pair of alternatives

In addition, from the intersection of the basis and the criteria, we can have the same criterion being divided into two separate pieces overlapping one basis' unit. Also, we can have two features of the same criterion overlapping the same pair. Figure 4.3 illustrates these situations. The first module of the algorithm also sums up all these values.

WS#	Ci#	AREA
1	1	1.2
4	1	0.5
3	2	0.9
1	2	2.6
3	2	0.3
4	18	0.5
1	18	3.6

WS/Criteria Table

SUM1 SUM2 SUM2

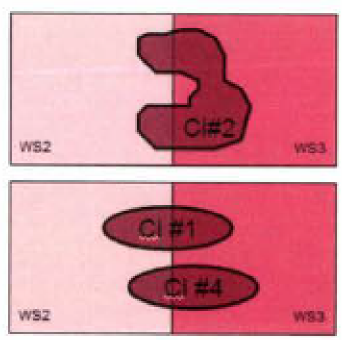


Figure 4.3. Illustration of common criteria being shared by the same pair of alternatives

As mentioned before, each pair of adjacent basis' units constitutes one alternative for the cluster analysis. The pairs are then evaluated in order to check if they should be clustered or not according to a distance measure. The 'measurement of closeness' for each pair is defined taking into account the overlapping area values of criteria over the basis' units, as described above. Considering that the calculations are performed based upon area values, it is not necessary to standardize the data. As soon as an adequate measurement unit is defined for the spatial data, uniform outputs are provided. In addition, the L2-norm subset of compromise programming handles different data dimensions.

According to Coelho et al. (2005) the 'measurement of closeness' is calculated considering the size and proportion of the common criteria areas overlapping each adjacent pair of the basis' units. Besides showing how relevant a common criterion is to the pair (size), the measure also needs to express how equal the overlapping parts are (proportion). The third aspect also considered is the common perimeter between adjacent basis' units. Figures 4.4 and 4.5 illustrate the concepts related to these three aspects. The common perimeter is demonstrated as a dashed green line.

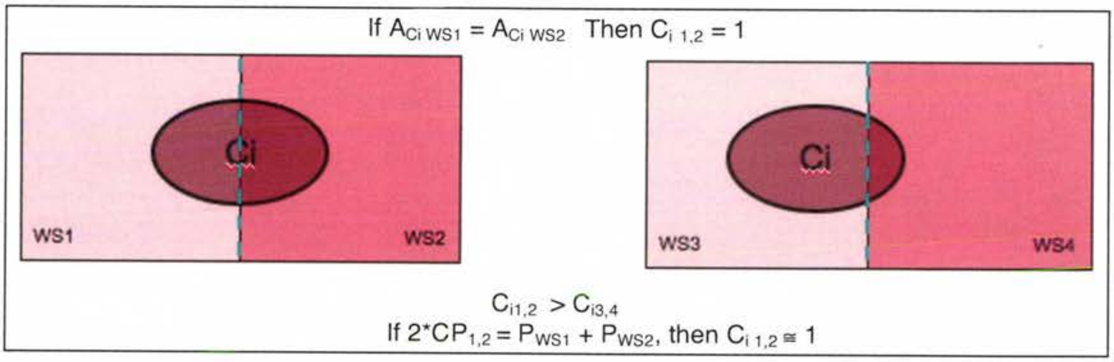


Figure 4.4. Sketch of the proportion and common perimeter aspects

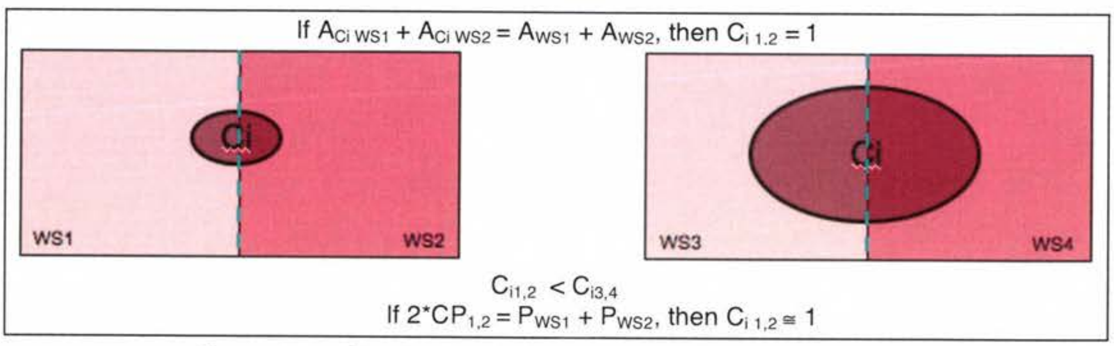


Figure 4.5. Sketch of the size and common perimeter aspects

By grouping these aspects, the following vector-based (Figure 4.6) equation (Equation 01) is adopted:

$$C_{i1,2} = \frac{2 \cdot CP_{1,2}}{P_{WS1} + P_{WS2}} \cdot \frac{A_{C1WS1}}{A_{WS1}} \cdot \frac{A_{C1WS2}}{A_{WS2}} \quad \text{(Eq. 01)}$$

Considering:

$C_{i\,1,2}$ ranges from 0 to 1

$A_{Ci\,WSa}$ = overlapping area of Criterion *i* over basis' unit WSa (*i* = 1, 2, ..., N)

A_{WSa} = area of basis' unit WSa

P_{WSa} = perimeter of basis' unit WSa

$C_{i\,a,b}$ = Measure of Closeness between basis' units a and b, considering Criterion *i*

$CP_{a,b}$ = common perimeter between basis' units a and b

N = number of criteria defined by the user

a = number assigned for the first basis' unit for the pair (a = 1, 2, ..., K)

b = number assigned for the second basis' unit for the pair (b = 1, 2, ..., K)

a,b = corresponding adjacent pair (alternative)

K = number of basis' units (elements) to be grouped

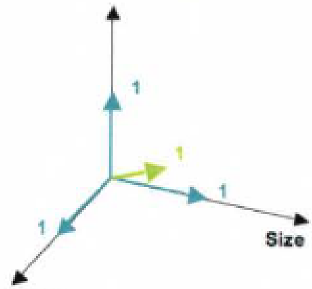


Figure 4.6. Vector-Based Approach Illustration

As soon as the list of alternatives (adjacent pairs) and respective measures of closeness is calculated, the second module of the algorithm is performed. This module is the L2-norm subset of compromise programming to sum up the measure of closeness of each criterion value for each alternative, resulting in the 'Total Measure of Closeness' for each alternative. This method is used to scale the criteria as integration factors that regulate at the distance of the basis' units. It is considered the most adequate method because of the different scale ranges and space dimensions among criteria values, as well as its ability to rank alternatives according to their *closeness* to certain *ideal* criteria levels (Hajkowicz and Collins, 2007; Labadie, 2007). The scaling function is applied using the best (maximum) and worst (minimum) values of the measure of closeness for each criterion, according to the following equation, which represents the L2-norm subset of compromise programming (Equation 02):

$$C_{1,2} = \sum_{i=1}^{N} \alpha_i \left[\frac{C_{ia,b} - C^{**}_{ia,b}}{C^{*}_{ia,b} - C^{**}_{ia,b}} \right]^2 \quad \text{(Eq. 02)}$$

Considering:
$C_{a,b}$ = Total Measure of Closeness between basis' units a and b
a = number assigned for the first basis' unit for the pair (a = 1, 2, ..., K)
b = number assigned for the second basis' unit for the pair (b = 1, 2, ..., K)
a,b = corresponding adjacent pair (alternative)
i = criteria reference
N = total number of criteria defined by the user
α = weight assigned to the respective Criterion *i*
$C_{i\ a,b}$ = Measure of Closeness between basis' units a and b, considering Criterion *i*
$C^{*}_{i\ a,b}$ = Maximum Measure of Closeness between basis' units a and b, considering Criterion *i*
$C^{**}_{i\ a,b}$ = Minimum Measure of Closeness between basis' units a and b, considering Criterion *i*
K = number of basis' units (elements) to be grouped

The Total Measure of Closeness '$C_{a,b}$' is assigned as a *link* between basis' units for each adjacent pair and represents the proximity between these units. Compromise solutions are the result of different sets of weights. After testing different L-norms, the L2-norm is adopted in this study, as specified in Equation 02 by the power of two.

The third module of the algorithm is the application of Cluster Analysis over alternatives to define different groups of basis' units, or clustering alternatives. Cluster analysis is a set of procedures used to create classification and reorganize data into homogeneous groups (MOPU, 1984; Kaufman and Rousseeuw, 1990). The first stage of the Cluster Analysis is to define a numerical measure of homogeneity (Bellman, 1973; Aldenderfer and Blashfield, 1984). The Total Measure of Closeness between each adjacent pair is used as the numerical measure of homogeneity, or the input to the similarity matrix of elements (basis' units) to be clustered. Alternatives of groups with higher similarity will be formed in order to delineate the *ideal* regions for water resources planning and management. Figure 4.7 illustrates the general concept of the procedure.

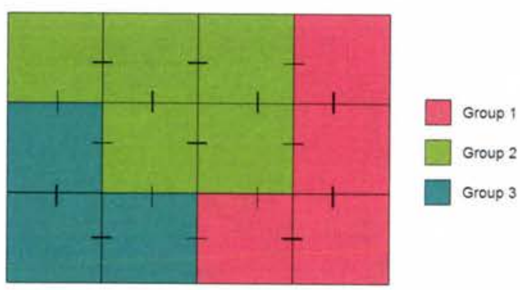
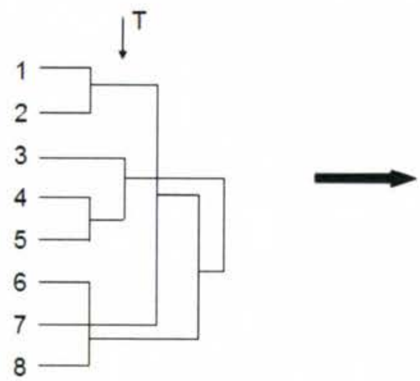


Figure 4.7. Cluster Analysis Schema, assuming highlighted links are the best ones

The first clustering method evaluated is the hierarchical agglomerative approach. This method requires that a threshold parameter T be defined. This parameter represents the maximum distance between elements that should be clustered or not, or the stop criteria. Figure 4.8 illustrates the parameter in the hierarchical tree, also know as dendogram.



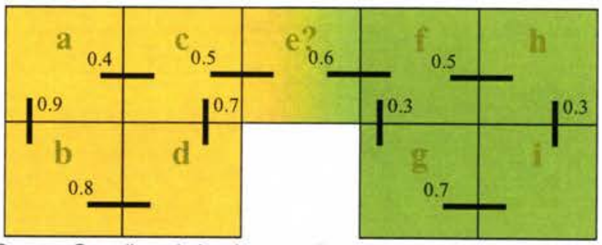
WS#	Group
1	1
2	1
3	2
4	2
5	2
6	3
7	4
8	3

Figure 4.8. Representation of Threshold Parameter T

Different grouping results can be generated using different T values. In this approach, one single distance link is necessary to define if the pair will be clustered or not. This is performed as a chain sequence, using previously established clusters. The average distances among all elements of the cluster are not considered in this case. Additional clustering methods may overcome the drawbacks of the hierarchical associative method. For instance, using basically the same approach, the hierarchical dissociative method undertakes fewer steps to reach the final ideal groups. In both methods, the following conditions apply:

If $C_{a,b} > T$, elements 'a' and 'b' are clustered.
If $C_{a,b} < T$, elements 'a' and 'b' are not clustered.
For the next step, considering 'a' and 'b' are clustered:
If $C_{a,c}$ or $C_{c,b} > T$, element 'c' is clustered to the group 'a,b'.
If $C_{a,c}$ or $C_{c,b} < T$, element 'c' is not clustered to the group 'a,b'.
$C_{a,b}$ = Total Measure of Closeness between elements 'a' and 'b'.

A third clustering method is the partitioning method, or k-means. In this alternative, the user can define the number of groups a priori and the method calculates the best division of the elements according to the overall distance of each cluster. The best advantage of this method is that the concept of pre-defining a number of groups is more easily understood by the user, different than the threshold parameter T. In addition, the partitioning method, in contrast to the hierarchical method, generally results in improved patterns of similarities between elements of the groups because the overall distance of the group is being considered (Kaufman and Rousseeuw, 1990; Aldenderfer and Blashfield, 1984). Considering that the distances between all elements is not provided, but just the distances between adjacent elements, the overall distance for the partitioning method is calculated considering the average proximity between all elements of the group. In this case, the goal is to maximize the overall proximity of all clusters or minimize intra-cluster variance. The constraints associated with the problem are derived from the knowledge rules existing in the KBS based upon the users preferences. Figure 4.9 illustrates the calculation of the average overall proximity measure as part of the partitioning method.



$D_{a,b,c,d}$ = Overall proximity of group yellow without "e" = $(C_{a,b} + C_{a,c} + C_{b,d} + C_{c,d})/N$ = (0.9 + 0.4 + 0.8 + 0.7) / 4 = 0.7

$D_{e,f,g,h,i}$ = Overall proximity of group green with "e" = $(C_{f,g} + C_{f,h} + C_{g,i} + C_{h,i} + C_{e,f})/N$ = (0.3 + 0.5 + 0.7 + 0.3 + 0.6) / 5 = 0.48

Overall proximity of the two clusters = (0.7+0.48)/2 = 0.59

$D_{a,b,c,d,e}$ = Overall proximity of group yellow with "e" = $(C_{a,b} + C_{a,c} + C_{b,d} + C_{c,d} + C_{c,e})/N$ = (0.9 + 0.4 + 0.8 + 0.7 + 0.5)/5 = 0.66

$D_{f,g,h,i}$ = Overall proximity of group green without "e" = $(C_{f,g} + C_{f,h} + C_{g,i} + C_{h,i})/N$ = (0.3 + 0.5 + 0.7 + 0.3) / 4 = 0.45

Overall proximity of the two clusters = (0.66+0.45)/2 = 0.55

Element "e" is grouped with group green because the average of overall proximity is higher (0.59 > 0.55)

N = number of elements in the group.

Figure 4.9. Representation of Overall Distance and Partitioning Method Procedure

A significant drawback of this method is the very large number of alternatives to be analyzed (Kaufman and Rousseeuw, 1990). Depending on the number of elements to be grouped, the analysis may become too extensive. In such cases, DP can be applied to support the evaluation of multiple alternatives. It speeds up the analysis consistently and is ideally suited for cluster analysis (Bellman, 1973; Esogbue, 1986). Additionally, DP allows the analysis of the optimum number of groups if a cost criterion is defined. In this case, the pre-defined number of clusters is not required.

The DP method is applied in this study using the generalized DP software developed by Labadie (1990). A 9-element data set is adopted as the trial exercise of the method in the study, assuming that it results from Step 1, Step 2 and Step 3 of the decision analysis process. The following proximity matrix contains the 'total measure of closeness' for each of the adjacent pairs in the analysis (Table 4.1).

Table 4.1 Proximity Matrix adopted as an example for the Cluster Analysis

NA	a	b	c	d	e	f	g	h	i
a	NA	0.2	0.4						
b	0.2	NA		0.8					
c	0.4		NA	0.7	0.5				
d		0.8	0.7	NA					
e			0.5		NA	0.6			
f					0.6	NA	0.1	0.5	
g						0.1	NA		0.7
h						0.5		NA	0.5
i							0.7	0.5	NA

The intra-cluster measure of homogeneity is calculated considering the average of the 'measures of closeness' contained in the proximity matrix. For example, for the 4-element cluster 'a-b-c-d', it is equal to 0.525, taking into account the list of pairs and respective 'measure of closeness' contained in Table 4.2. The inter-cluster measure of homogeneity is then calculated by taking the average of the intra-cluster measures of homogeneity. For example, the nine available elements can be clustered in three groups of two, three and four elements, respectively. The inter-cluster measure of homogeneity is then the average of the three intra-cluster measures of homogeneity, as shown in Table 4.3.

Table 4.2 Intra-Cluster Measure of Homogeneity

a,b	0.2		
a,c	0.4	Sum	Average
b,d	0.8	2.1	0.525
c,d	0.7		

Table 4.3 Inter-Cluster Measure of Homogeneity

a,b	0.2					
a,c	0.4	Sum	Average	a,b,c,d		
b,d	0.8	2.1	0.525			
c,d	0.7					
e,f	0.6	Sum	Average	e,f,g	Sum	Average
f,g	0.1	0.7	0.35		0.875	0.292
h,i	0.3	-	-	h,i		

It is assumed that if the cluster has one element, the intra-cluster measure of homogeneity is equal to zero. The objective is to reduce the inter-cluster measure of homogeneity if there are clusters containing just one single element. This way, the best grouping alternatives—or the ones containing the highest inter-cluster measure of homogeneity—are more homogeneous. For example: having clusters 'e-f' and 'c-d' (Inter-Cluster = 0.65, as the average of 0.6 and 0.7) is better than having clusters 'c-d-e' and 'f' (Inter-Cluster = 0.30, as the average of 0.60 and 0.00). Also, considering that the intra-cluster measure of homogeneity is calculated by the average of the adjacent measure of closeness links, this value is carried on to the inter-cluster measure of homogeneity, as a function of the stage. In such a case, the more the number of links, the higher the overall objective, and groups with more elements are chosen. The calculation favors adding more elements to a bigger group instead of a smaller one, because the average is decreased more when the new element, with a lower measure of closeness, is added to a smaller group.

Considering the concepts presented above, the objective of the problem is to maximize the inter-cluster measure of homogeneity. For that, the DP analysis is divided into two parts, according to the method suggested by Bellman and Zadeh (1970), Bellman (1973), and Esogbue (1986). It consists of dividing the set of alternatives into *l* groups, according to the intra-cluster measure of homogeneity, and determining the optimal value of *l* according to the inter-cluster measure of homogeneity and then the optimal subdivision. The additive objective function is set up to maximize the total benefits of allocating *n* elements to *l* clusters. The initial DP recursion relation and other related equations are defined as follows (Equation 03). The equations will be adjusted, in the sequence, in order to incorporate a deeper analysis of the alternatives. However, it is useful to understand the general concept first and then the more detailed analysis.

$$F_i(x_{i+1}) = \max\left[B(b_i) + F_{i-1}(x_i)\right] \quad \text{(Eq. 03)}$$

Subject to:
$0 <= x_i <= n$
$0 < b_i = x_{i+1} - x_i <= n$ (no cluster with 0 elements)
$b_i = 1,2, \ldots, n$
$F_i(x_{i+1})$ is recursively evaluated for all discrete x_{i+1}: $n-(n-1) <= x_{i+1} <= n$

Over stages $i = 1, 2, \ldots, I$
For boundary conditions: $F_0(x_1) = 0$
$x_1 = 0$; $x_I = n$ (all elements should be clustered at the end)
Optimal solution can be found in any stage when $x_{i+1} = n$
$\text{Max}_i\ F_i(x_{i+1})$

Considering:
n = total number of elements to be clustered
I = maximum number of clusters (not necessarily the optimal number)
b_i = number of elements in the cluster (decision variables)
$B(b_i)$ = intra-cluster measure of homogeneity (benefit)
$\Sigma\ b_i <= n$ for $i = 1, \ldots, I$
i = stage reference = respective cluster
x_i = state variables

The decision variable is the number of elements to be included in the cluster in each stage. The state variables are the number of elements allocated in previous clusters, using the concept of the resources allocation problem. They are both integer values, according to the nature of the problem. The benefit is equal to the intra-cluster measure of homogeneity (average of the measures of closeness). It is calculated in a pre-optimization step that returns the best possible benefit for a cluster having b_i elements. The DP solution to this problem uses a forward recursion relation for calculating the DP optimal return function and the inverted form of the state dynamic equation ($u_i = x_{i+1} - x_i$).

The important concept that is added to Bellman's initial proposed recursion relation is the ability to store the information calculated in the stage before and use it as an input for the sequence of the solution. The proposed method stores the best results in each stage to be used in the next stage in order to exclude the elements already clustered. In order to be able to perform this task, the binary string concept is applied. This is a really efficient and unique way to organize the data. Considering all possible combinations among the elements, the position in a string determines if an element is included in the cluster or not. Therefore, in each stage and state variable discretization, the algorithm returns a unique number that is associated with a string that represents the clustered elements. There is a unique integer number associated with each possible combination, or each binary string (Table 4.4). This unique number is used to guarantee that the elements previously clustered are not included in the current stage.

Table 4.4 Unique Number and Binary String for Different Combinations

Elements	Binary Code	Binary String							
b	128	0	1	0	0	0	0	0	0
c-d	96	0	0	1	1	0	0	0	0
c-d-e	224	0	1	1	1	0	0	0	0
c-e-f	88	0	0	1	0	1	1	0	0
c-e-f-h	90	0	0	1	0	1	1	0	1	0

In addition, the running average concept, as defined by Lee and Labadie (2007) is analyzed in order to adapt the objective function to the format required by the intra-cluster measure of homogeneity. Considering that the average is required in each stage of the problem, in order to calculate the inter-cluster measure of homogeneity, discount factors (DF) might be added in both parts of the DP recursion equation, as shown in Equation 04. As a result, the inter-cluster measure of homogeneity is adapted to the DP format, and the 'running average' is calculated in each stage. It is important to note that the discount factor varies along the stages. CSUDP software allows the user to define a unique DF for the objective function.

$$F_i(x_{i+1}) = \max\left\{\left[\left(\frac{1}{i}\right)B(b_i)\right] + \left[\left(\frac{i-1}{i}\right)F_{i-1}(x_i)\right]\right\} \qquad \text{(Eq. 04)}$$

Another important observation is that it is not necessary to run all the stages of the DP formulation. For this problem, there is one solution to be analyzed in each stage, following Bellman's principle of optimality: "No matter what the initial state and stage of a sequential decision process, there exists an optimal policy from that state and stage to the end". For instance, in Stage 3, three clusters are defined; in stage 4, four clusters are defined; then both sets of clusters are compared to test for the higher benefit (inter-cluster measure of homogeneity). Considering that the optimal solution can be found in any stage when $x_{i+1}= 0$ (meaning all elements are clustered), it is possible to check for a peak of the best possible solutions along the stages. As demonstrated in Figure 4.10, after Stage 3, the benefits start to decrease. Therefore, the optimum solution is to have three clusters located in Stage 3. The best solution is not located at the end because the last stage is always composed of clusters with one element. Therefore, it is recommended to stop the algorithm when the return values start to decrease in order to increase its efficiency, as suggested by Esogbue and Bellman (1984), Tsitsiklis and Roy (1999), Krichen and Abdelaziz (2007), Yoshida (1994) and Stein (1980). In order to get the optimal feedback policies in CSUSP, it is necessary to re-run DP for the respective optimum stage. If the user pre-defines the number of clusters, then the optimum solution for that selected number of clusters is always given at the respective stage. Therefore, CSUDP will run just for the selected number of stages.

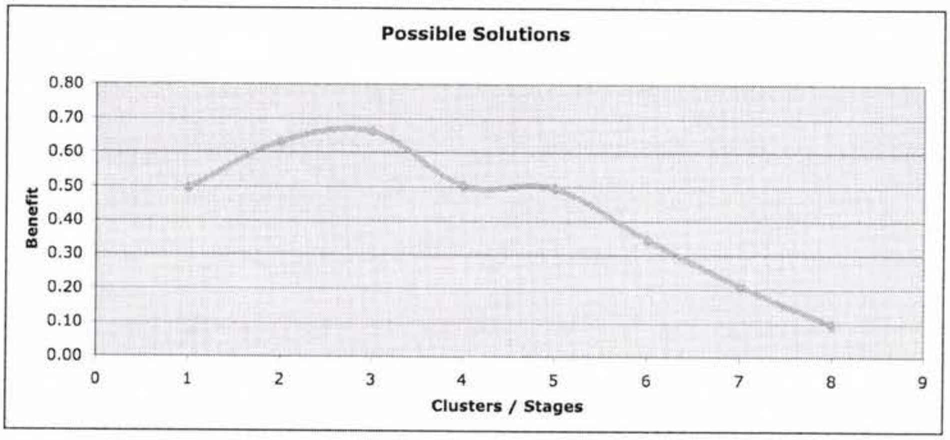


Figure 4.10. Possible Solutions and Respective Return Values in each Stage

Table 4.5 presents the maximum benefit and the best solution for the given 9-element data set adopted as the trial exercise of the method in study.

Table 4.5 Maximum Benefit representing the best solution for given data set

Clusters	$f_i(m_i)$	m_i	X_i	X_{i+1}
b-d	0.8	2	9	7
g-i	0.7	5	7	5
a-c-e-f-h	0.5	2	5	0
	Max	0.67	3 clusters	

At this point, after the general concept of the DP formulation has been explained, it is necessary to describe the detailed DP formulation actually used to solve the problem. The initial presented formulation may not be sufficient to prove the best solution is reached because not all necessary alternatives are analyzed as part of the combinatorial problem. The pre-optimization step used in this initial formulation, which returns the best possible benefit for a cluster having b_i elements, was verified as not the most adequate method for solving the problem. Despite the fact that the method is really fast, some clustering alternatives that may lead to the best solution are ignored. This was proven using a exhaustive enumeration algorithm that tested all possible combinations of the clustering alternatives.

In order to address this issue, the new recursion relation considers the proposed binary code concept as the decision variable. The modified DP formulation of optimal clustering algorithm is presented below (Equation 05).

$$F_i(x_{i+1}) = \max\left\{\left[\left(\frac{1}{i}\right)B(u_i)\right]+\left[\left(\frac{i-1}{i}\right)F_{i-1}(x_i)\right]\right\} \quad \text{(Eq. 05)}$$

Subject to:

$0 <= x_i <= N$

$0 < u_i = x_{i+1} - x_i <= N$ (no cluster with 0 elements, being $u_i = 0$ the respective binary string representing no elements in the cluster)

$\Sigma\, s_\ell(u_i) = 1$ for $\ell = 1, \ldots, n$ (all elements must be included in a cluster)

$\Sigma\, u_i = N$ when $x_l = N$ for $i = 1, \ldots, l$

$u_i = 1, 2, \ldots, N$

$s_\ell(u_i) \neq s_\ell(u^*_{k-1}(x_k))\ \forall \ell \ni s_\ell(u_i) = 1$

$x_{k-1} = x_k - u^*_{k-1}(x_k)$ for $k = i, \ldots, 1$

$F_i(x_{i+1})$ is recursively evaluated for all discrete x_{i+1}: $n-(n-1) <= x_{i+1} <= N$

Over stages $i = 1, 2, \ldots, l$

For boundary conditions: $F_0(x_1) = 0$

$x_1 = 0$; $x_l = N$ (all elements should be clustered at the end)

Optimal solution can be found in any stage when $x_{i+1} = N$

$\mathrm{Max}_i\, F_i(x_{i+1})$

Considering:

n = total number of elements to be clustered

l = maximum number of clusters (not necessarily the optimal number)

$N = 2^n - 1$: total number of binary strings

u_i = respective binary string code of the cluster selected in stage i (decision variables)

$u^*_i(x_{i+1})$ = optimal clustering policies stored at each stage i

$s(j)$ = set of binary strings of length n

$j = 1, \ldots, N$: unique integer number associated with each binary string as a code

ℓ = location reference of each element at the binary string

if $\ell = 1$, element l is included in the cluster represented by the respective binary string

$s_\ell(u_i)$ = element ℓ of binary string $s(u_i)$ with associated integer code u_i

$B(u_i)$ = intra-cluster measure of homogeneity (benefit)

$u_i = j$: decision variable u_i represent the integer value associated with string $s(j)$

i = stage reference = respective cluster

x_i = state variables

According to the formulation presented above, the clustering algorithm is initiated by generating a set of binary strings s(j) of length n, where n is the total number of elements to be clustered and j = 1,...,N, where N is the total number of unique binary strings containing elements with bit values = 1. Location ℓ in the binary string with bit value = 1 specifies that element ℓ is included in the cluster represented by that binary string. Each binary string s(j) is coded with an unique integer value j, calculated according to the binary string property. Associated with each binary string s(j) are precalculated benefits B(j), representing the intra-cluster measure of homogeneity value of a binary string s(j). Binary strings with a single nonzero element are allowed, primarily for guaranteeing feasibility, but are assigned a reduced benefit, as detailed before. The decision variables $u_i = j$ represent the integer code j associated with string s(j) for each stage $i = 1,\dots,I$, where i represents the number of clusters that are defined at that stage and I is the maximum number of clusters (not necessarily the optimal number). The state variables are no longer the number of elements allocated but an artificial number related to the range of binary codes. The decision variable is which cluster to consider in that stage, among all available clusters available, represented by binary codes. The term $u^*_i(x_{i+1})$ supports the back calculation of the stored optimal clustering policies from the stages previous to stage i, to ensure that elements selected for clustering in stage i have not been previously clustered. The DP solution to this problem also uses a forward recursion relation for calculating the DP optimal return function and the inverted form of the state dynamic equation ($u_i = x_{i+1} - x_i$).

The optimal number of clusters i^* and optimal accumulated integer code values for all optimal binary strings is then calculated. Traceback solutions (Figure 4.11) through the optimal storage integer codes gives the optimal clustering defined by binary strings by sequentially retrieving the stored optimal clustering policies for each stage i.

Set $i = i^*$, $x_{i+1} = x^*_{i+1}$
For $i = i^*,\dots,1$
  retrieve $s\left(u_i^*\left(x_{i+1}\right)\right)$
  IF $i > 1$, calculate $x_i = x_{i+1} - u_i^*(x_{i+1})$
Loop end

Figure 4.11. Illustration of the Traceback Formulation

Despite the fact that the modified DP formulation may be too computationally intensive, no clustering alternative is ignored. In addition, the binary coding system provides an additional feature that is well suited to this problem. The interesting outcome of the proposed approach is that the sum of the binary codes associated with the selected clusters in each stage is always equal to the maximum value N of binary coding for that number of elements, when all elements are clustered. Table 4.6 illustrates this affirmation. Therefore the condition x_{i+1}= N is true for the recursion relation, considering x_1 = 0, and the optimal solution can still be found in any stage when x_{i+1}= N, meaning that all elements are clustered. This fact also guarantees that the range of binary codes, adopted as the range of the state and decision variables, is sufficient to analyze all necessary alternatives in the DP structure. For instance, for the 9-element case, there is no need to check the combination of clusters 280 and 410 because the sum is over 511.

Table 4.6 Illustration of the binary code property

Elements	Binary Code	Binary String								
Possible Solution #1										
b-d	160	0	1	0	1	0	0	0	0	0
g-i	5	0	0	0	0	0	0	1	0	1
a-c-e-f-h	346	1	0	1	0	1	1	0	1	0
SUM	511	1	1	1	1	1	1	1	1	1
Possible Solution #2										
c-e-f-h	90	0	0	1	0	1	1	0	1	0
g-i	5	0	0	0	0	0	0	1	0	1
a	256	1	0	0	0	0	0	0	0	0
b-d	160	0	1	0	1	0	0	0	0	0
SUM	511	1	1	1	1	1	1	1	1	1

The major drawback of this method, as mentioned before, is that it may become too computationally intensive. For instance, when seventeen elements need to be clustered, N is equal to 131,071, which is also equal to the number of decision and state variables. In this case, the algorithm is inefficient in terms of time. In order to address this issue, a 'recoding system' is suggested, as well as the elimination of some clustering alternatives. The maximum number *m* of elements per cluster is used to ignore all the clustering alternatives that contain a higher number of elements. The 'recoding' also eliminates additional alternatives because it ignores the combinations that are not valid. For the 17-elements case, for instance, element #1 is not adjacent to element #17. Therefore, the clustering alternative 1-17 is not valid. When using the original binary code property, the respective code for the alternative 1-17 is checked in the DP analysis and is then considered infeasible. In the new recoding system, this alternative is not checked. The number of combinations to be analyzed is then much smaller. The last modified DP formulation of the optimal clustering algorithm, incorporating the 'recoding system is presented below (Equation 06).

$$F_i(x_{i+1}) = \max\left\{\left[\left(\frac{1}{i}\right)B(u_i)\right] + \left[\left(\frac{i-1}{i}\right)F_{i-1}(x_i)\right]\right\} \text{ (Eq. 06)}$$

Subject to:

$0 <= x_i <= x_{max}$

$0 < u_i = x_{i+1} - x_i <= N$ (no cluster with 0 elements, being $u_i = 0$ the respective binary string representing no elements in the cluster)

$\Sigma\, s_\ell(u_i) = 1$ for $\ell = 1, \ldots, n$ (all elements must be included in a cluster)

$\Sigma\, u_i <= x_{max}$ for $i = 1, \ldots, I$

$s_\ell(u_i) \neq s_\ell(u^*_{k-1}(x_k))\ \forall \ell \ni s_\ell(u_i) = 1$

$x_{k-1} = x_k - u^*_{k-1}(x_k)$ for $k = i, \ldots, 1$

$u_i = 1, 2, \ldots, x_{max}$

$F_i(x_{i+1})$ is recursively evaluated for all discrete x_{i+1}: $n-(n-1) <= x_{i+1} <= x_{max}$

Over stages $i = 1, 2, \ldots, I$

For boundary conditions: $F_0(x_1) = 0$

$x_1 = 0$;

$\text{Max}_i\, F_i(x_{i+1})$

Considering:

n = total number of elements to be clustered

m < n: m is the maximum number of elements per cluster

I = maximum number of clusters (not necessarily the optimal number)

x_{max} = arbitrary upper bound on the total accumulated integer code for binary strings selected at each stage

u_i = respective binary string code of the cluster selected in stage *i* (decision variables)

$u^*_i(x_{i+1})$ = optimal clustering policies stored at each stage *i*

s(j) = set of binary strings of length n

j = 1, ..., N: unique integer number associated with each binary string as a code

N = total number of unique binary strings with a maximum of *m* elements with bit values =1

ℓ = location reference of each element at the binary string

if $\ell = 1$, element I is included in the cluster represented by the respective binary string

$s_\ell(u_i)$ = element ℓ of binary string $s(u_i)$ with associated integer code u_i

$B(u_i)$ = intra-cluster measure of homogeneity (benefit)

$u_i = j$: decision variable u_i represent the integer value associated with string s(j)

i = stage reference = respective cluster

x_i = state variables

According to the formulation presented above, the modified clustering algorithm is initiated by: 1) listing all clustering alternatives; 2) generating a set of binary strings s(j) of length n, respective to the list of clustering alternatives, where n is the total number of elements to be clustered and j = 1,...,N, where N is the total number of unique binary strings with a maximum of m (< n) elements with bit values = 1, which represent the elements included in the cluster; 3) eliminating the clustering alternatives that have more elements than *m*; 4) re-ordering the valid clustering alternatives considering the original binary codes (the ordering of bit strings with the same number of bit values set to 1 is arbitrary, but if the original binary code sequence is preserved, x_{max} can be reduced); and 3) replacing these codes by a sequential order of unique integer values, so that bit strings s(j) are uniquely associated with an integer code value j. For example, the ordering procedure assigns the integer code j = 717 to the bit string [0 0 0 1 0 1 1 0 0 1 1 0 1] , which indicates that elements 4, 6, 7, 10, and 13 are cluster alternative. The total number of combinations of binary strings with a maximum of nonzero elements is calculated using Equation 07.

$$N = \sum_{k=1}^{m} \begin{bmatrix} k \\ n \end{bmatrix} \quad \text{(Eq. 07)}$$

The same as in the previous formulations, associated with each binary string s(j) are precalculated benefits B(j), representing the intra-cluster measure of homogeneity value of a binary string s(j). Binary strings with a single nonzero element are allowed, primarily for guaranteeing feasibility, but are assigned a reduced benefit, as detailed before. The decision variables u_i = j represent the integer code j associated with string s(j) for each stage $i = 1,\ldots,I$, where i represents the number of clusters that are defined at that stage and I is the maximum number of clusters (not necessarily the optimal number). As explained before, the state variables are no longer the number of elements allocated but an artificial number related to the range of binary codes, varying from 1 to x_{max}. The decision variable is which cluster to consider in that stage, among all available clusters available, represented by binary codes. A reasonable initial estimate for x_{max} is I*(N/2), but this can be increased if the results indicate that the selected value for x_{max} is over-constraining the solution. The assumption $\Sigma\ u_i <= x_{max}$ requires that the accumulated integer codes selected for all stages not exceed x_{max}. It is equivalently represented as a state equation for solution by DP. The DP solution to this problem also uses a forward recursion relation for calculating the DP optimal return function and the inverted form of the state dynamic equation ($u_i = x_{i+1} - x_i$). The term $u^*_i(x_{i+1})$ continues to support the back calculation of the stored optimal clustering policies from the stages previous to stage i, to ensure that elements selected for clustering in stage i have not been previously clustered.

In these forward computations through stages $i = 1,\ldots,I$, termination may occur prior to reaching the final stage I if feasible solutions cannot be found at that stage. Infeasible solutions encountered at stage i can occur if forcing a solution comprised of exactly i clusters is unattainable since a predetermined maximum number of elements m is allowed in any cluster. The optimal number of clusters i^* and optimal accumulated integer code values for all optimal binary strings is then calculated. As illustrated before, traceback solutions through the optimal storage integer codes gives the optimal clustering defined by binary strings by sequentially retrieving the stored optimal clustering policies for each stage i.

It is important to highlight that the properties of the binary code system, illustrated in Table 4.6, does not apply any longer. The optimal solution is not always found in any stage when x_{i+1}= N. In addition, when x_{i+1}= N, it is not possible to assume that all elements are clustered. Thus, the range of state variables should be increased to the x_{max} value. The decision variable range may still be equal to the maximum value N of the unique code associated with the clustering alternatives. In each stage, the results should be tested to verify if all elements are clustered before the optimization step. Even considering this extra step, the 'recoding system' algorithm is more efficient in terms of time. The solutions were again compared to the exhaustive enumeration algorithm results and considered valid in all the tests.

The 'recoding system' is recommended for problems containing more than ten elements to be clustered in order to speed up the algorithm run time. The last modified DP formulation is not too computationally intensive and no clustering alternative, within the range of the maximum number m of elements per cluster, is ignored.

In order to test the efficiency of the DP optimization procedure, the genetic algorithm approach was also evaluated. The clustering problem was set up using GOAL software developed by Ángel Martín, Version 2.0, January 2002. The following parameters were defined:

- Binary variables representing all clustering alternatives;
- Objective Function: maximize the inter-cluster measure of homogeneity;
- Object function incorporates the intra-cluster measure of homogeneity for each clustering alternative, associated with the respective binary variable;

- Penalties are added to the objective function if the same element is used in more than one cluster;
- Population: 40;
- Generations: 300;
- Reproduction type: 2 points Crossover;
- Selection type: tournament selection;
- Elitism: 2;
- Mutation probability: 0.05;
- Reproduction probability: 0.85;
- Selection probability: 0.85.

The optimum solution for 5-element and 7-element trial datasets, using the genetic algorithm approach, was reached after trying different parameters. However, the method was considered less advantageous because the set up of the objective function, penalties, and associated binary values is more time consuming than the DP approach set up. No specific analysis was performed to compare the time used by both methods because they were approximately equal. In addition, the DP method offers the alternative to have multiple optimum clusters defined in one run, for instance the best solution for three, four, five, six, etc. clusters. Therefore, DP is selected as the best optimization approach for this problem.

Given the results of the cluster analysis step, the algorithm reaches its end. The DSS provides two extra analyses regarding the presented results. First, an automatic report, based upon knowledge rules, is generated, providing additional information to the user and important details about the results, such as the number of clusters created, the elements contained in each cluster, the area of each cluster, and the most significant aspects considered to define each cluster. Because size and distances may constitute an important constraint to the model, the users should have access to the necessary information related to that.

Second, the fuzzy membership values, or membership coefficients, of each element to the assigned cluster, as well as to other adjacent clusters, are given. Considering the fuzziness associated with this problem, it is assumed that no sharply defined boundaries exist. The objective function is considered subjective, especially because of the qualitative judgments related to the solutions and imprecise knowledge. The uncertainty is also related to the ill-structured nature of the problem and the selection of criteria by the decision maker. It is clear, in this context, that the elements have a continuous grade of membership to more than one cluster, representing the situations that do not completely fulfill the quantitative results, or that have no sharp boundaries. Therefore, the uncertainty associated with defining element X as part of cluster Y should be represented and may be used by the decision makers in the decision-making process. As part of the solution, a fuzzy membership value table is generated in each simulation. According to Bellman and Zadeh (1970), fuzzy is the best way to demonstrate the difference between human intelligence and machine ability, as well as model and reality.

The fuzzy membership values are calculated considering first the decrease in the object function by assigning the respective element to a different adjacent cluster. The percentage of decrease is used as a reduction factor for the 'measure of closeness' associated with the respective element and the adjacent cluster in analysis. Then, the measures of closeness of the respective element are balanced to represent the fuzzy membership values. The next topics present an example of the fuzzy membership calculation process.

Assuming:

- Element #3 is assigned to Cluster #5.
- Element #3 is also adjacent to Clusters #1 and #6.
- The 'measure of closeness' between Element #3 and Cluster #5 is equal to 0.248.
- The 'measure of closeness' between Element #3 and Cluster #1 is equal to 0.038.
- The 'measure of closeness' between Element #3 and Cluster #6 is equal to 0.118.
- The total 'measures of closeness' is equal to 0.405.
- The Maximum Total Benefit of the respective simulation is equal to 0.347.
- If Element #3 is clustered to Cluster #1, the total benefit is reduced to 0.338.
- It represents 97% of the original maximum total benefit.
- Using the reduction factor, 0.038 becomes 0.037.
- It represents 97% of the original 'measure of closeness' value.
- If Element #3 is clustered to Cluster #6, the benefit is reduced to 0.327.
- It represents 94% of the original maximum total benefit.
- Using the reduction factor, 0.118 becomes 0.111.

- It represents 94% of the original 'measure of closeness' value.
- Then, the reduced value, 0.037 represents 9.2% of total 'measure of closeness', 0.405.
- The value 9.2% is assigned as the membership function value of Element #3 to Cluster #1.
- Then, the reduced value, 0.111 represents 27.4% of total 'measure of closeness', 0.405.
- The value 27.4% is assigned as the membership function value of Element #3 to Cluster #6.
- The difference, 63.4% is assigned as the membership function of Element #3 to Cluster #5.

Finally, the DSS also allows the user to store different simulation results for future comparison. The different simulations can be performed according to the users' preferences, using different weights for the criteria, different numbers of clusters, and different limits for the number of elements per cluster. If a number of clusters is defined by the user, no optimization of the best number of clusters is performed. Considering that the DSS is not a *decision making system*, it is important to reinforce that the objective of the DSS is not to give an optimum number of clusters or an optimum solution. Instead, different simulations of clustering alternatives seems to be more important for the decision makers in order to evaluate the problem and learn about the important aspects related to the analysis of the problem.

The key of cluster analysis is to define 'real groups' instead of 'imposed groups', in order to be as close to the reality as possible. In this case, the combination of DSS, GIS, cluster analysis, DP and fuzzy analysis constitute an adequate structure to provide 'good enough' solutions and the necessary support for the decision analysis process. The combination of all these techniques used to solve the addressed problem is the innovation proposed with this study.

4.2. DSS Procedures and Structure

WARPLAM DSS is structured using ESRI ArcGIS and Microsoft Excel functionalities. The first two phases of the decision analysis process are supported mainly by ArcGIS functionalities. The criteria and basis selection is facilitated through the use of GIS. All input data are easily manipulated, especially because of the graphic interface. The KBS is integrated into the GIS interface to provide the necessary understanding of the criteria and basis selection process, based upon heuristic rules derived from the comparative study, presented in Chapter 3. Therefore, users are able to learn from past experiences and to decide, based upon their own preferences, which of these aspects are important in the specific context of the case in analysis. As soon as the criteria are selected, data can be easily imported into the model. The ESRI Geodatabase format is recommended to increase the integration among the ArcGIS and the Excel, but data may also be used in shapefile or coverage formats. Homogeneous and better resolution of data in GIS operations may produce better and more precise values for criteria evaluation.

After data are selected, the Database Management System handles all pre-processing analysis, as part of Step 3 of the decision analysis process, in order to prepare the input data for the model system. Knowledge rules, imported from the KBS, are directly integrated into the database. The intersection among chosen criteria and the consistent basis is performed. In order to support the creation of a more functional and user-friendly interface, the Model Builder ArcGIS functionality is used. This tool allows all the repeated tasks to be performed at one click according to the selected functionalities. In such cases, the calculation of all overlapping areas is performed by one click and the results are incorporated into the model system through the use of a single workspace. Figure 4.12 illustrates a representation of the tool.

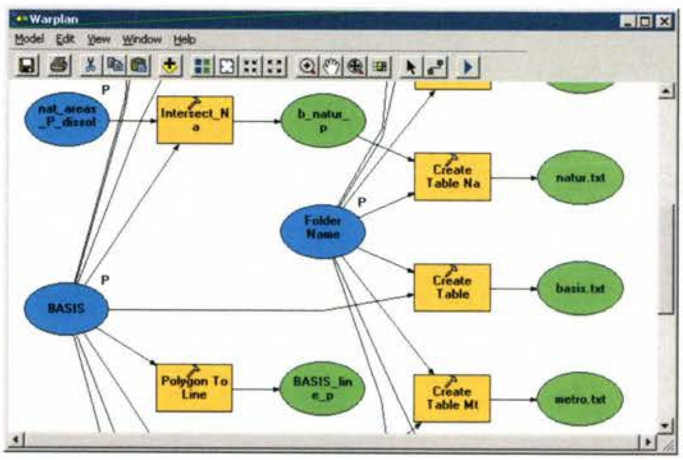


Figure 4.12. Illustration of the Model Builder Tool

As a result of this pre-processing stage, all overlapping areas of selected criteria are calculated and combined with the knowledge rules from the KBS. In addition, all adjacent pairs are listed as possible alternatives to be grouped. The use of GIS is really advantageous because the GIS structure easily provides the valid pairs of alternatives and the adjacency property, which is an important step to facilitate the definition of the cluster algorithm. This way, the necessary input for the model system is ready and the second module of the algorithm can be started.

The algorithm is developed using Microsoft Excel Macros, which guarantee the necessary integration among the data management system and the model system. As soon as the data are ready in the model system, the user needs to define the weights for each criterion and some parameters for the analysis. This is also facilitated though a user-friendly graphical user interface (GUI) in Excel.

In addition, optimization techniques are applied to support the clustering process and to increase the algorithm's efficiency. CSUDP generalized DP software (Labadie, 1990) is used to perform the clustering process. Integration between CSUDP and Excel is also guaranteed. Finally, the results of the simulation are displayed in the GIS interface automatically, as well as in Excel. Figure 4.13 illustrates a summary of the procedures.

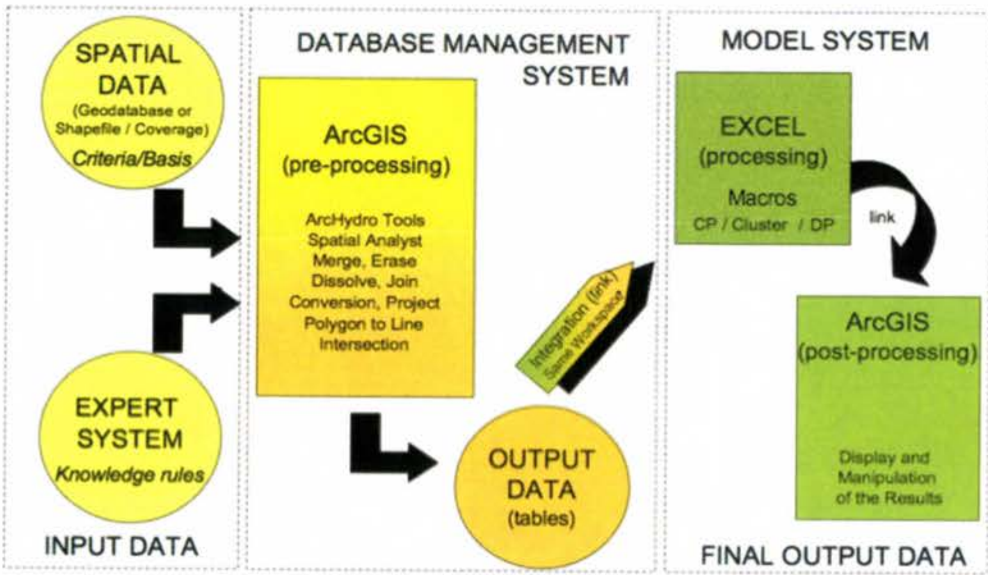


Figure 4.13. Overview of DSS procedures

4.3. Components of the DSS

The main components of the WARPLAM DSS are database management subsystem, dialog or user interface and model. WARPLAM Database Management Subsystem (Figure 4.14) is the integration locus between ESRI-ArcGIS spatial data and Microsoft Excel data. It allows: 1) input data and KBS data to be integrated, 2) output data from GIS pre-processing analysis to be applied as input data for further analysis, and 3) the final results of the analysis to be displayed in GIS. It also provides adequate coordination, integration, and storage of data, in a separate environment from the model. All spatial information is stored in geodatabase format and can be accessed and visualized through ArcGIS. Geodatabase format provides an integrated structure in order to combine inputs and outputs from GIS and Excel. Communication between software is done based upon txt format.

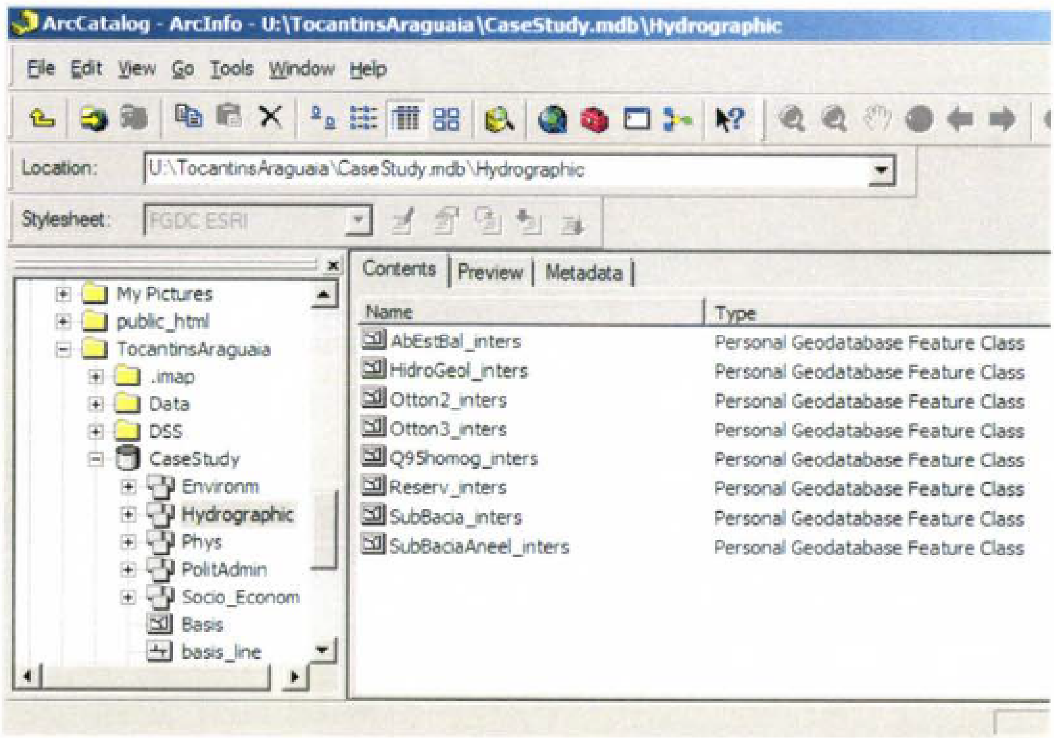


Figure 4.14. Illustration of the WARPLAM DSS Database Management Subsystem

The Excel Graphical User Interface (Figure 4.15) is the dialog subsystem, where the user can set different weights for each criterion, check logic, and manipulate the results. It is an interactive and user-friendly interface, easily understood and with minimal intervention required. It also contains warning messages to alert the user if any information is missing or wrong, as well as necessary instructions. ArcGIS graphic interface, integrated with EXCEL GUI are standardized to integrate the DSS.

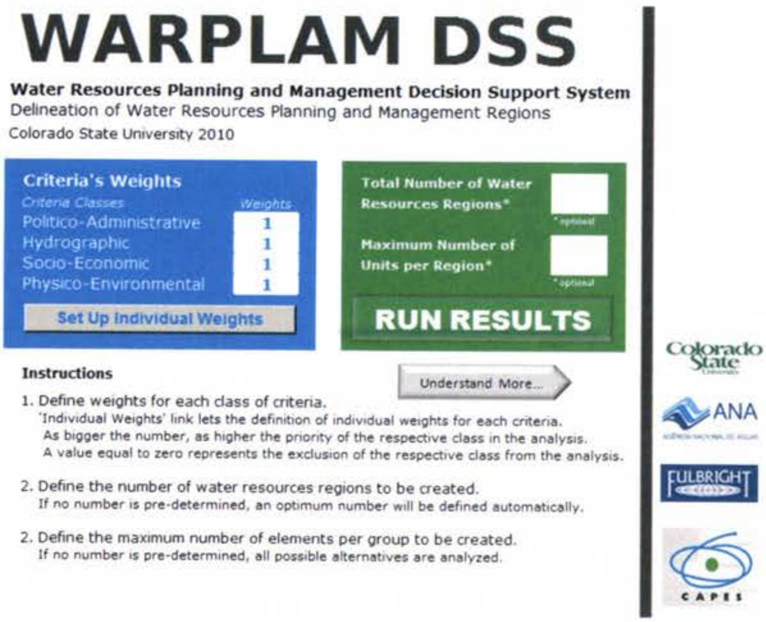


Figure 4.15. Illustration of WARPLAM DSS User Interface

Finally, the Model Subsystem is developed in Microsoft Excel and CSUDP, based upon the input results from the Database Management System. The algorithm is developed using MCDA, cluster analysis, fuzzy analysis, and optimization techniques. Output data is then exported again for visualization in ArcGIS (Figure 4.16).

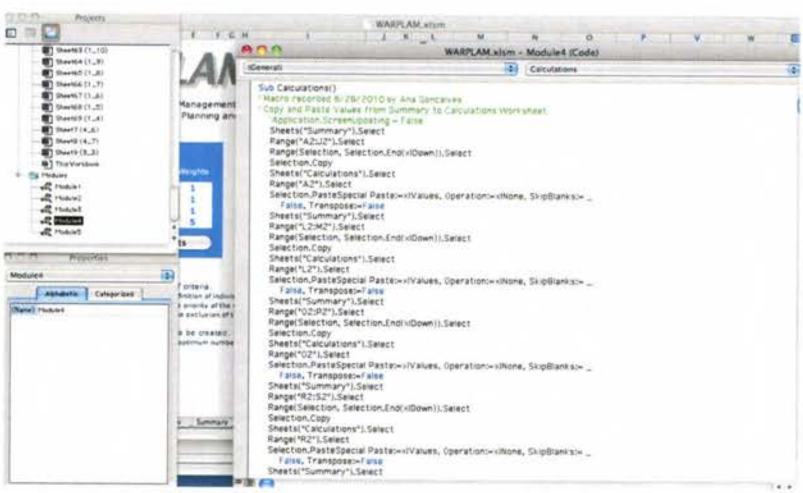


Figure 4.16. Illustration of WARPLAM DSS Model

5. CASE STUDY: TOCANTINS-ARAGUAIA WATER RESOURCES PLANNING AND MANAGEMENT REGIONS

As described before, the process of developing WARPLAM DSS can be summarized in three main phases: Phase 1) Evaluating the aspects related to the delineation of water resources planning and management regions through a comparative analysis in eleven different countries; Phase 2) Building the DSS through the definition of a suitable approach utilizing the aspects identified in Phase 1; and Phase 3) Demonstrating the capability of WARPLAM DSS through a case study in Brazil.

This chapter presents Phase 3, referred to as findings. This phase constitutes the application of the proposed approach in the selected case study area: Tocantins-Araguaia River Basin, in Brazil. As a way to verify the potentials of the DSS, different simulations are performed, considering different aspects, and some heuristic rules. The chapter includes a description of the case study region, including the criteria and basis selected for the analysis. Both clustering methods are also compared, and the main findings are presented.

No final best solution is included in this analysis because the case study is performed mainly for demonstration purposes. Some assumptions were made in order to constitute an example of the proposed approach and criteria to be considered. A final best solution might be obtained by decision makers who have the necessary understanding about the importance of criteria, context-specific considerations, and their own preferences. Therefore, this study does not intend to present a real-world analysis of the case.

5.1. Tocantins-Araguaia River Basin

Tocantins-Araguaia River Basin is the second biggest river basin in Brazil in terms of area and flows. Its drainage area—918,822 km^2—represents 11 percent of the country's territory, comprised of six states: Pará, Tocantins, Goiás, Mato Grosso, Marahão and Distrito Federal (Figure 5.1). It is the biggest river basin completely contained in Brazil, and it has 8 percent of the country's average flow, corresponding to 13,800 m^3/s. The average precipitation is 1,733 mm per year and the area is covered by two important biomes: Amazon Forest and Cerrado. With 7.2 million people, approximately 75 percent living in urban areas, Tocantins-Araguaia River Basin has a dynamic developing process. It has a strategic position in terms of socioeconomic development because of its water resources, agriculture, livestock, mineral, navigation and energy potentials (ANA, 2009).

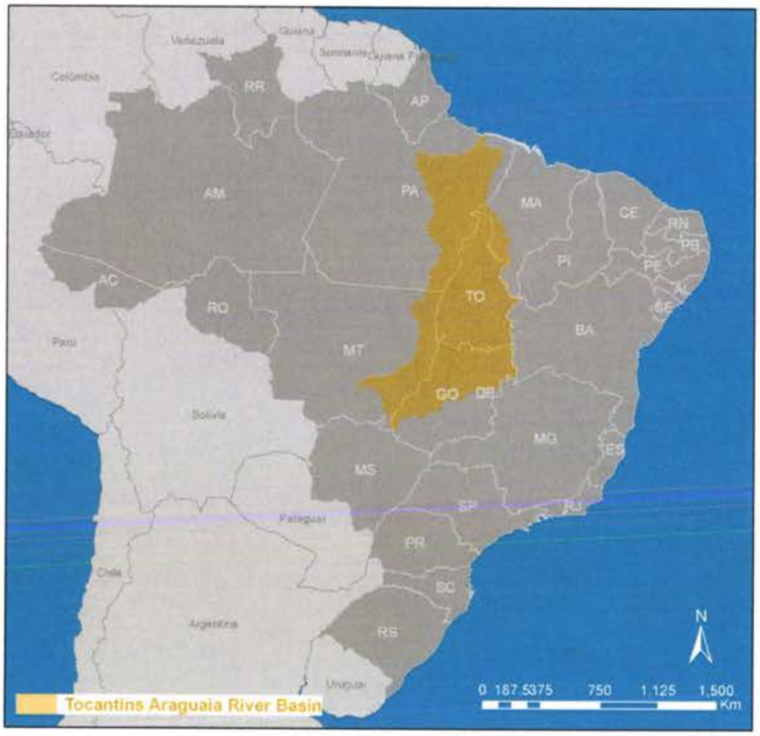


Figure 5.1. Tocantins-Araguaia River Basin (Source: Elaborated by the author, with data from ANA, 2009)

Because of its current strategic position, the National Water Agency, together with the State Water Institutions, developed the Water Resources Strategic Plan of the Tocantins-Araguaia River Basin in 2009. The plan has an overview of the basin's main characteristics and main issues related to water resources. A deep investigation was developed and an incredible amount of data was collected and analyzed.

In terms of established water resources regions, Tocantins-Araguaia River Basin is one of the 12 National Hydrographic Regions of Brazil. In addition, the states have divided their territory into 43 water resources units for planning and management purposes (Figure 5.2). The state units differ in terms of scale, comprising second or third level subbasins or even small catchment areas. For instance, Para State has three water resources units, and Tocantins State has 30 water resources units, both having approximately the same area. For the Strategic Plan, 17 water resources planning units were established using the hydrologic information available and the existing hydroelectric generation plants (ANA, 2009).

As observed, Tocantins-Araguaia River Basin represents a generally common problem in Brazil: the existence of no harmonized water resources regions among the states and at the federal level. Redefining integrated water resources planning and management regions is, therefore, really important in order to guarantee the jurisdiction premises, suitable subsidiarity level, and integration with other sectors.

According to Barraqué (2000a), since Brazil legislation established the administration at the river basin level, including the creation of committees and agencies, it has become necessary to elaborate specific studies on the suitable territorial division, especially where the dual domain of water resources is existing.

5.2. Selection of the Basis and the Criteria

As the first step of the case study, it is necessary to select a consistent basis over which to develop the aggregation process. It should represent the leading aspect to be adopted for the definition of water resources regions, as explained before. The Water Resources Strategic Plan of the Tocantins-Araguaia River Basin defined 17 units for water resources planning (Figure 5.3). They are adopted in this study as the basis for the definition of water resources planning and management regions. It is assumed that they represent homogeneous units that are appropriate to define integrated water resources regions.

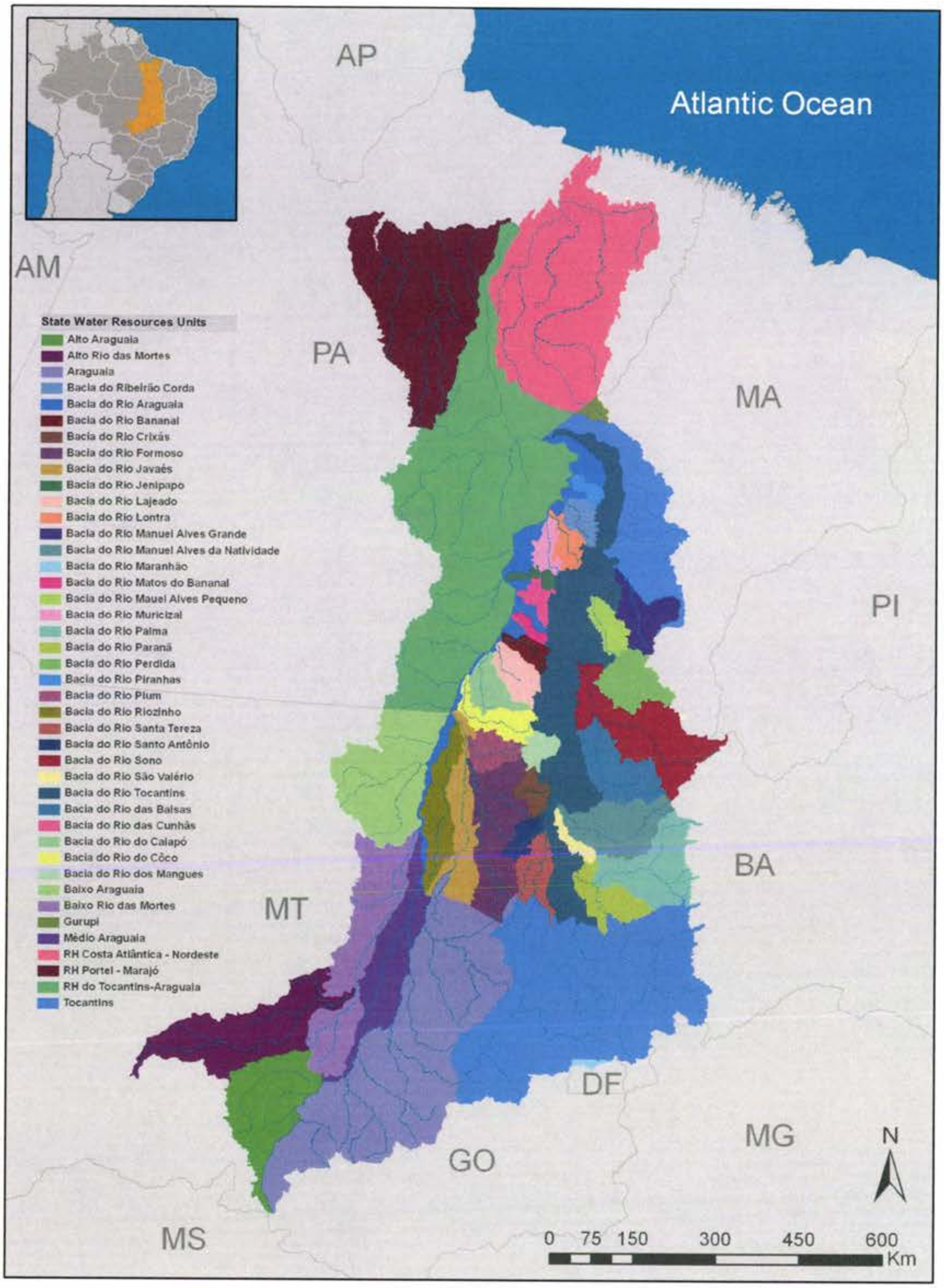


Figure 5.2. State Water Resources Units (Source: Elaborated by the author, with data from ANA, 2007a)

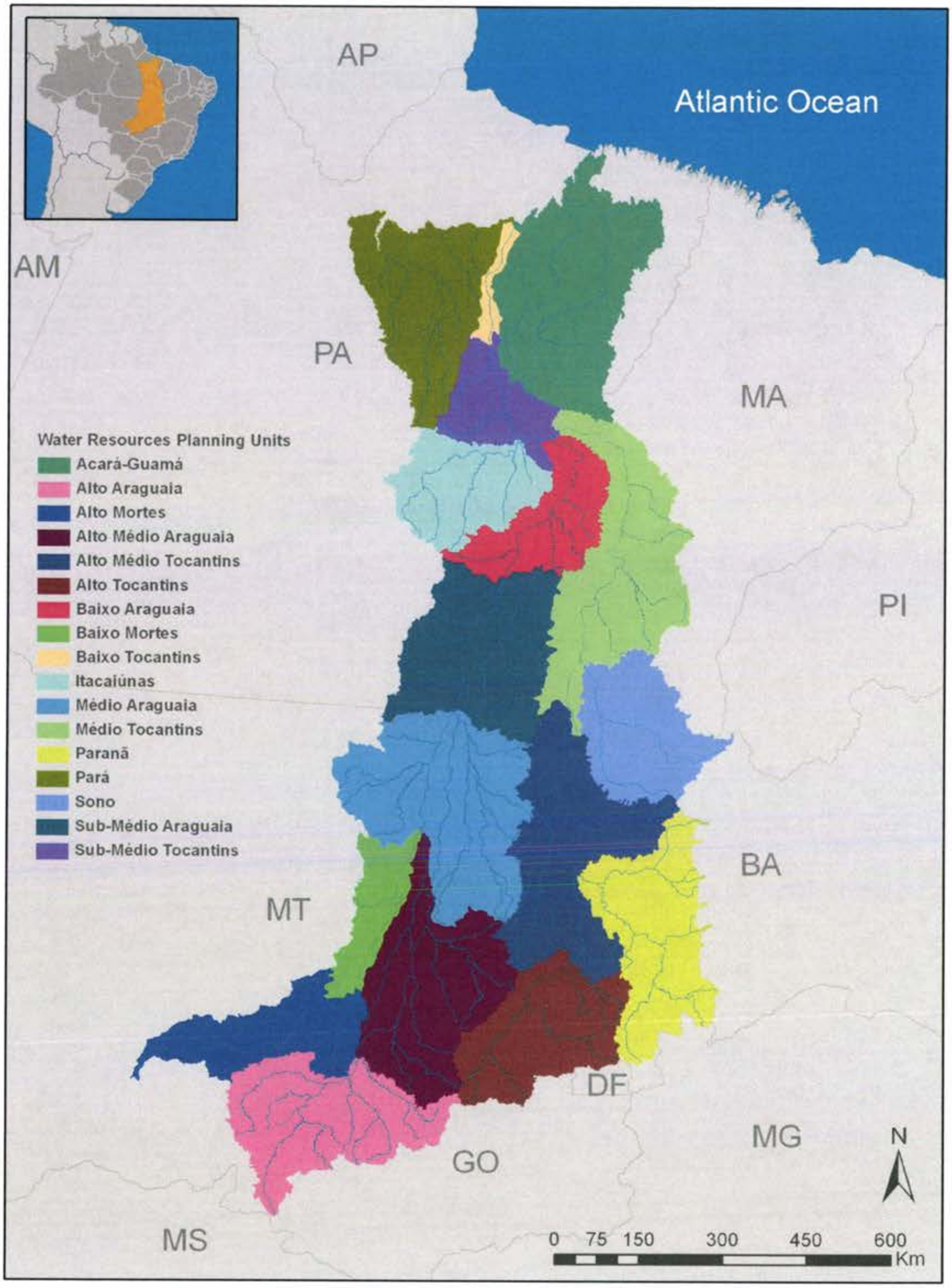


Figure 5.3. Water Resources Planning Units (Source: Elaborated by the author, with data from ANA, 2009)

The seventeen water resources planning units were defined considering mainly hydrographic basin limits, homogeneous hydrologic information available, and existing hydroelectricity generation plants. A brief description of each of these regions (ANA, 2007b) is presented below, reflecting some additional aspects, including socioeconomic, and physical-environmental criteria:

1. Alto Araguaia: it is located in the south region of the river basin area and has several hydroelectricity projects and some irrigated areas.
2. Alto Mortes: it is characterized by several irrigated areas and some mining activities.
3. Baixo Mortes: it is characterized by several native tribes and a less intense land use.
4. Alto Médio Araguaia: it is characterized by several irrigated areas and intensive livestock.
5. Médio Araguaia: the area has a flat topography and is regularly flooded. It has the highest occurrence of rice irrigation of the region and several native tribes. Ilha do Bananal, the largest fluvial island in the world, formed from the bisection of the Araguaia River, is located in this unit. It constitutes an environmental conservation unit, composed of national park and native tribe preservation areas.
6. Sub-Médio Araguaia: it is characterized by a flat topography and intensive livestock. There are also several environmental conservation units.
7. Baixo Araguaia: it is characterized by the substitution of prior forest for dirty fields, currently used for livestock. The region has also a projected hydroelectricity plant.
8. Alto Tocantins: it is characterized by a non-flat topography and has some irrigated areas and hydroelectricity plants.
9. Sub-bacia do rio Paranã: it is characterized by the driest climate of the region and the Urucuia aquifer. It has also some small hydroelectricity plants and several irrigated areas.
10. Alto Médio Tocantins: it is characterized by a totally regulated river reach that contains two hydroelectricity plants in operation and two projected ones.
11. Sub-bacia do rio do Sono: it is characterized by the existence of several projected hydroelectricity plants and occurrence of the Urucuia aquifer. The area contains an important conservation unit: Jalapão National Park.
12. Médio Tocantins: it is characterized by relatively high density and several projected hydroelectricity plants.

13. Sub-bacia do rio Itacaiúnas: it is characterized by a big mining complex, named Serra de Carajás. It has three projected hydroelectricity plants and an important preserved area of the Amazon Forest.
14. Sub-Médio Tocantins: it is characterized mainly by the equatorial forest.
15. Baixo Tocantins: it is characterized mainly by the equatorial climate.
16. Sub-bacia do rio Pará: it is characterized by the equatorial climate and high precipitation levels, up to 3000mm per year. It is covered by forests and has a low density. Its rivers flow into the island of Marajó.
17. Bacias do Acará-Guamá: it is characterized by Belém Metropolitan Region, which places strong pressure over water resources in the region.

The second step is the selection of criteria, beyond river basin limits, that reflect the main aspects related to IWRM principles. These criteria represent the recognition of more comprehensive objectives and multiple interests in the analysis, considering water resources planning and management purposes. In this simulation, the criteria are selected based upon the list of aspects presented in Chapter 2, as well as data availability. They are organized into four categories: physical-environmental, political-administrative, hydrographic and socioeconomic aspects.

Considering physical-environmental aspects, the following criteria are analyzed:

1. Geology (Figure 5.4), which considers the geological compartments of the river basin area;

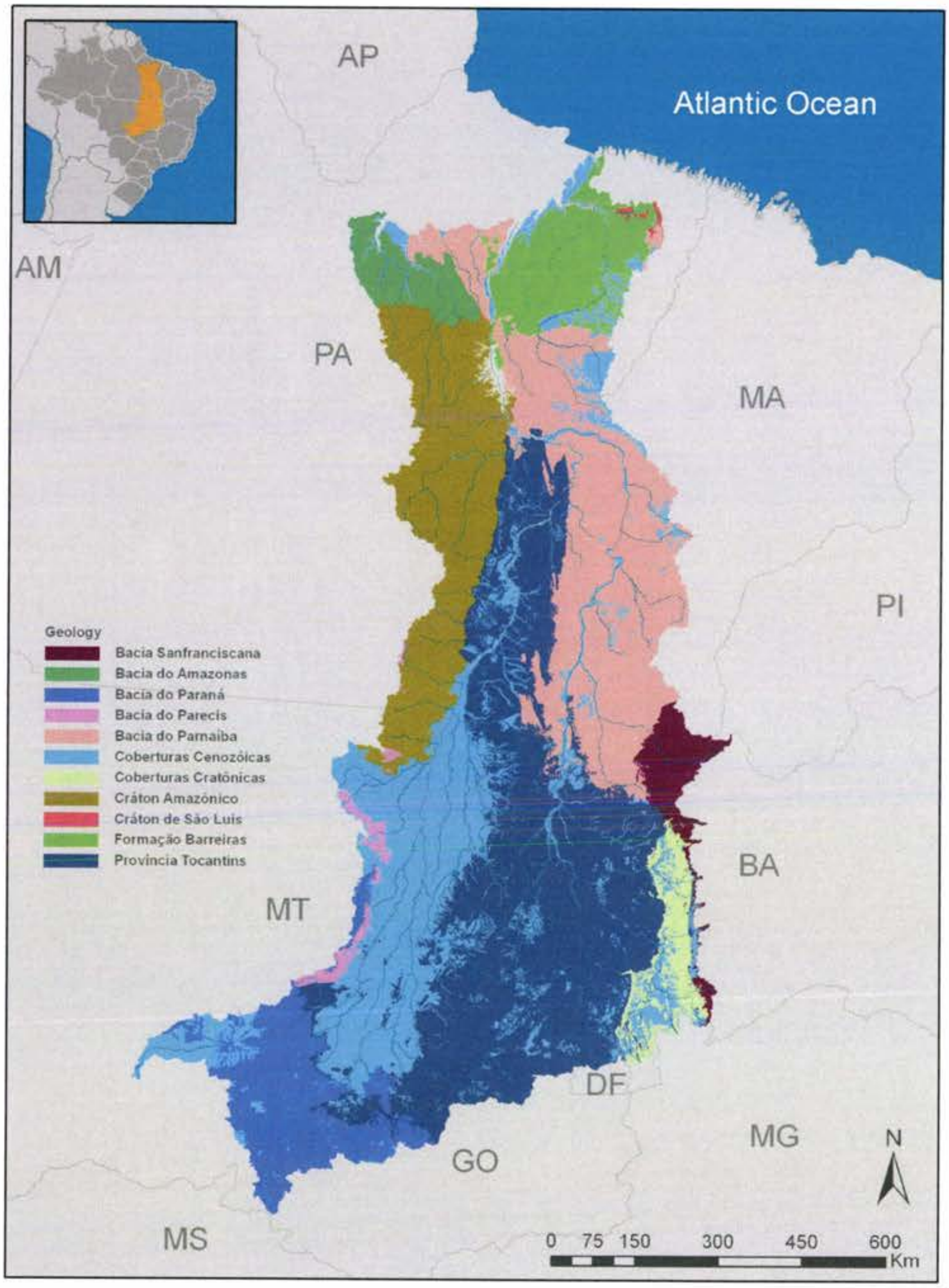


Figure 5.4. Geology Map (Source: Elaborated by the author, with data from ANA, 2009)

2. Geomorphology (Figure 5.5), which considers the main topographic units and geomorphologic domains, and represents, also, in this study, the hypsometry aspects;

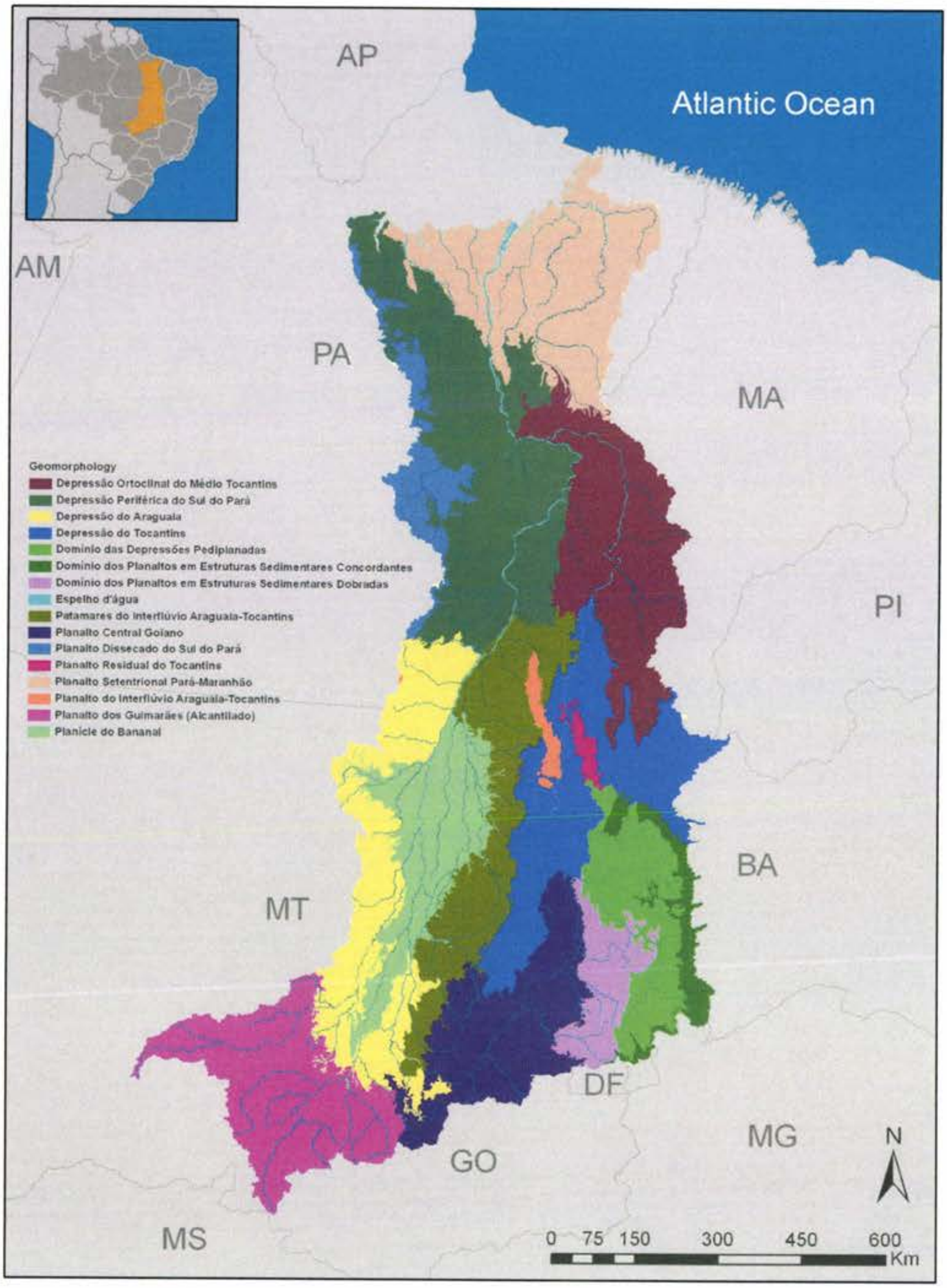


Figure 5.5. Geomorphology Map (Source: Elaborated by the author, with data from ANA, 2009)

3. Soils (Figure 5.6), which considers the main types of soil existing in the river basin area;

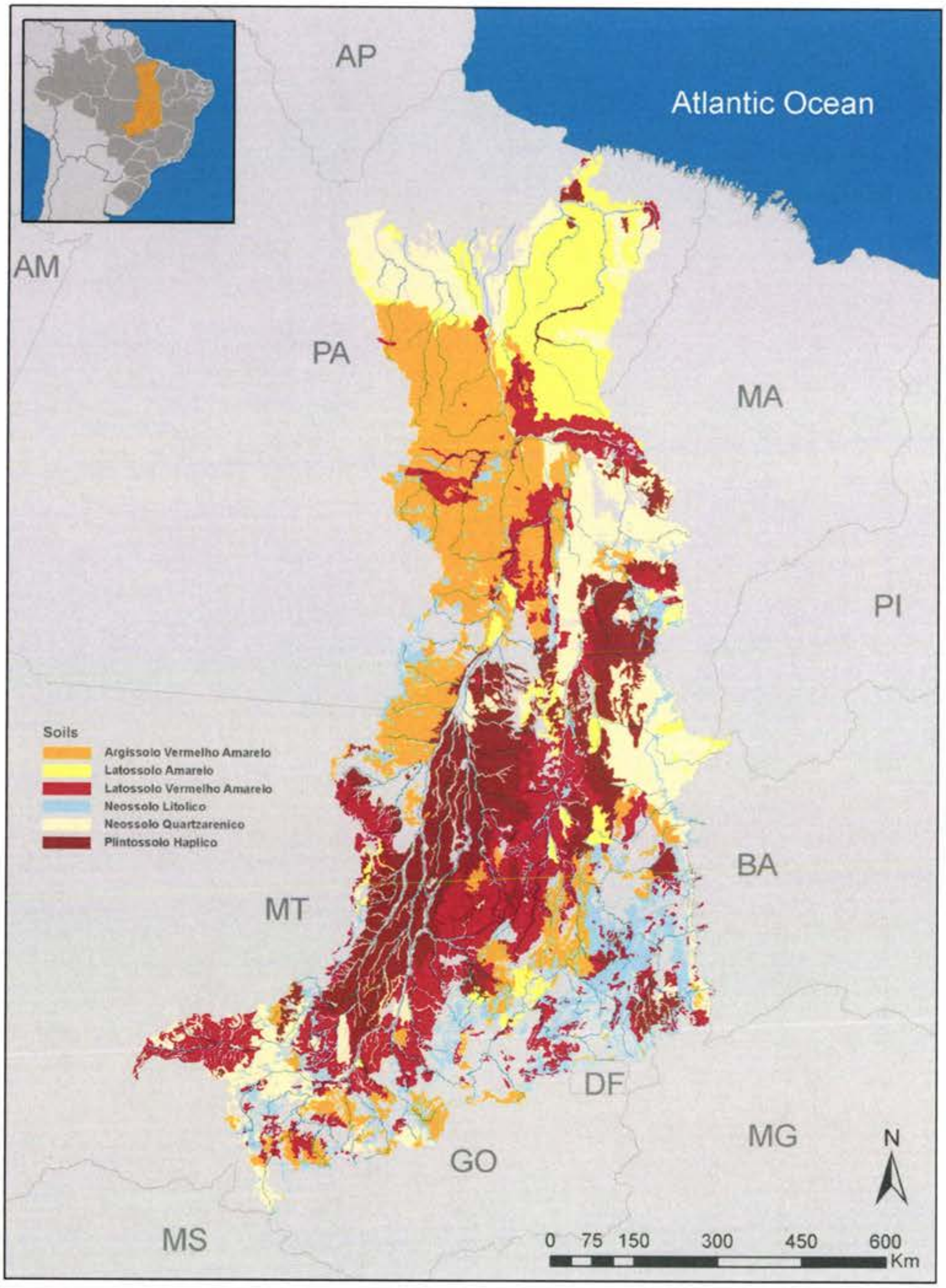


Figure 5.6. Soils Map (Source: Elaborated by the author, with data from ANA, 2009)

4. Total Annual Precipitation (Figure 5.7), which considers the main ranges of precipitation occurring in the river basin area;

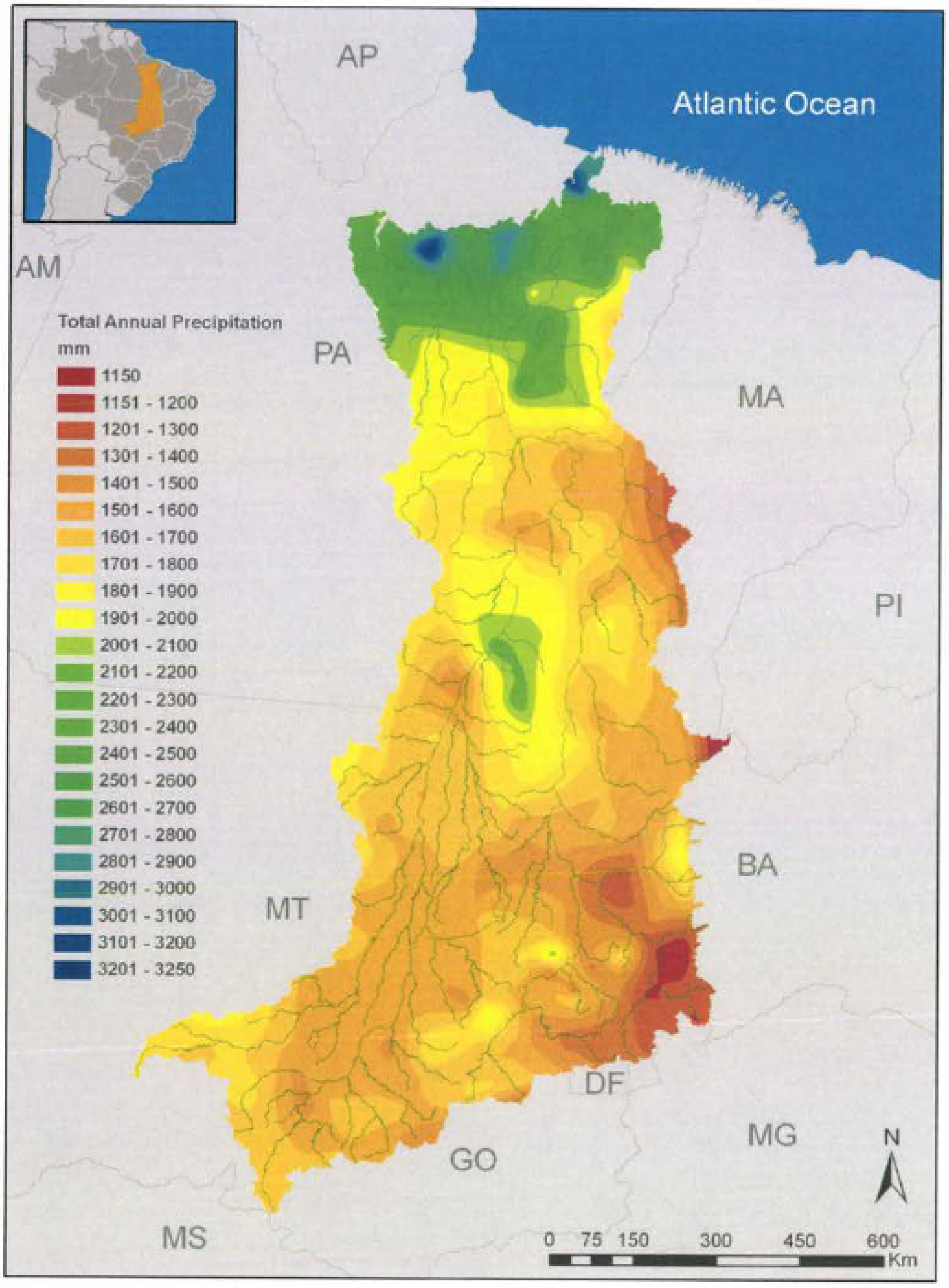


Figure 5.7. Total Annual Precipitation Ranges Map (Source: Elaborated by the author, with data from ANA, 2009)

5. Climate Classification (Figure 5.8), which considers Koppen climate classification system;

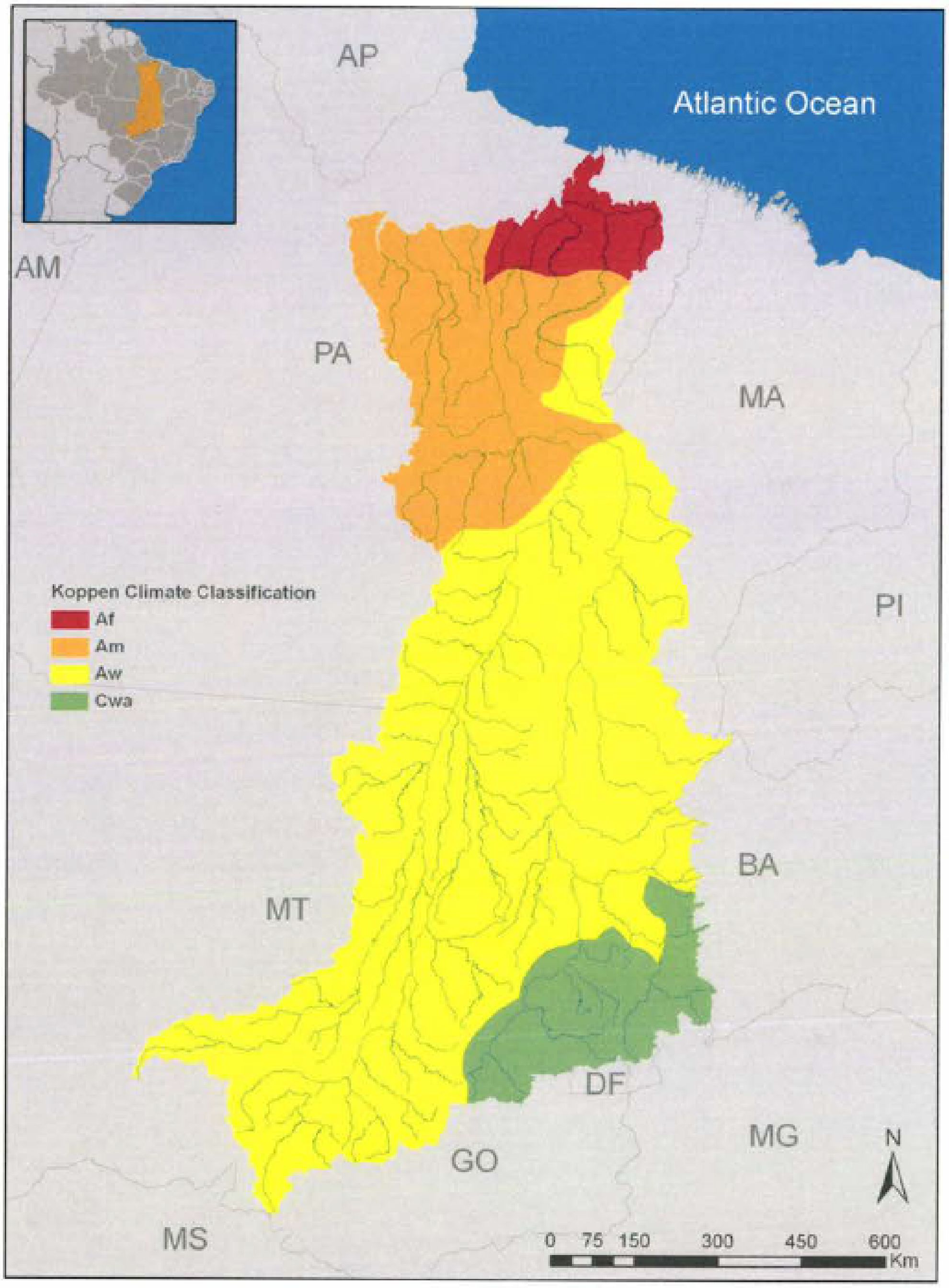


Figure 5.8. Koppen Climate Classification Map (Source: Elaborated by the author, with data from ANA, 2009)

6. Conservation Units (Figure 5.9), which represent the map of major conservation units, including national parks, environmental protection areas, etc.;

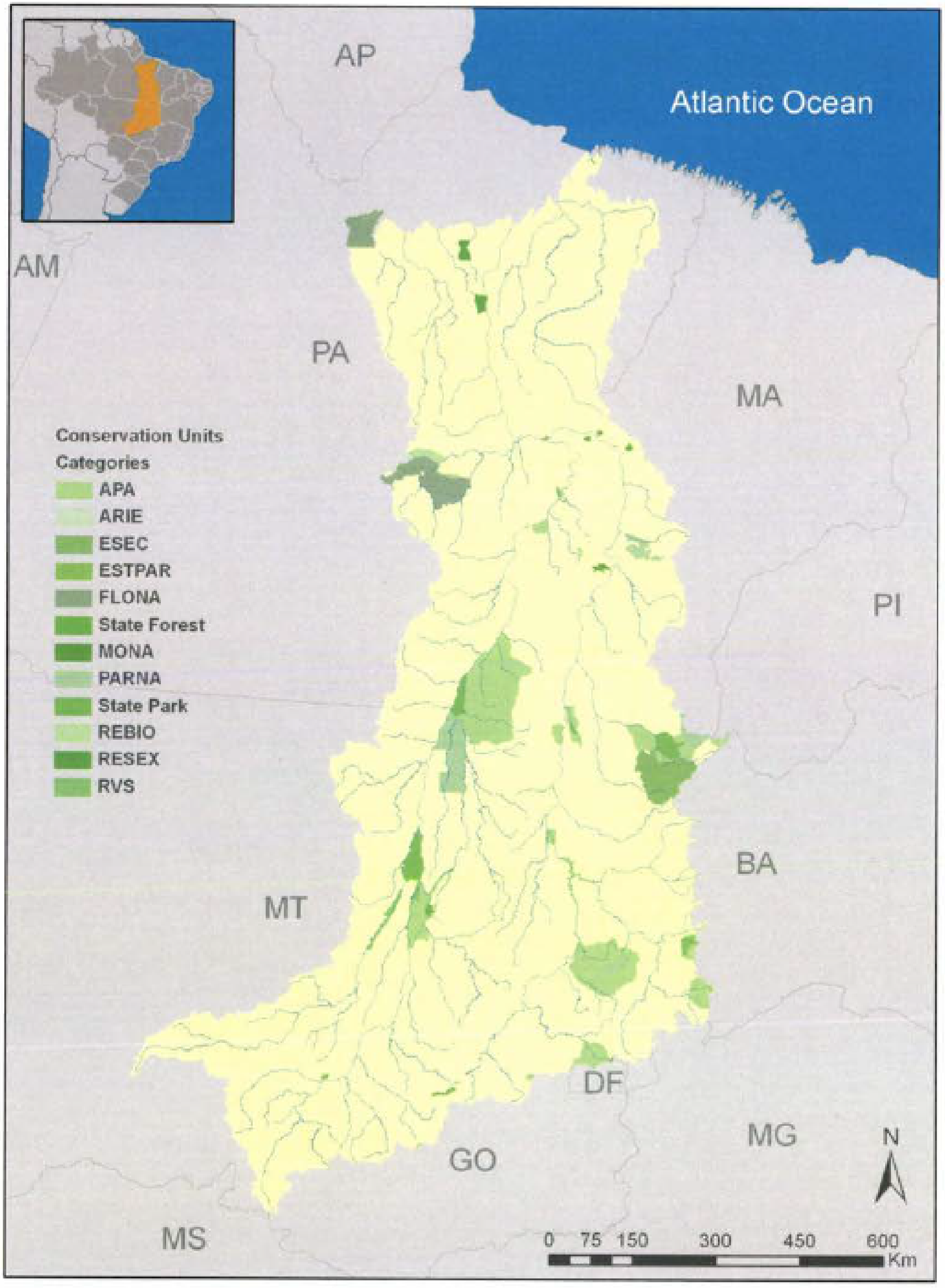


Figure 5.9. Conservation Units Map (Source: Elaborated by the author, with data from ANA, 2009)

7. Ecosystems (Figure 5.10), which consider the main functional units existing in the area, including plateaus, interfluves and depressions, mostly related to relief features or surface configurations;

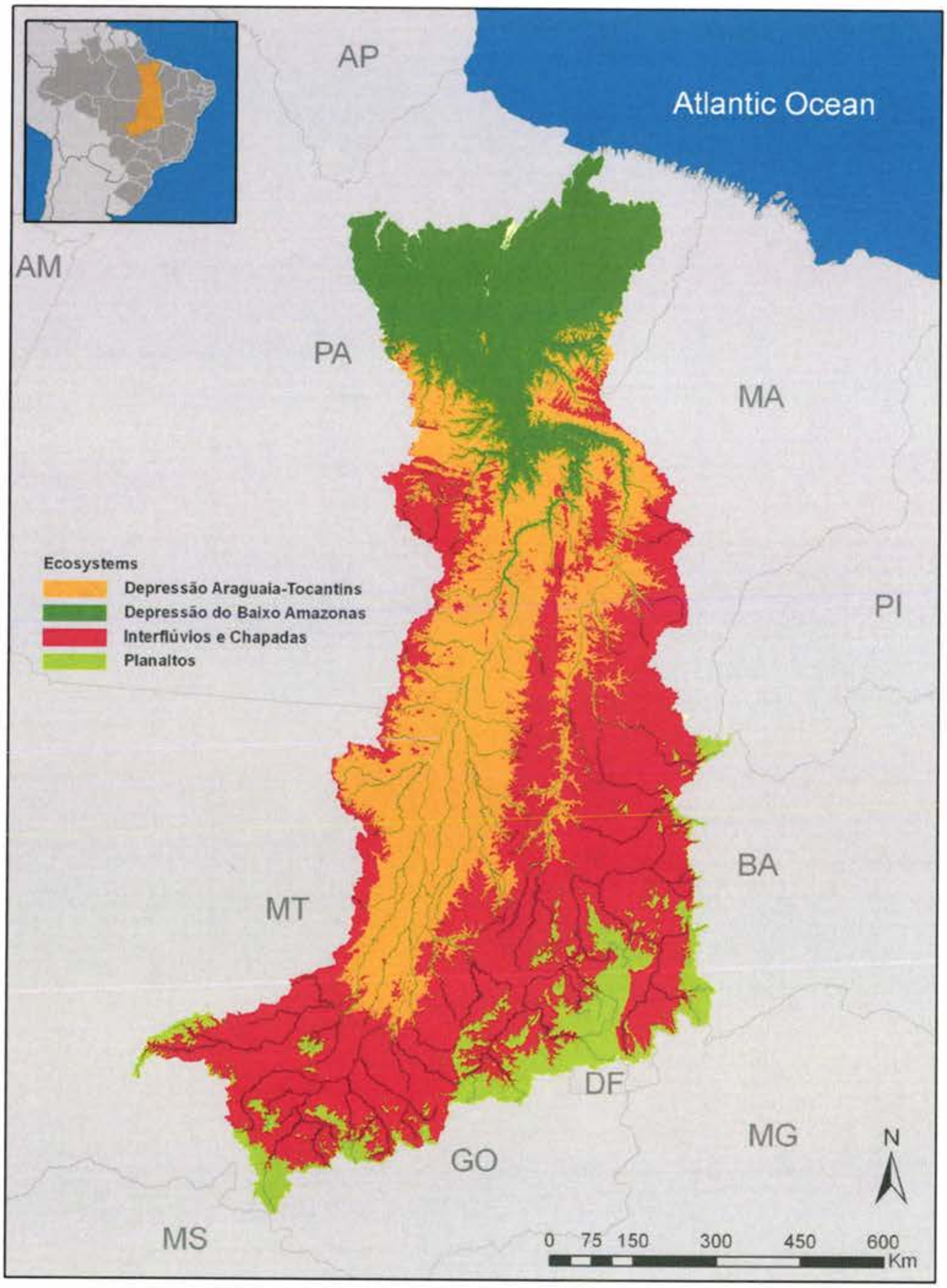


Figure 5.10. Ecosystems Map (Source: Elaborated by the author, with data from ANA, 2009)

8. Biomes (Figure 5.11), which consider two areas with common geographic and climatic characteristics in the river basin: Amazon and Cerrado (tropical savanna);

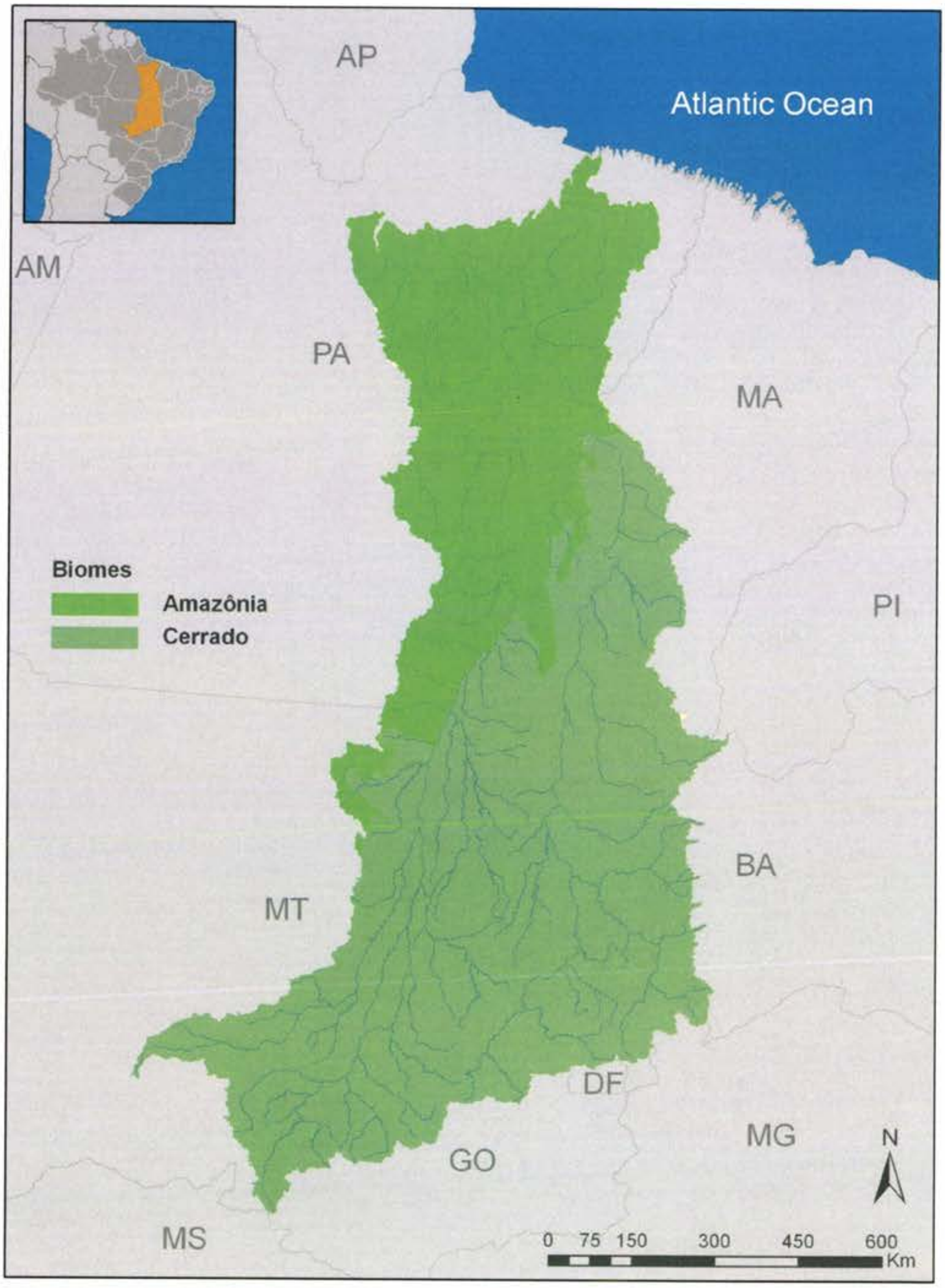


Figure 5.11. Biomes Map (Source: Elaborated by the author, with data from ANA, 2009)

9. Ecoregions (Figure 5.12), according to Dinnerstein (1995, cited by ANA, 2007c) concept of natural communities with similar environmental conditions, dynamic and ecological process. There are four Ecoregions in the Tocantins-Araguaia Region: Interflúvio Tocantins-Araguaia/Maranhão, Interflúvio Xingu/Tocantins-Araguaia, Cerrado, and Florestas Secas do Mato Grosso;

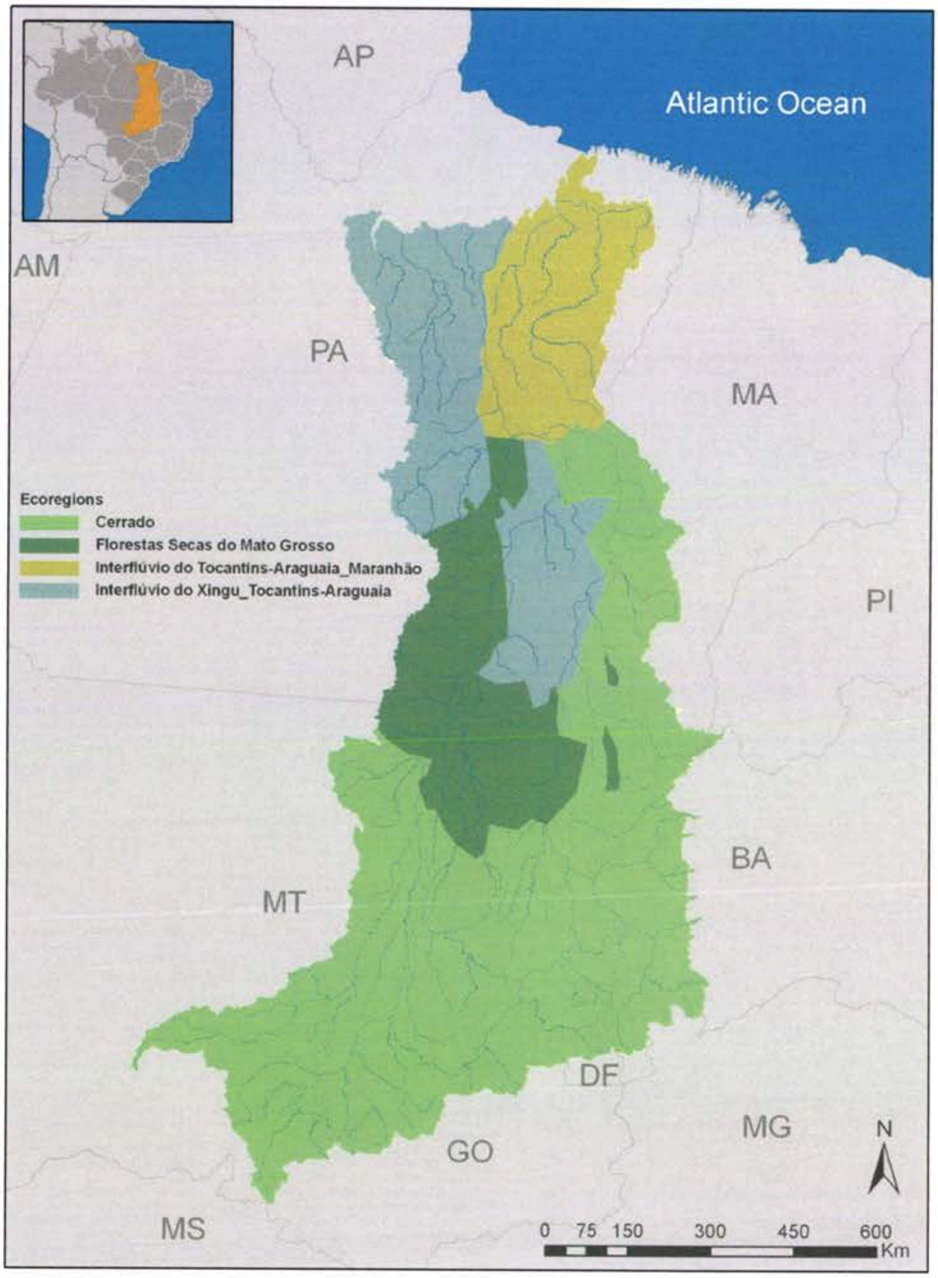


Figure 5.12. Ecoregions Map (Source: Elaborated by the author, with data from ANA, 2007c)

10. Estuary (Figure 5.13), which considers the estuary zones classified as protection areas by the Environmental Ministry of Brazil;

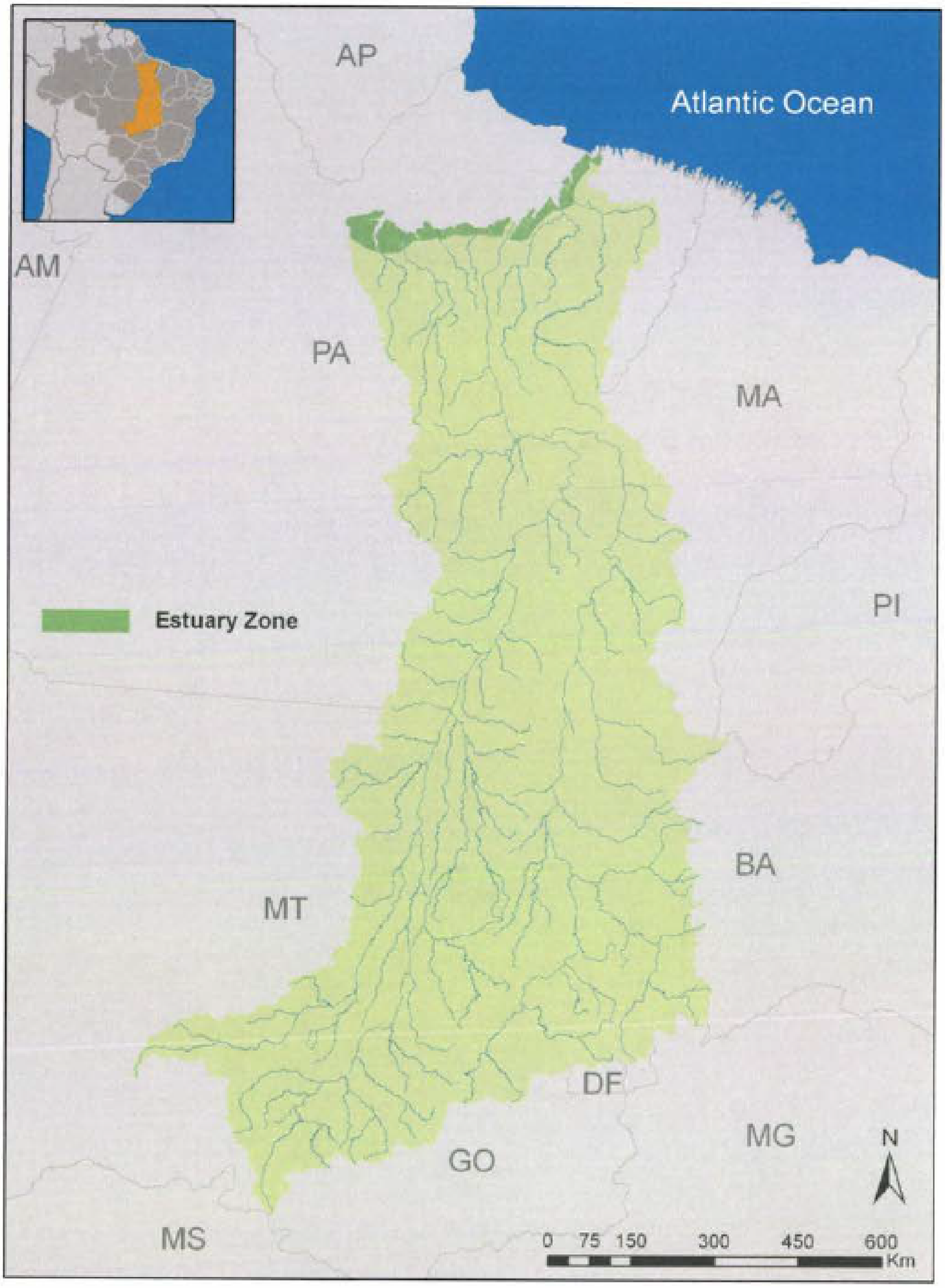


Figure 5.13. Estuary Zone Map (Source: Elaborated by the author, with data from MMA, 2010)

11. Biodiversity Conservation Zones (Figure 5.14), which are the areas with priority for conservation considering landscape, connectivity, vulnerability, natural resources, sustainable use, human occupation, and protection factors;

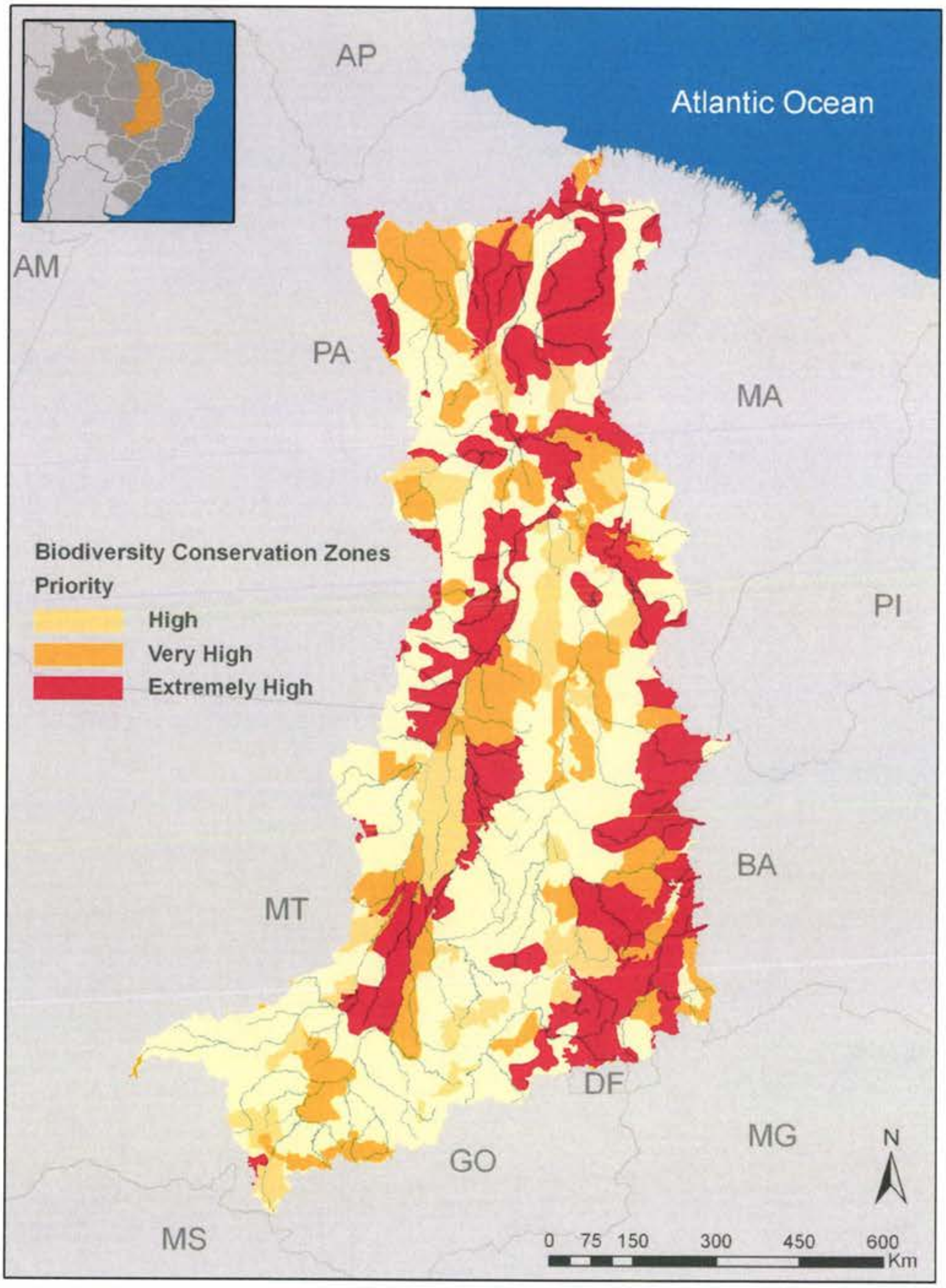


Figure 5.14. Biodiversity Conservation Zones Map (Source: Elaborated by the author, with data from ANA, 2009)

12. Native Tribes (Figure 5.15) which consider the map of existing native tribes of indigenous people living in the river basin, corresponding to special protection areas that have similar status to Conservation Units; therefore being presented as part of the physical-environmental aspects category;

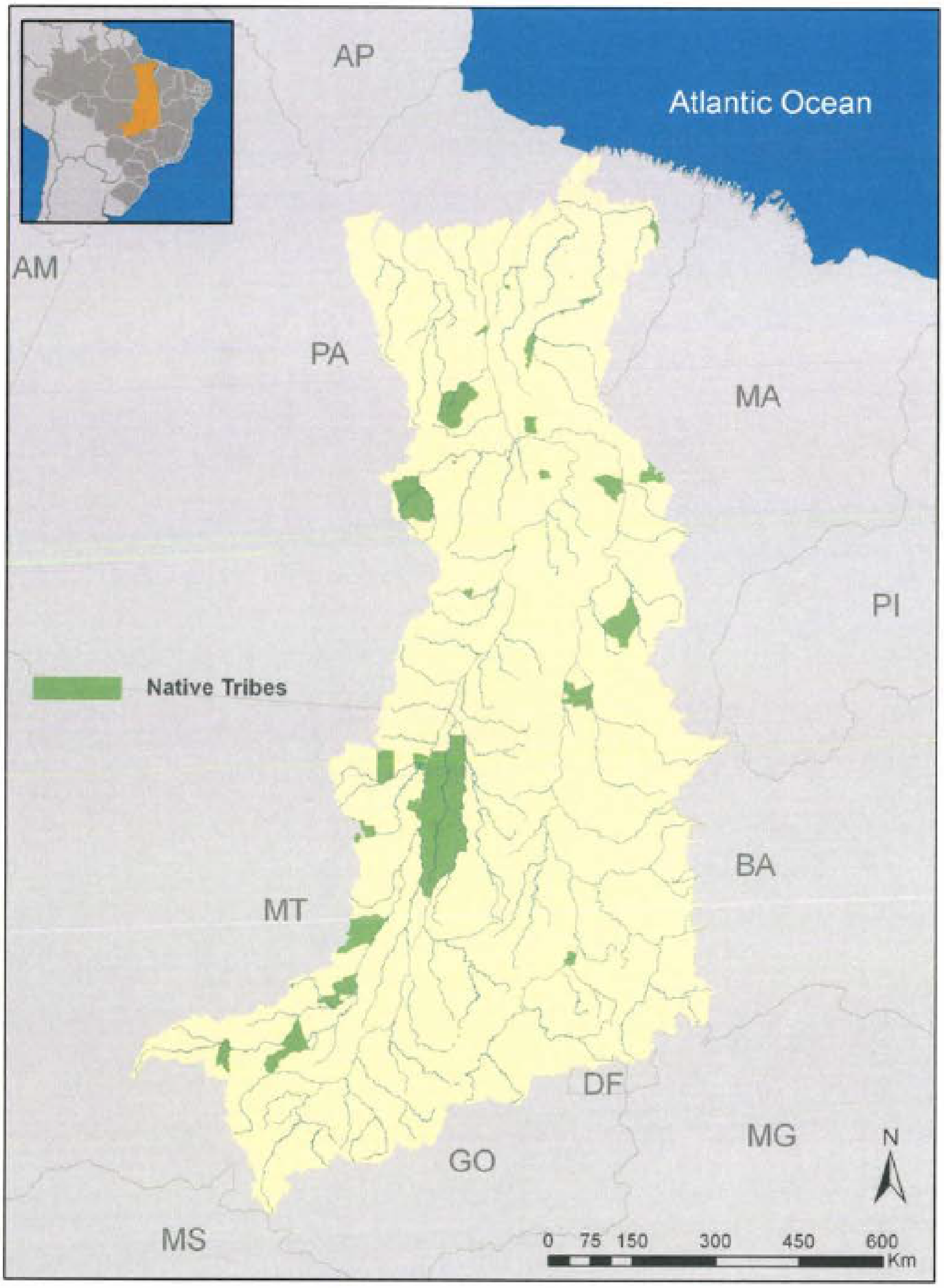


Figure 5.15. Native Tribes Map (Source: Elaborated by the author, with data from ANA, 2009)

13. Quilombolas (Figure 5.16), which consider the villages that have descendents of slaves living in Quilombos in the river basin area, corresponding to special protection areas that have similar status to Conservation Units; therefore being presented as part of the physical-environmental aspects category;

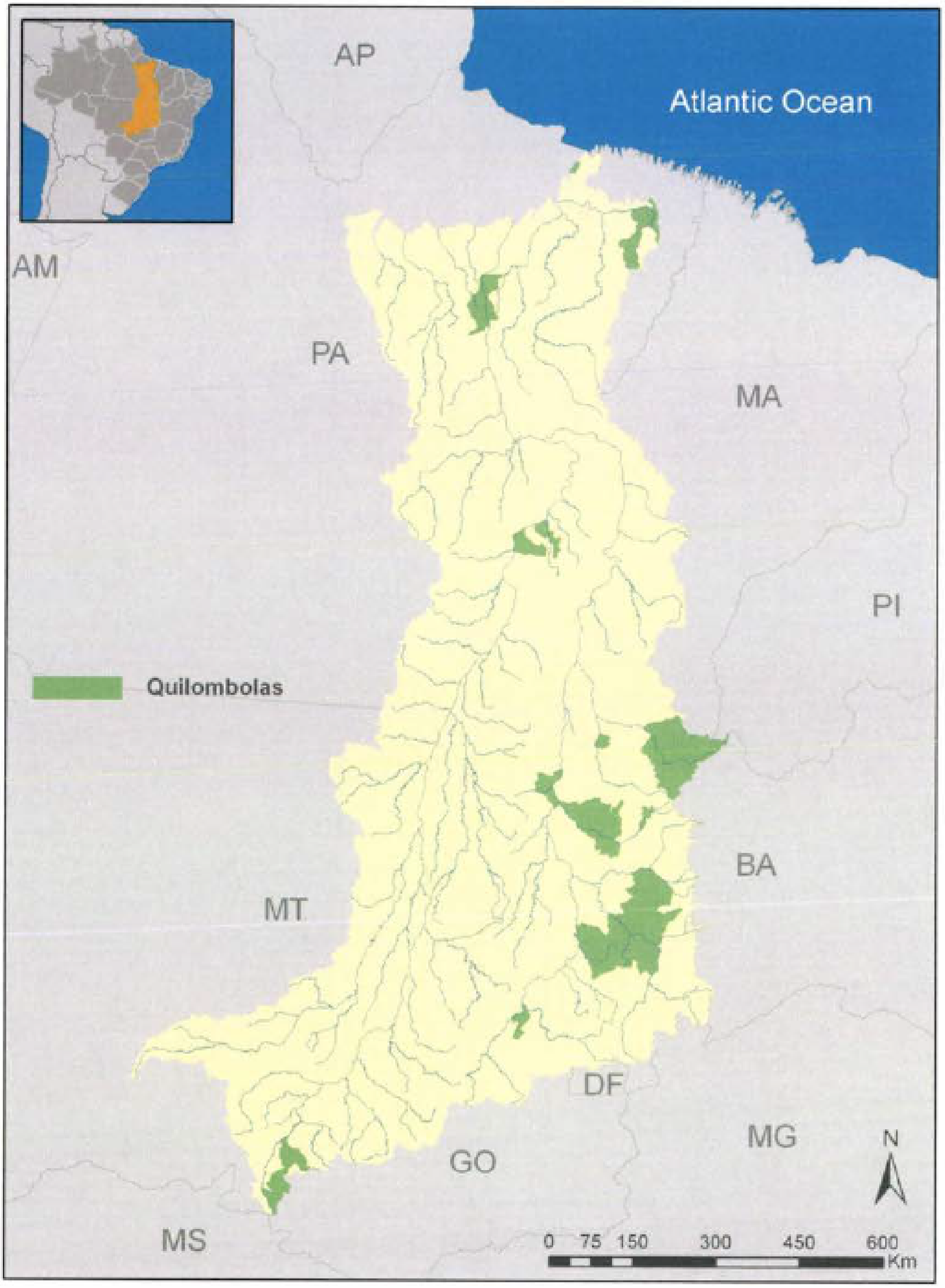


Figure 5.16. Quilombolas Map (Source: Elaborated by the author, with data from ANA, 2009)

Considering political-administrative aspects, the following criteria are analyzed:

1. Municipalities (Figure 5.17), which consider the political boundaries of the municipalities;

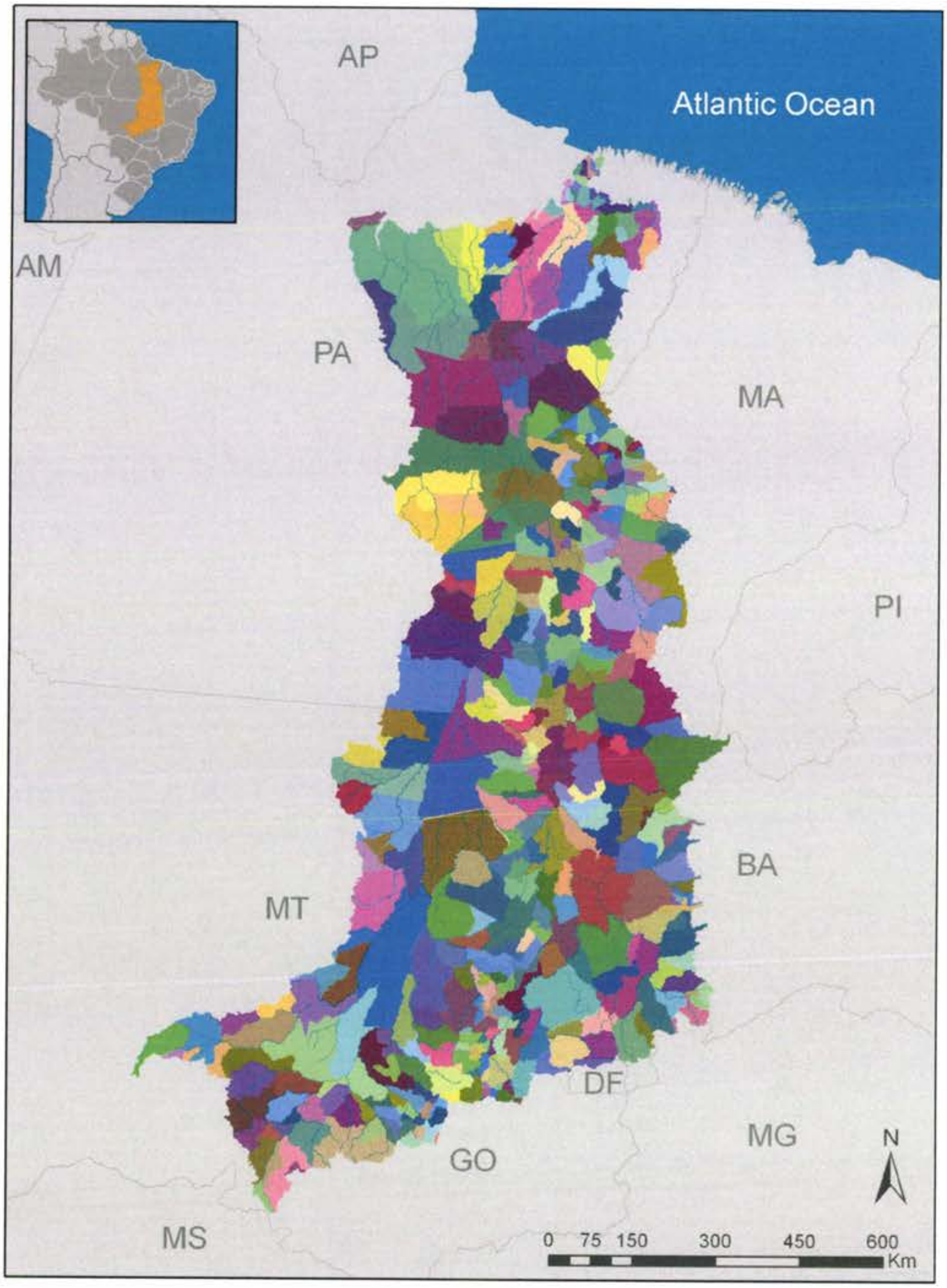


Figure 5.17. Municipalities Map (Source: Elaborated by the author, with data from IBGE, 2010)

2. States (Figure 5.18), which consider the political boundaries of the states;

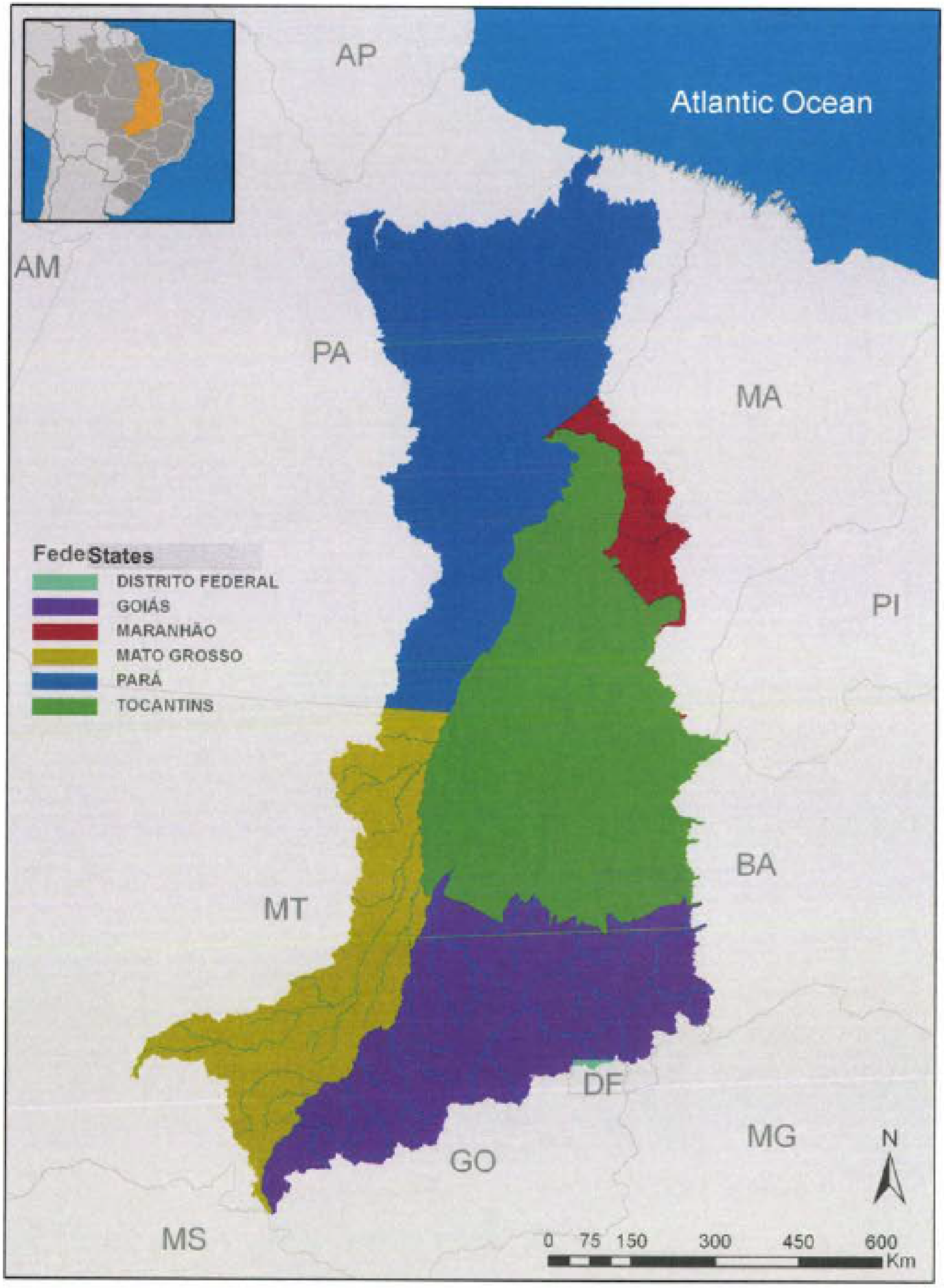


Figure 5.18. States Map (Source: Elaborated by the author, with data from IBGE, 2010)

3. State Water Resources Units (Figure 5.19), which consider the political-administrative boundaries of the state subbasins. The consideration of this criterion assumes that the units established by the states represent political interests from each state.

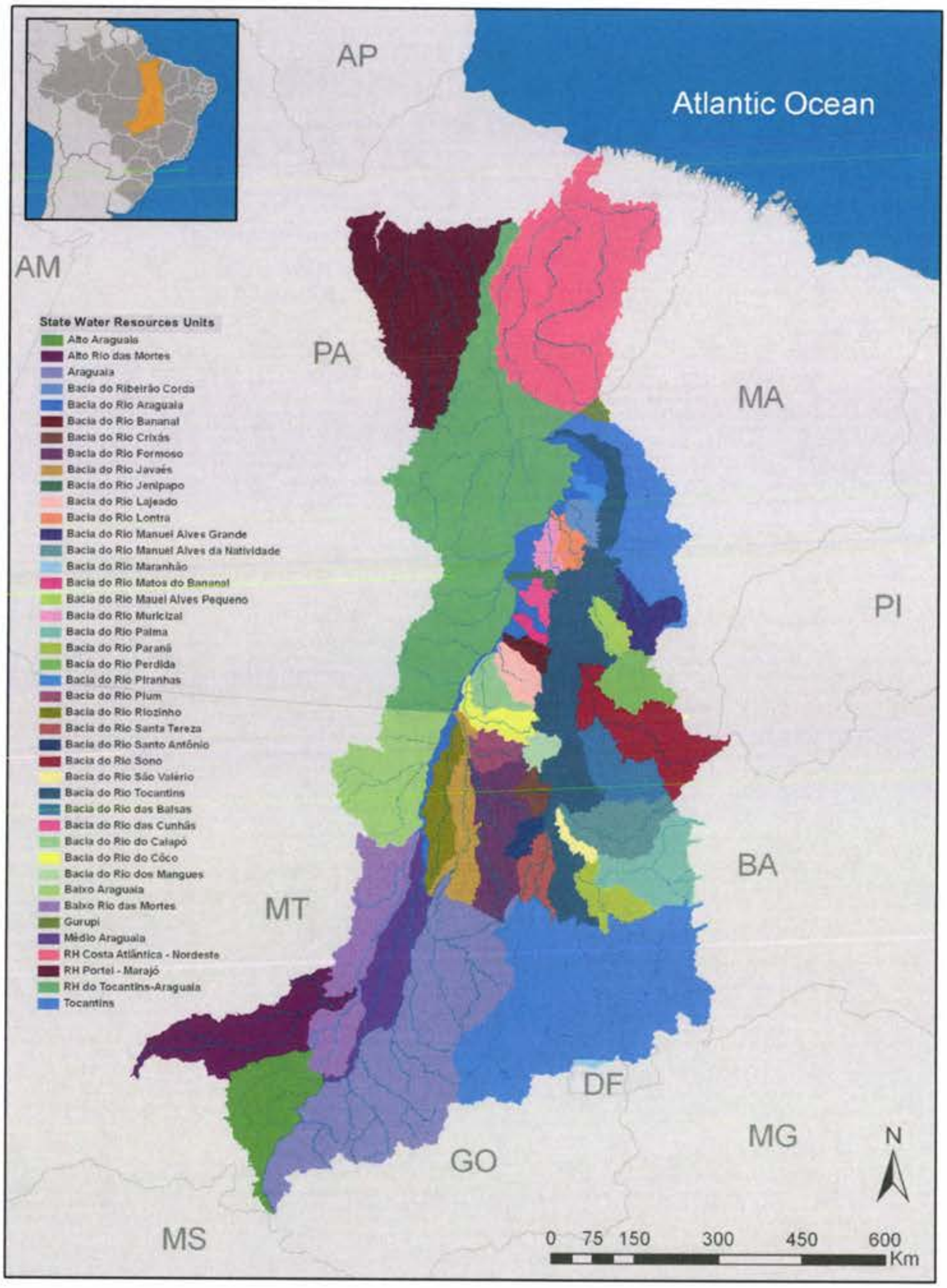


Figure 5.19. State Water Resources Units Map (Source: Elaborated by the author, with data from ANA, 2007a)

Considering hydrographic aspects, the following criteria are analyzed:

1. Aquifers (Figure 5.20), which represent hydrogeology aspects and groundwater limits, directly related to the geology map. The aquifer systems were divided into porous and fractured areas based upon the way they store and transport water (ANA, 2007a);

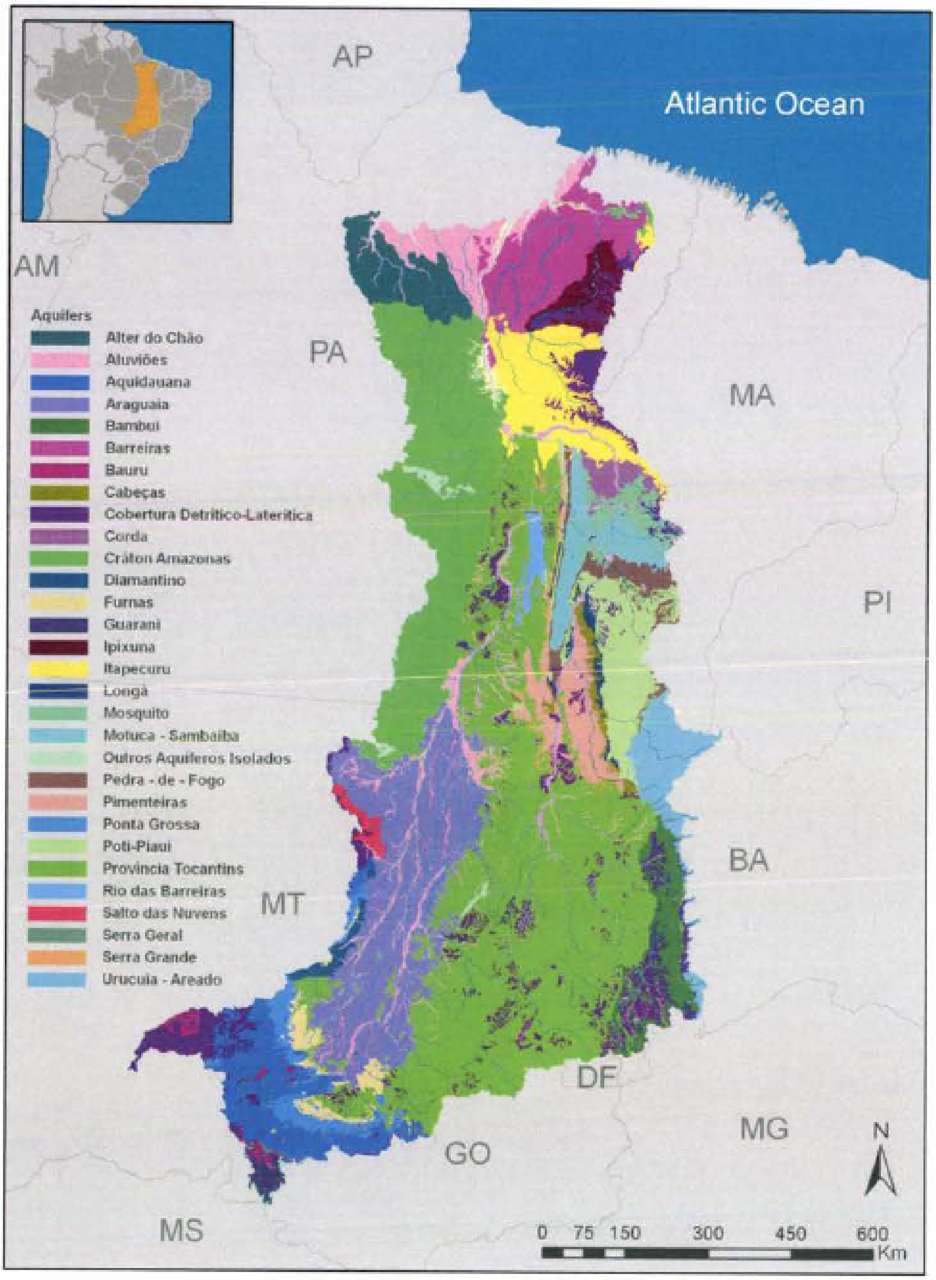


Figure 5.20. Aquifers Map (Source: Elaborated by the author, with data from ANA, 2007a)

2. Subregions (Figure 5.21), which represent the major subbasins of the region and were used at the Water Resources Strategic Plan of the Tocantins-Araguaia River Basin to group the proposed action plan and intervention programs;

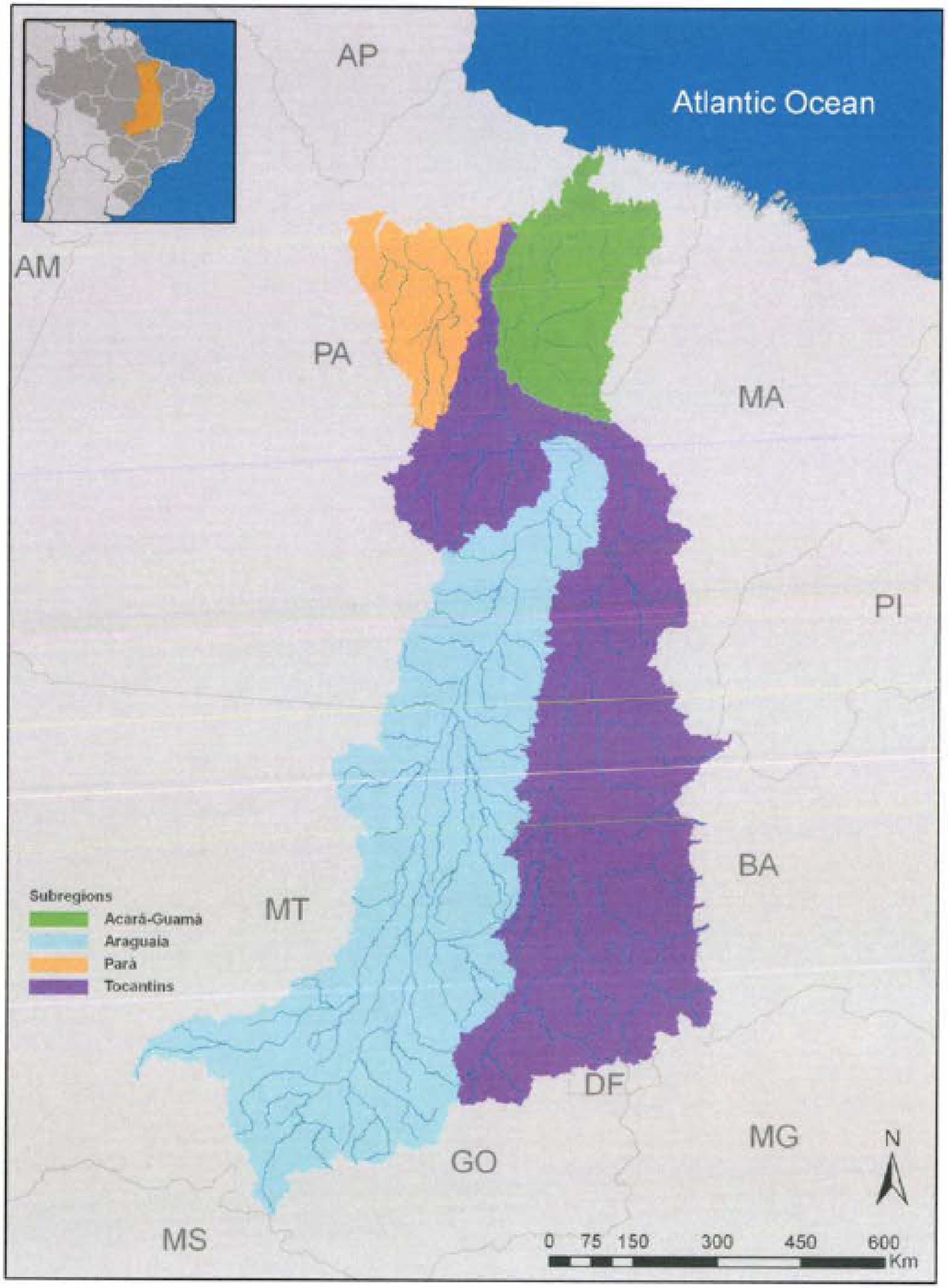


Figure 5.21. Subregions Map (Source: Elaborated by the author, with data from ANA, 2007a)

3. River Gauge Areas (Figure 5.22), which represent the Thiessen polygons of the river gauges of the Meteorology National Institute of Brazil;

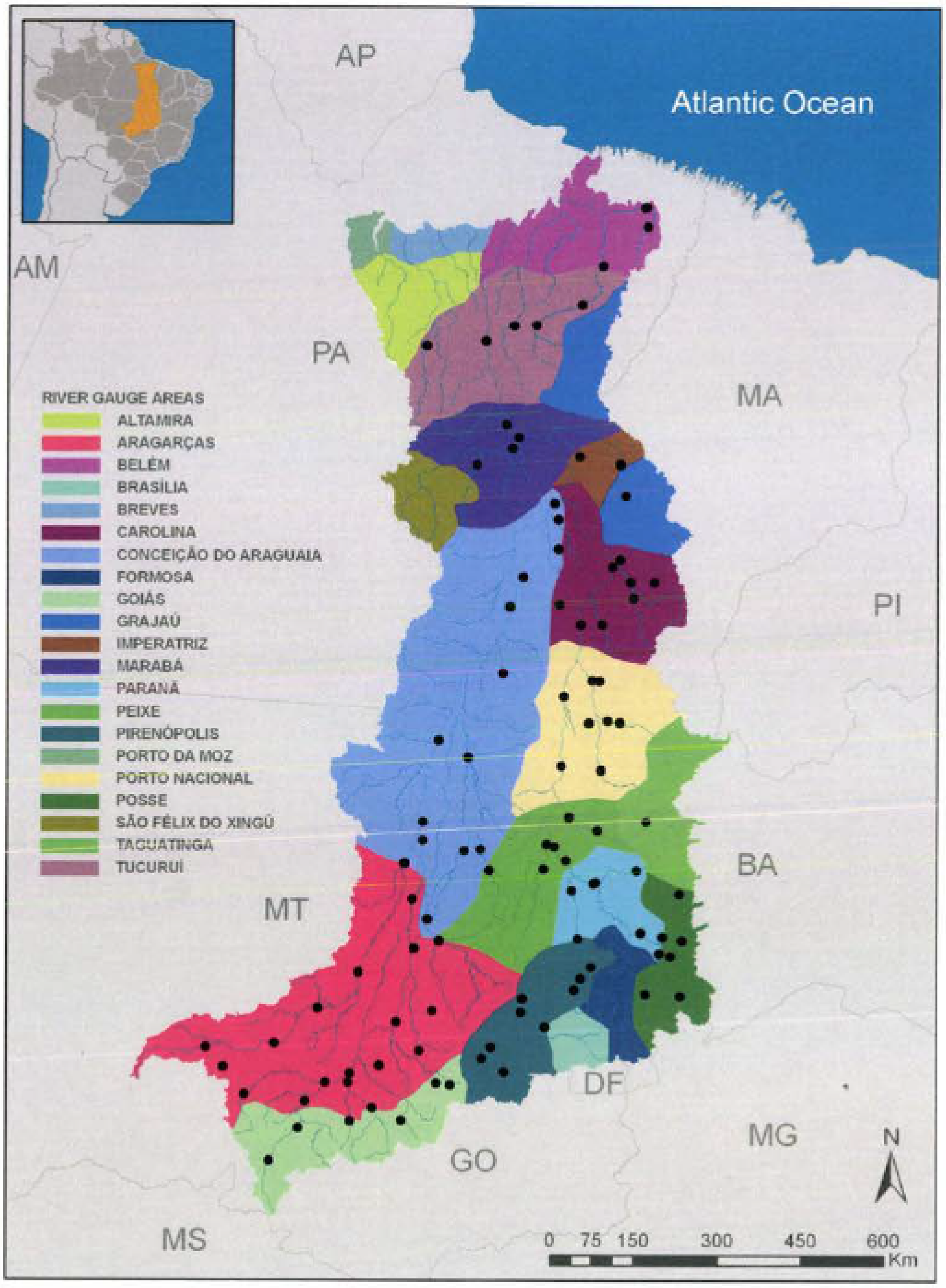


Figure 5.22. River Gauges Areas Map (Source: Elaborated by the author, with data from ANA, 2007b)

4. Reservoirs (Figure 5.23), which represent the main reservoir lakes existing in the river basin;

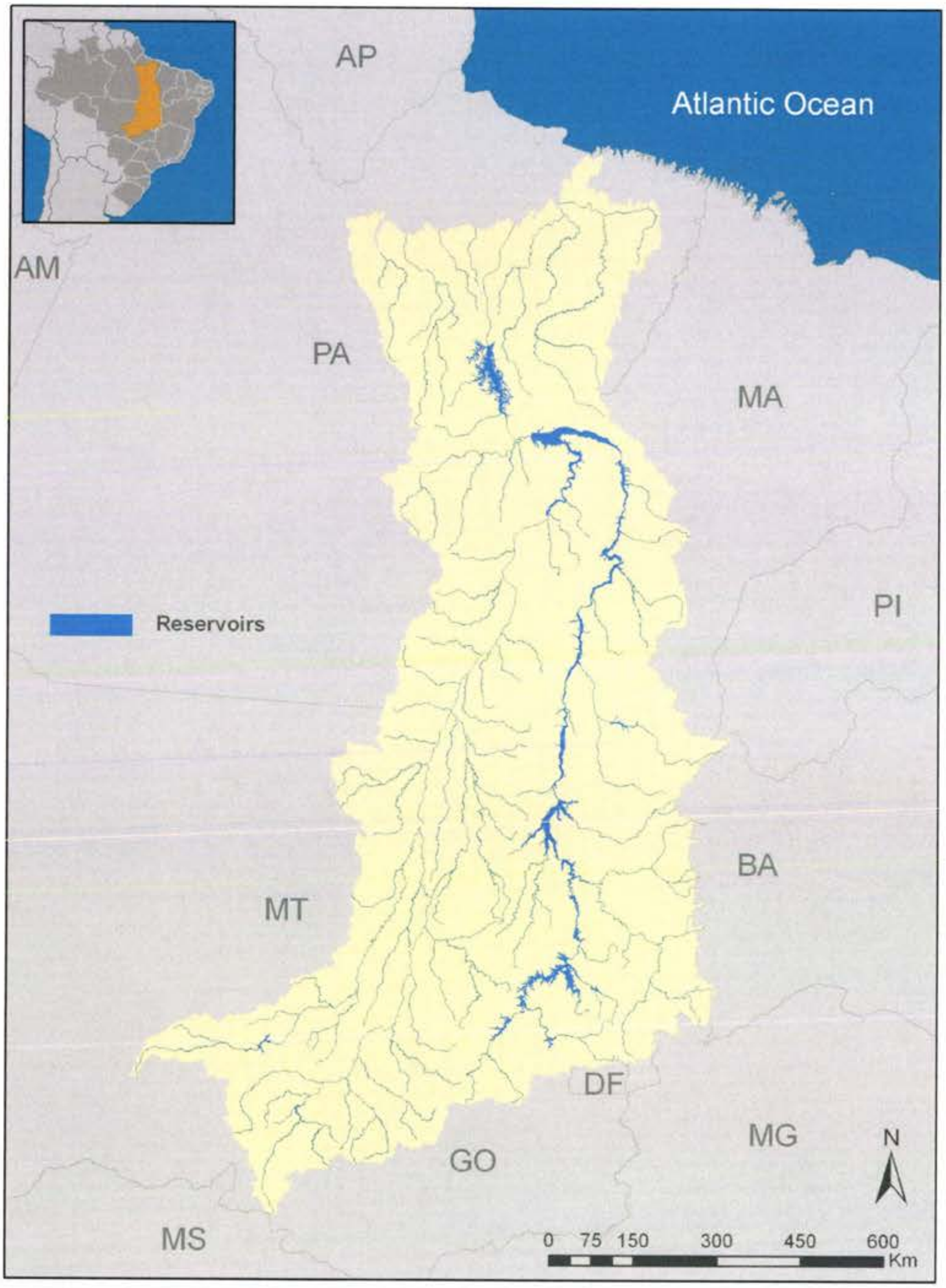


Figure 5.23. Reservoirs Map (Source: Elaborated by the author, with data from ANA, 2009)

5. Minimum Flows (Figure 5.24), which represent the homogeneous regions of Q95 minimum flow values or the regions with similar patterns of flow that are not exceeded 95 percent of the time;

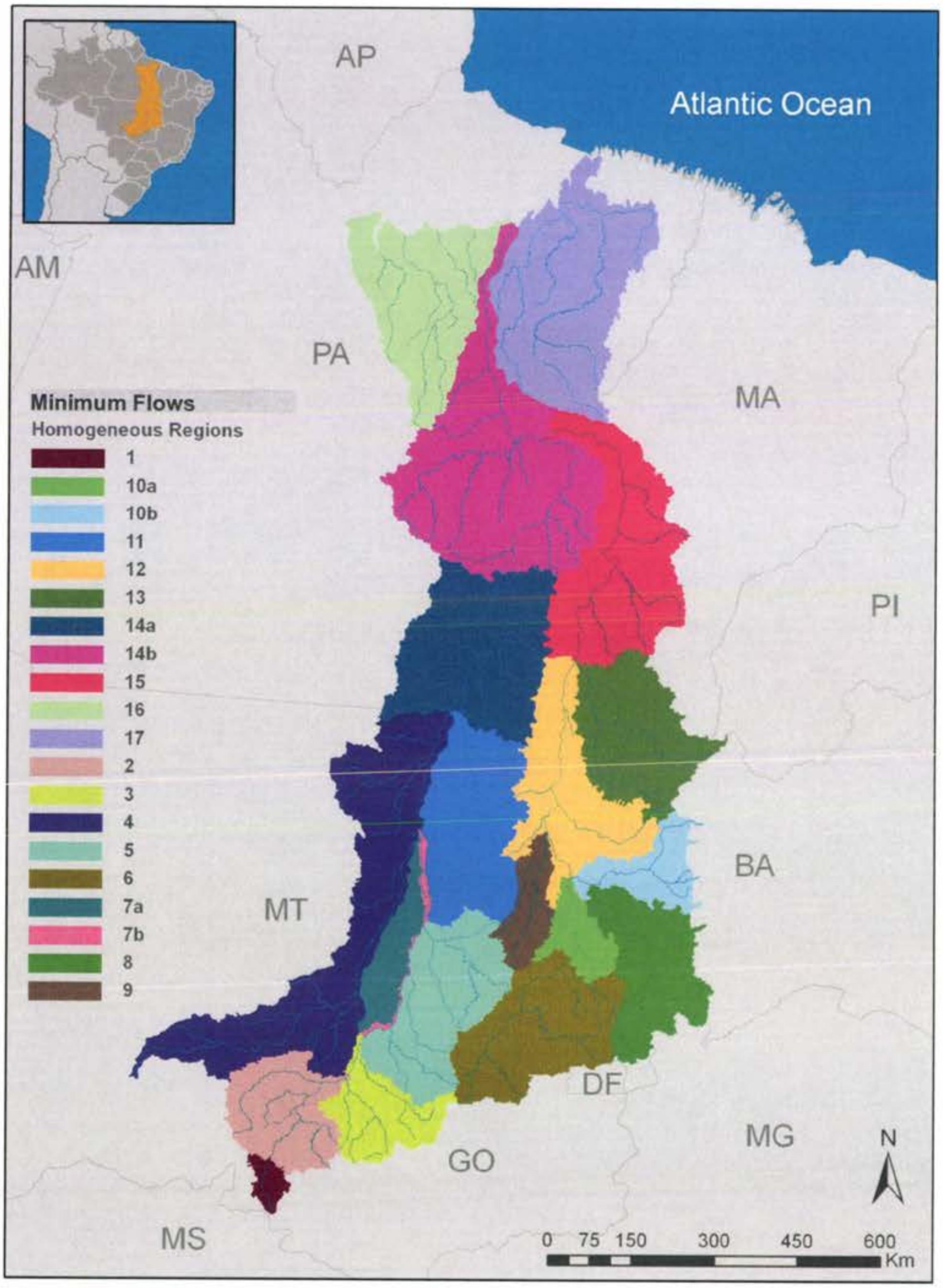


Figure 5.24. Minimum Flows Map (Source: Elaborated by the author, with data from ANA, 2007b)

6. Water Transfers, which represent the existing water transfers among rivers. There is no significant water transfer in Tocantins-Araguaia River Basin;
7. ANEEL Subbasins (Figure 5.25), which represent the river basin delineation adopted by the Electric Energy National Agency of Brazil. Considering that electric energy is a strong and traditional sector in Brazil which dominated water resources planning and management in the past, this criterion can also represent historical aspects;

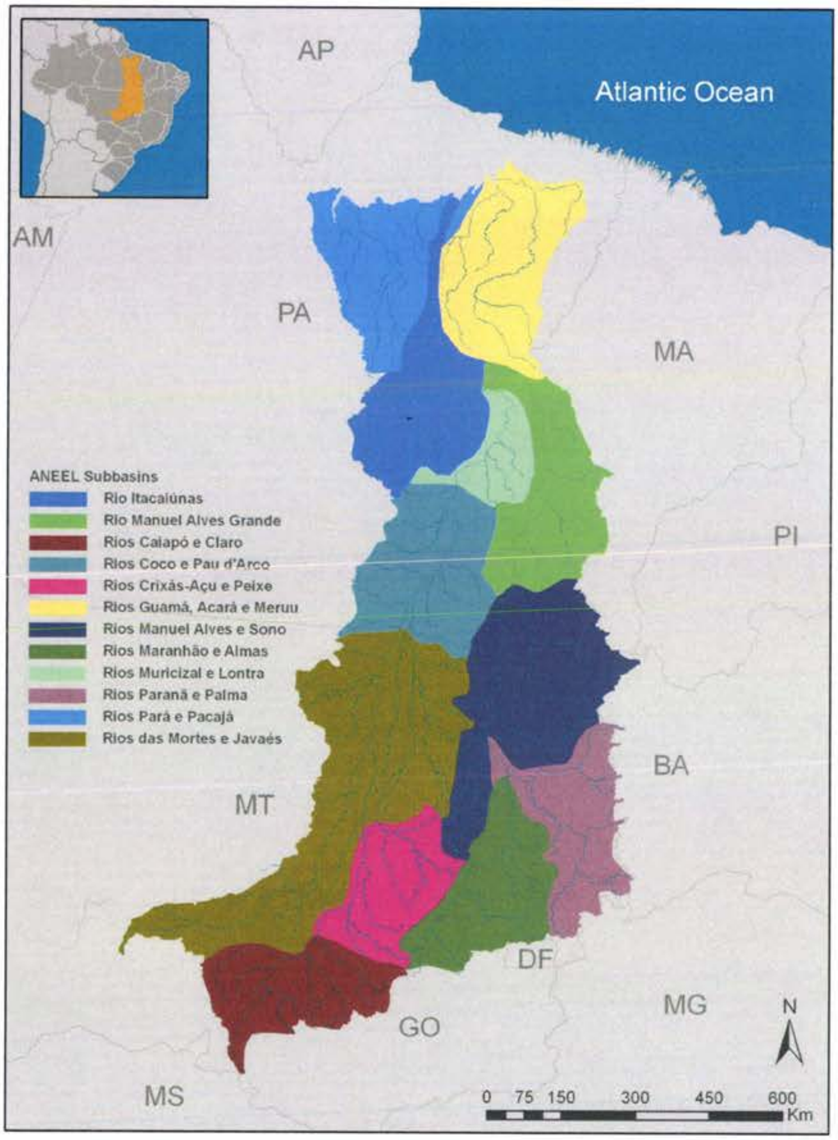


Figure 5.25. ANEEL Subbasins Map (Source: Elaborated by the author, with data from ANA, 2007b)

8. Otto River Basins (Figure 5.26), which represent a river basin classification based upon topological relationships, as proposed by Pfafstetter (1989).

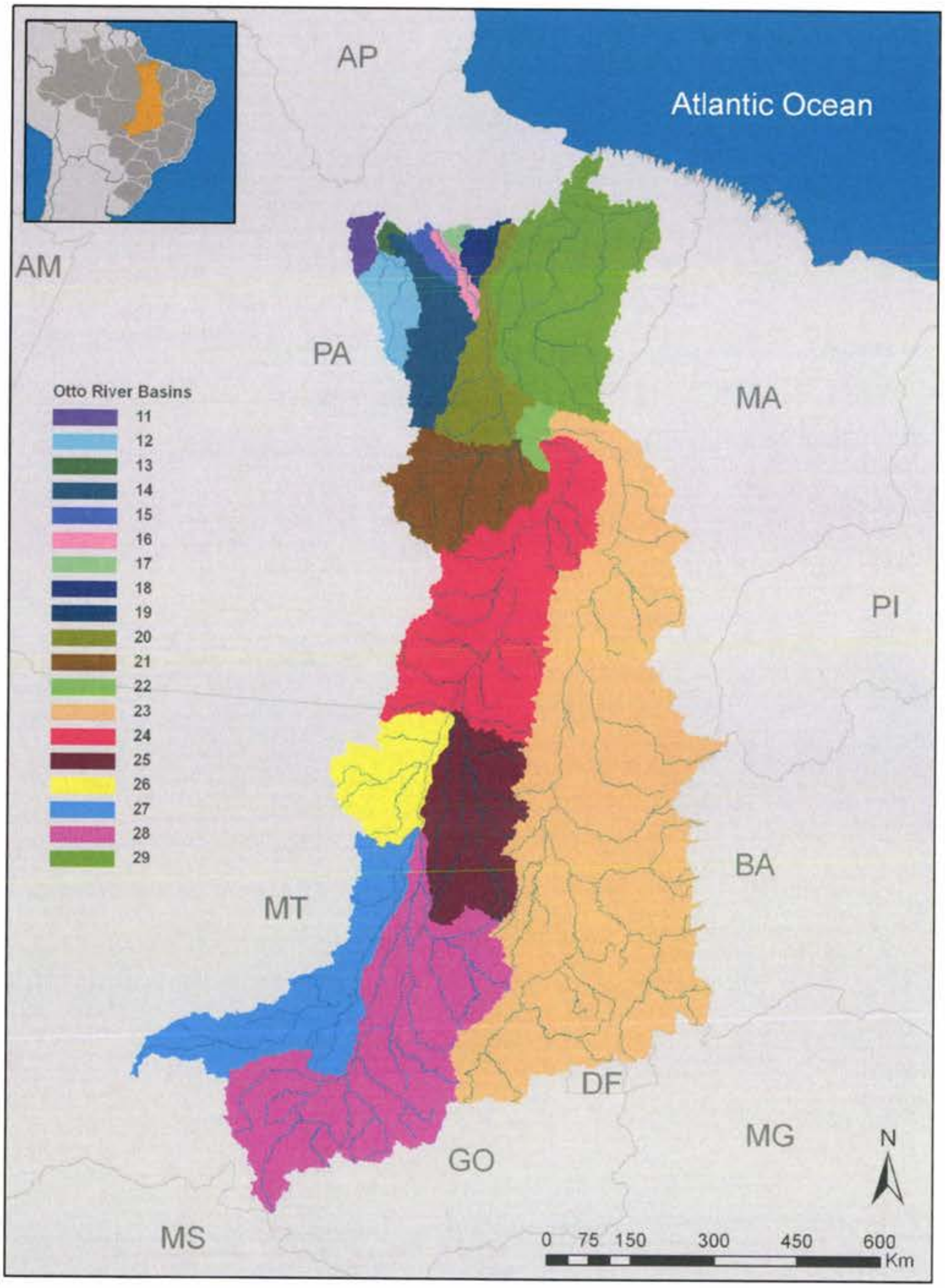


Figure 5.26. Otto River Basins Map (Source: Elaborated by the author, with data from ANA, 2010a)

Considering socioeconomic aspects, the following criteria are analyzed:

1. Land Use (Figure 5.27), which represents the main types of land use and occupation, including existing vegetation. In general, the region is not dense. Its occupation was motivated by some road projects and the transfer of Brazil's capital to Brasília. Currently, forests, agricultural areas, open fields and small urban centers are the dominant types of land use;

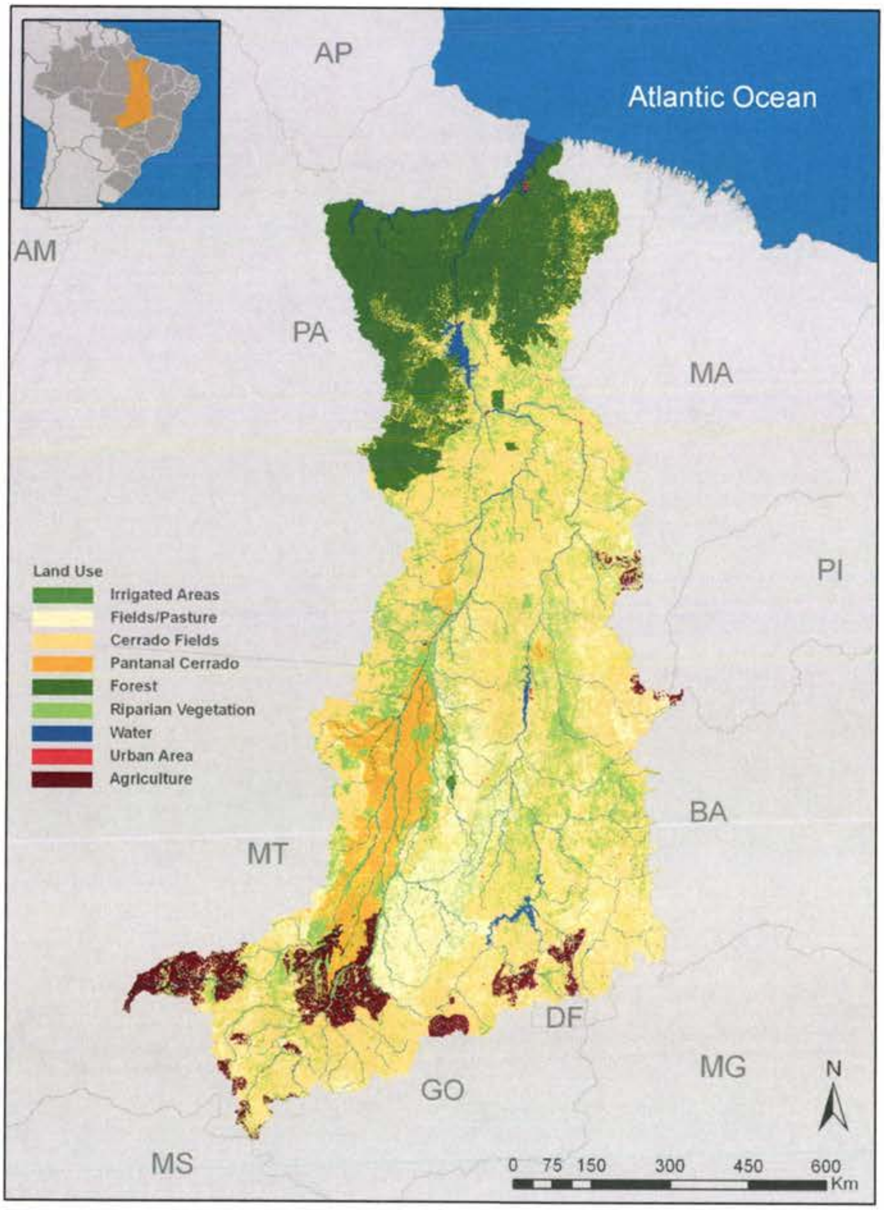


Figure 5.27. Land Use Map (Source: Elaborated by the author, with data from ANA, 2009)

2. Predominant Economic Base (Figure 5.28), which represents the major economic activity in each municipality of the region. The classification includes agriculture and livestock, representing the primary and secondary sectors of the economy which correspond to 59 percent of the region; urban-industrial, representing the services, commerce and industry which correspond to 20 percent of the region; transition, representing 7 percent of the region; and rare, representing preserved or inactive rural areas and small industrial or service activities, which correspond to 14 percent of the region;

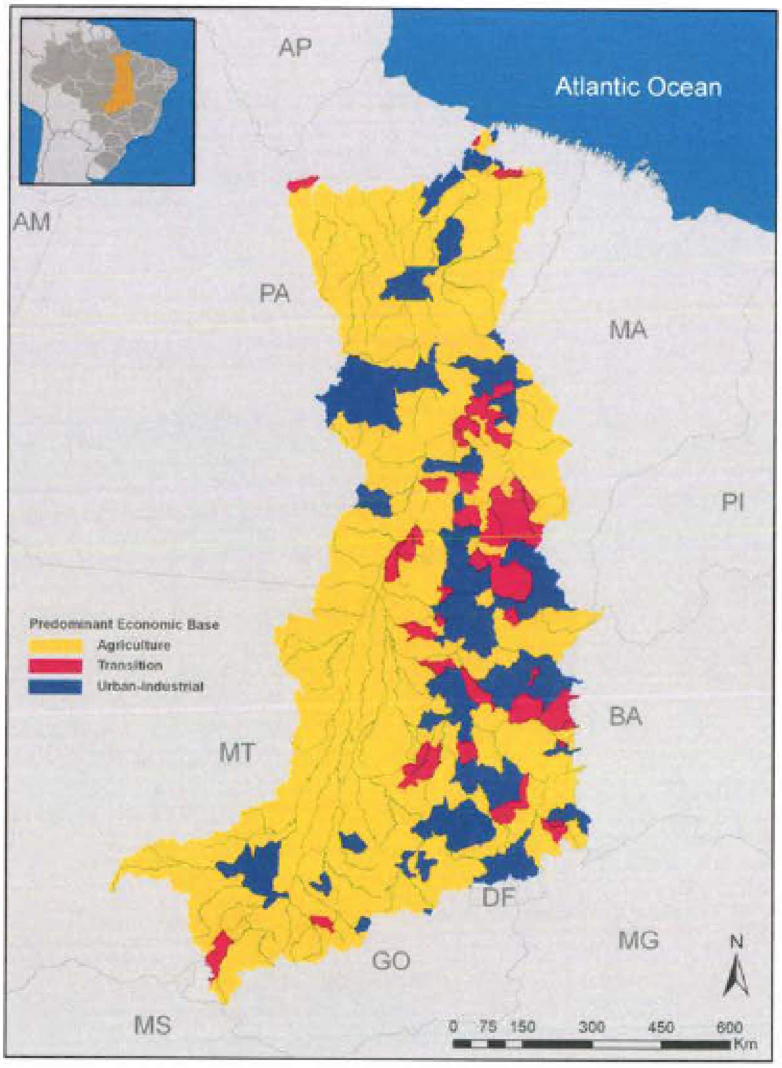


Figure 5.28. Predominant Economic Base Map (Source: Elaborated by the author, with data from ANA, 2009)

3. HDI (Figure 5.29), which represents the average UN Human Development Index. Each of the seventeen planning regions is classified into five intervals, resulting in homogeneous areas;

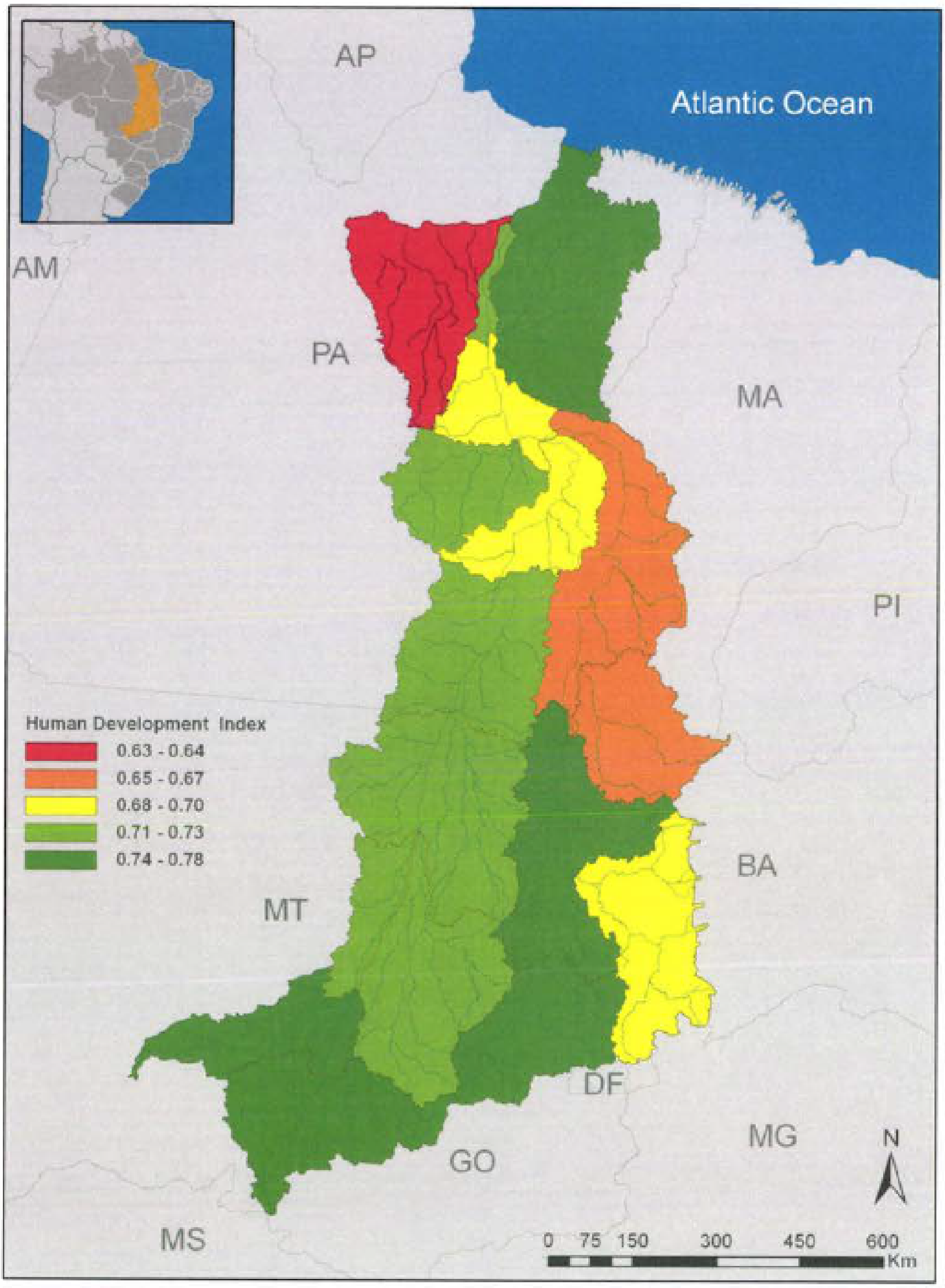


Figure 5.29. Human Development Index Map (Source: Elaborated by the author, with data from ANA, 2009)

4. GNP (Figure 5.30), which represents the Gross National Product. Each of the seventeen planning regions is classified into four intervals, resulting in homogeneous areas;

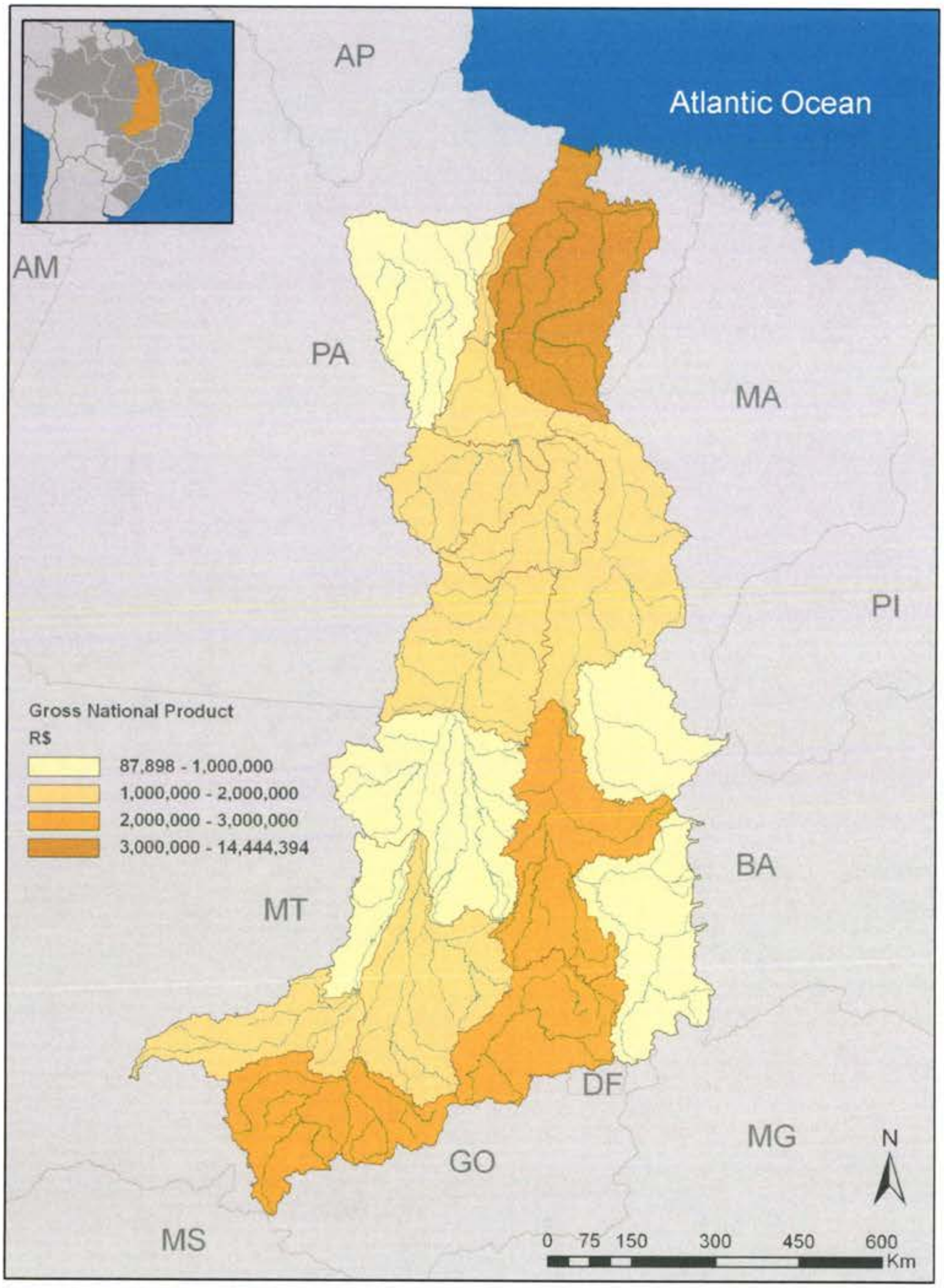


Figure 5.30. Gross National Product Map (Source: Elaborated by the author, with data from ANA, 2009)

5. Mesoregions (Figure 5.31), which represent the mesoregions established by the Brazilian Institute of Geography and Statistics. They comprise areas with similar socioeconomic characteristics;

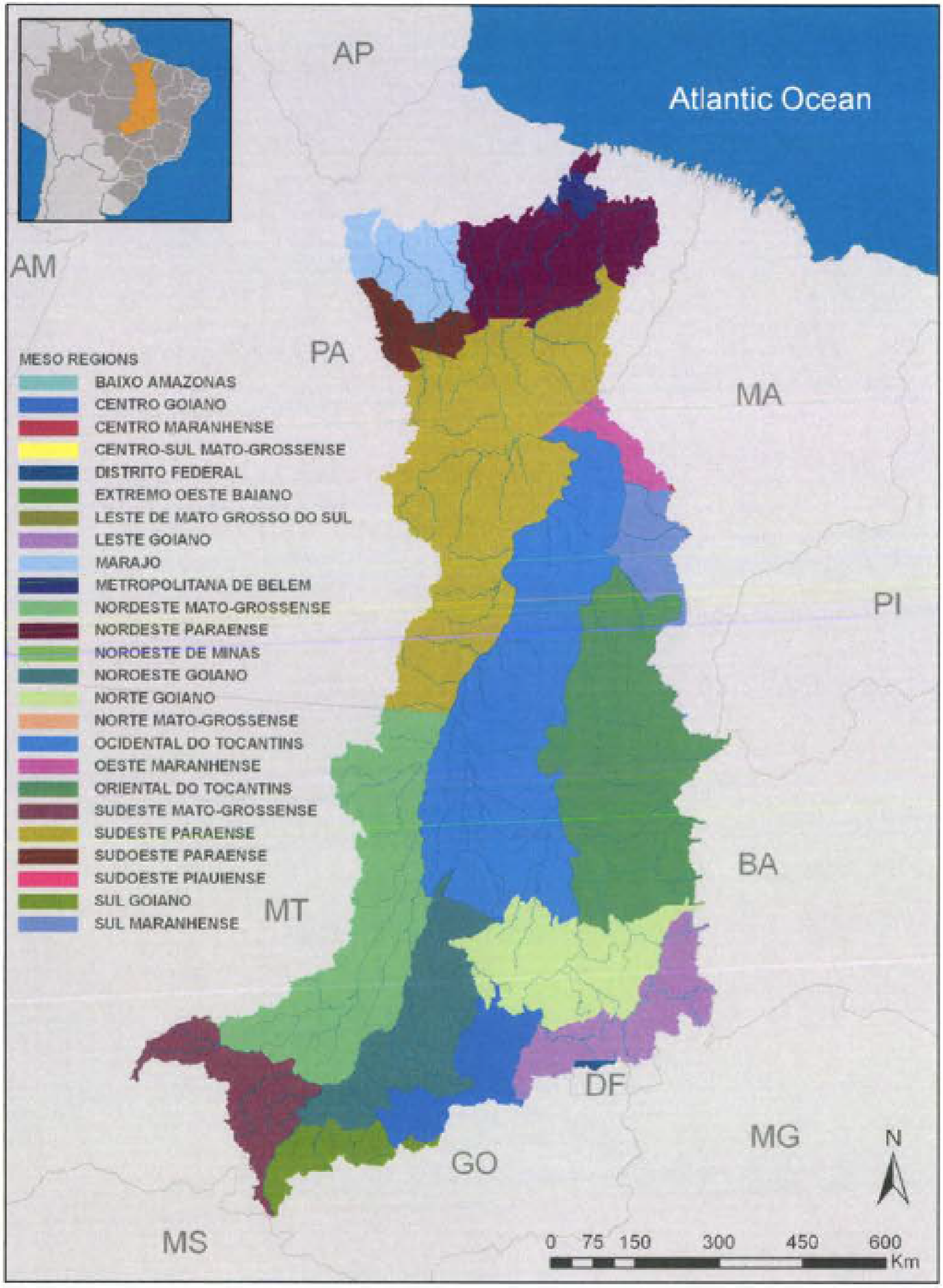


Figure 5.31. Mesoregions Map (Source: Elaborated by the author, with data from MMA, 2010)

6. Regional Centers (Figure 5.32), which represent the influence of the biggest cities over the municipalities, through major transportation roads, which results in established links to support industry, commerce, and services. In the north area, Belém Metropolitan Region presents commercial fluxes and services related to agriculture and livestock, including wood extraction and processing. In the north-center region, there is mining activity. In the south, the region is connected by the strong influence of Brasília and Goiânia;

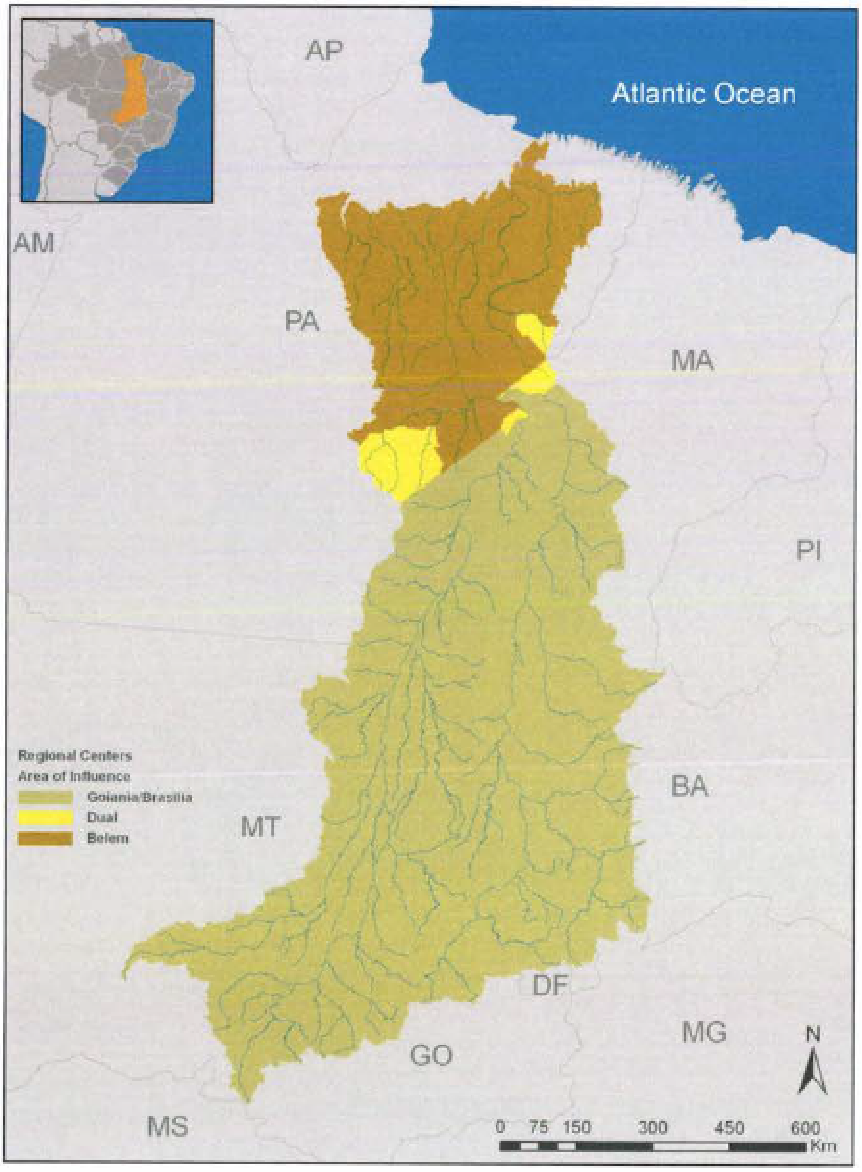


Figure 5.32. Regional Centers Map (Source: Elaborated by the author, with data from ANA, 2009)

7. Metropolitan Regions, which represent the influence of big urban centers. In the region, there is only one metropolitan region—Belém—which has local influence in terms of area. The regional centers map is used to represent the pressure and connections of this metropolitan region;
8. Demographic Density (Figure 5.33), which represents the human occupation in the river basin area and is directly related to the existence of relatively big urban centers. Each of the seventeen planning regions is classified into five intervals, resulting in homogeneous areas;

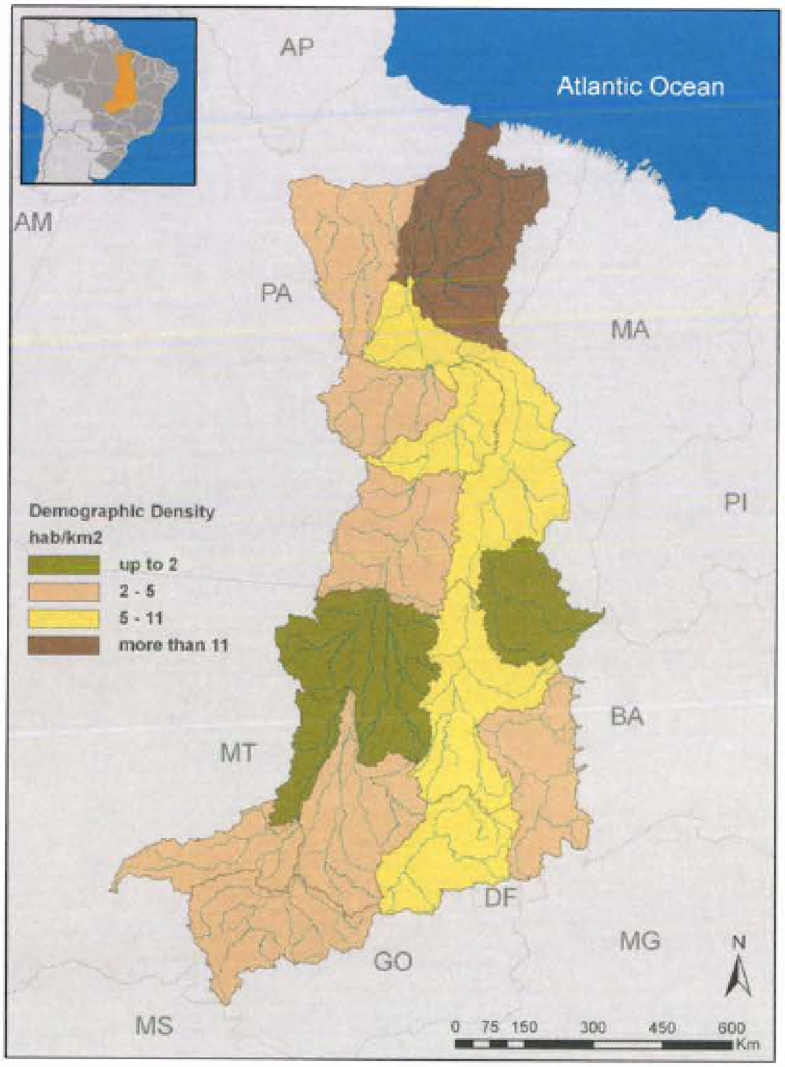


Figure 5.33. Demographic Density Map (Source: Elaborated by the author, with data from ANA, 2007a)

9. Irrigation (Figure 5.34), which represents the agricultural areas currently relying on irrigation and corresponding to one of the major water demands in the river basin. Some of the seventeen planning regions were selected according to the existence of irrigated areas;

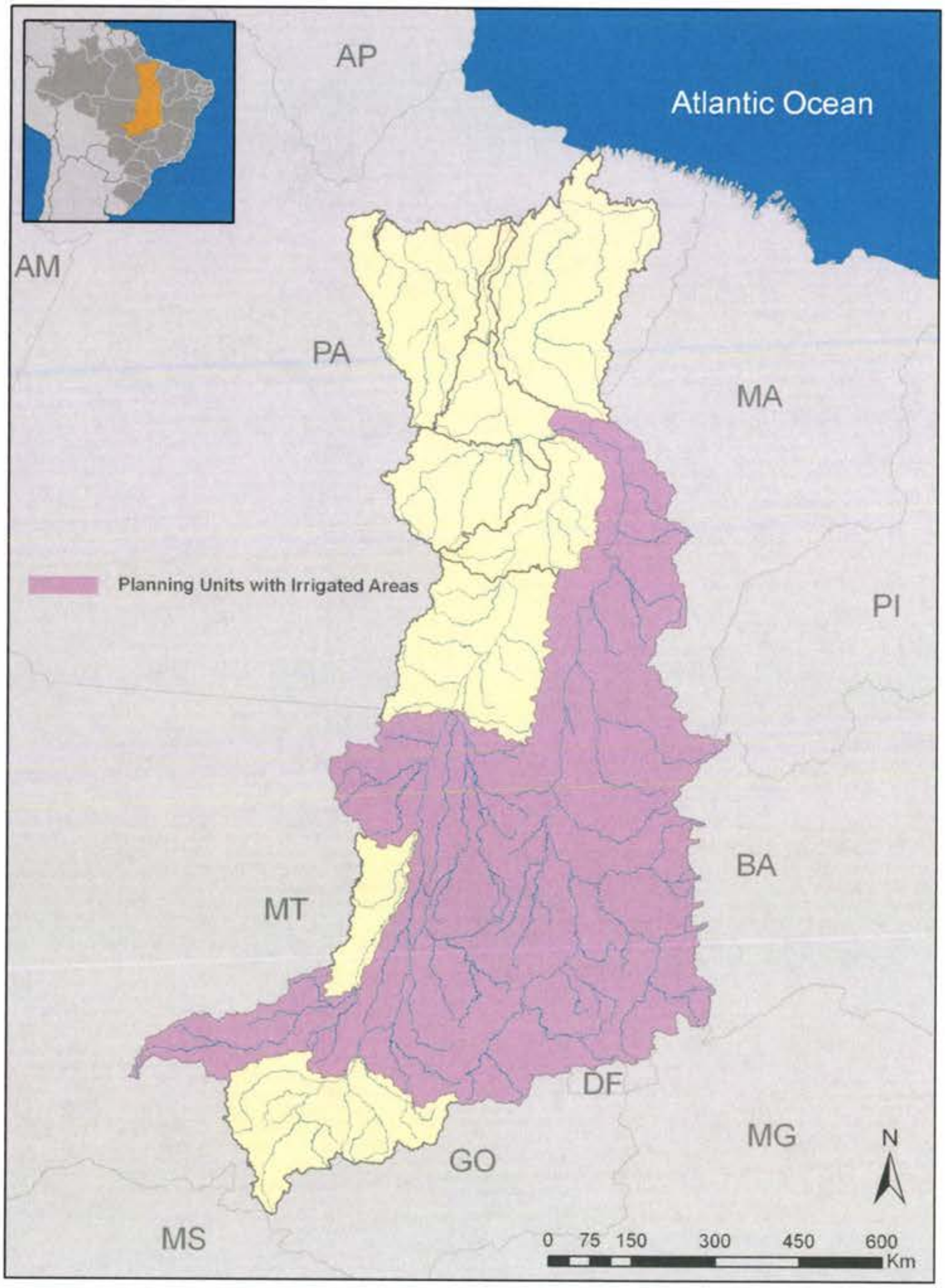


Figure 5.34. Irrigation Map (Source: Elaborated by the author, with data from ANA, 2009 and ANA, 2007d)

10. Aquaculture (Figure 5.35), which represents the areas of fish farming in the river basin. Some municipalities were selected according to the existence of aquaculture projects;

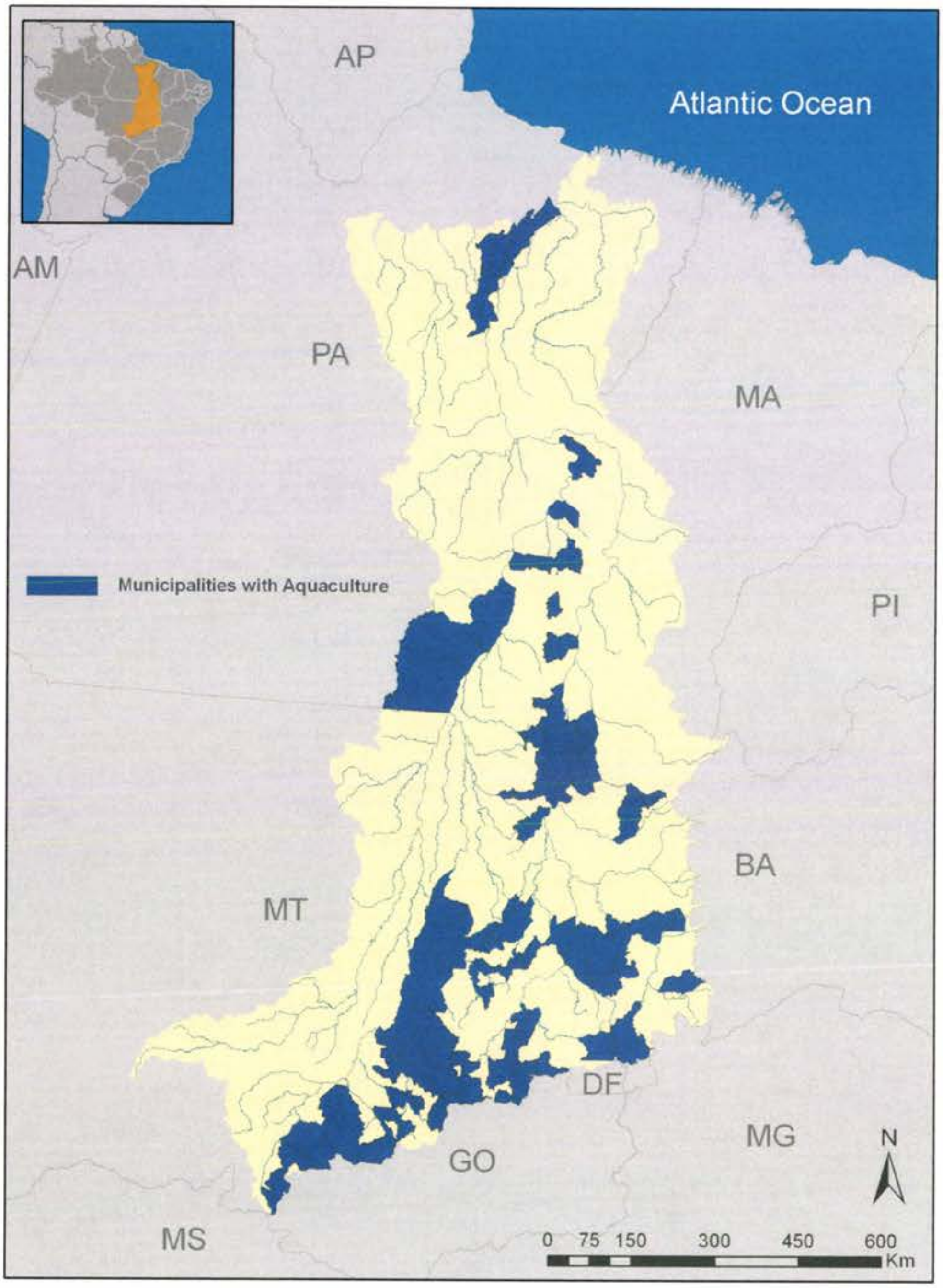


Figure 5.35. Aquaculture Map (Source: Elaborated by the author, with data from ANA, 2009)

11. Mining Activity (Figure 5.36), which represents the mineral provinces where extraction activities are intense, corresponding to significant water demands in the region;

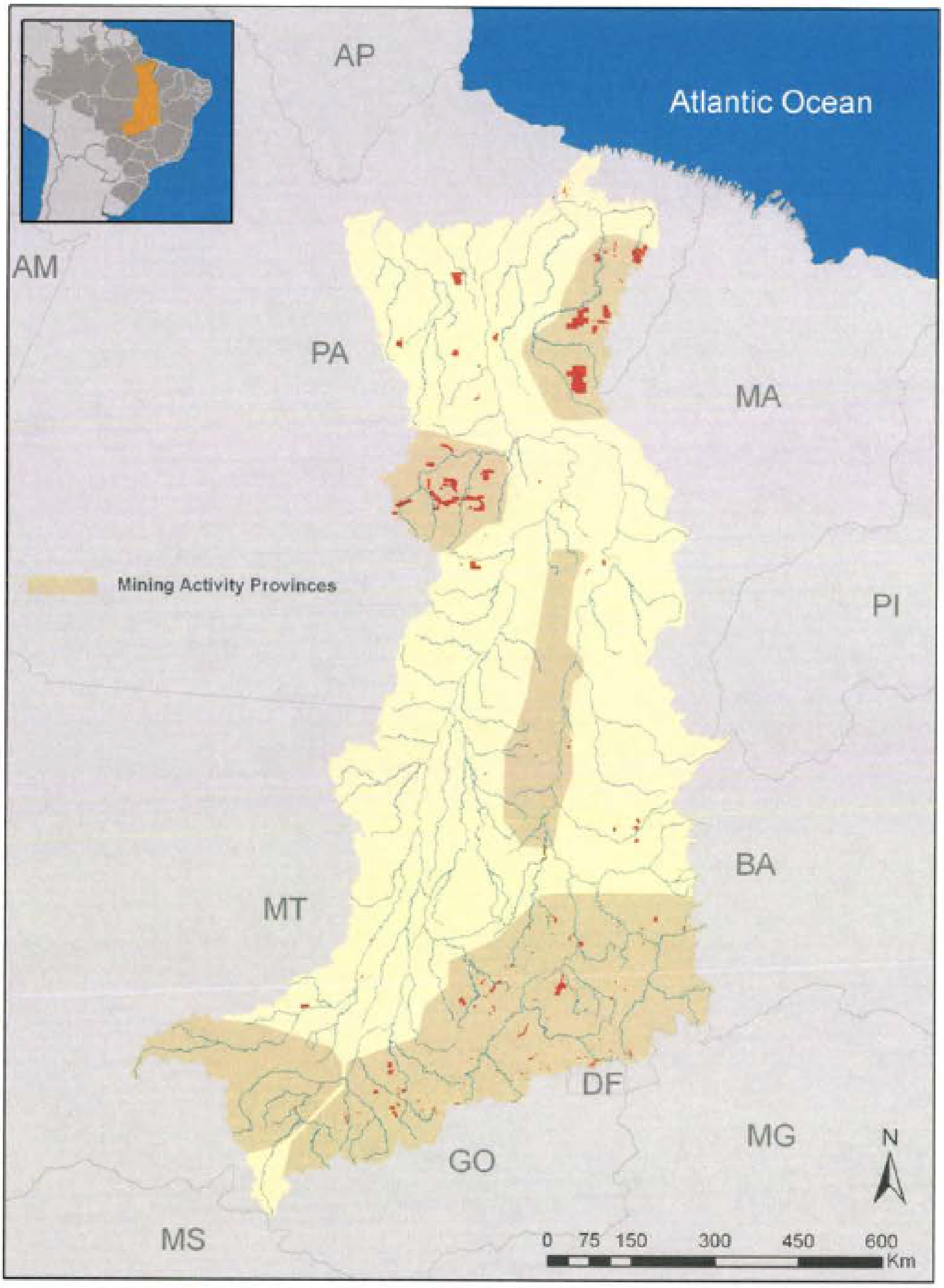


Figure 5.36. Mining Activity Provinces Map (Source: Elaborated by the author, with data from ANA, 2009)

12. Tourism Developing Areas (Figure 5.47), which represent the general areas of influence of the major tourism and recreational activities, corresponding to significant water demands and pressures over natural resources;

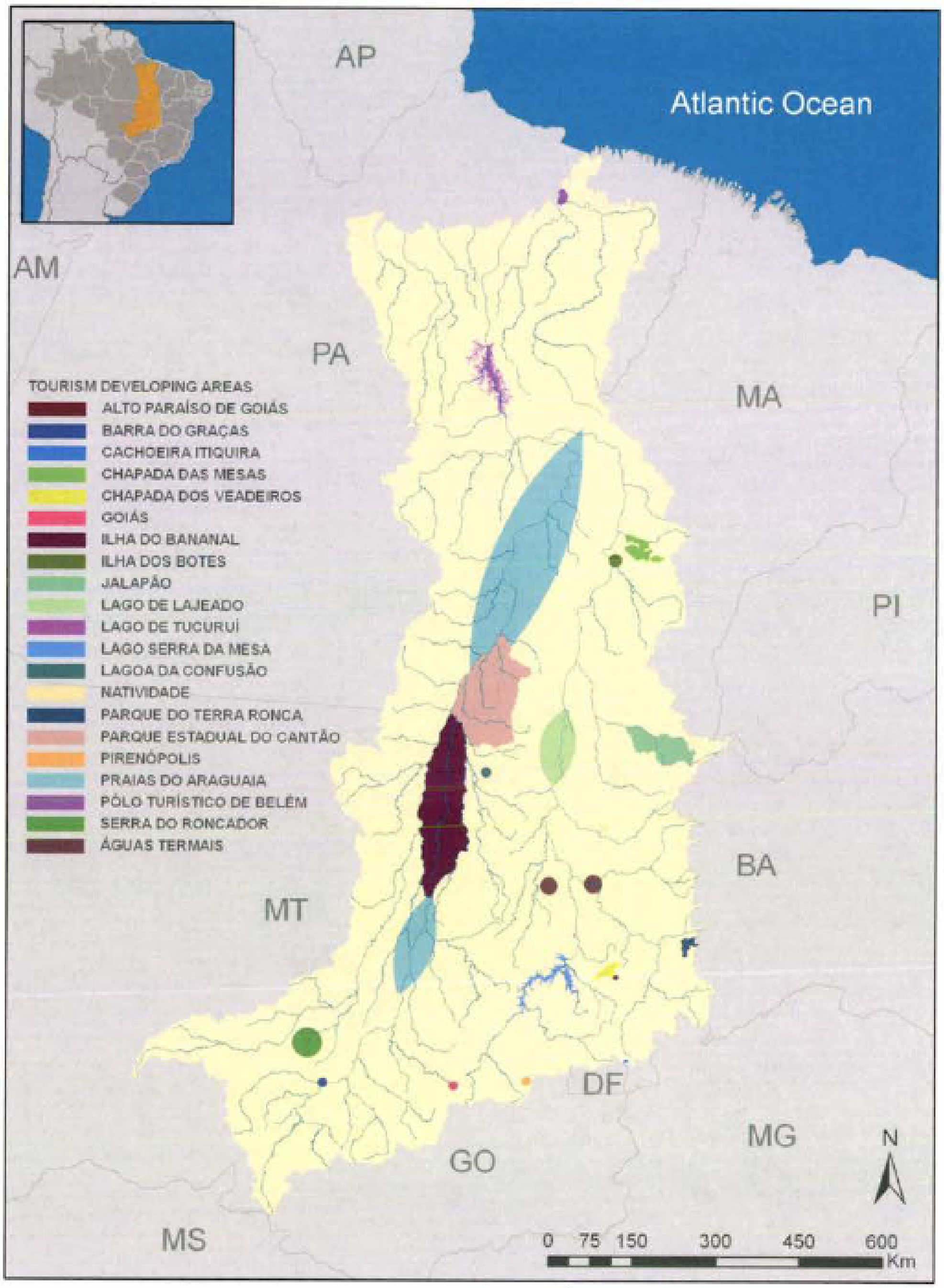


Figure 5.37. Tourism Developing Areas Map (Source: Elaborated by the author, with data from ANA, 2009)

13. Hydroelectricity Energy Potential (Figure 5.38), which represents homogeneous areas in terms of hydroelectricity energy generation potential. These areas are under pressure because of projected hydroelectricity plants and subsequent water demands. Each of the seventeen planning regions is classified into three intervals, resulting in homogeneous areas;

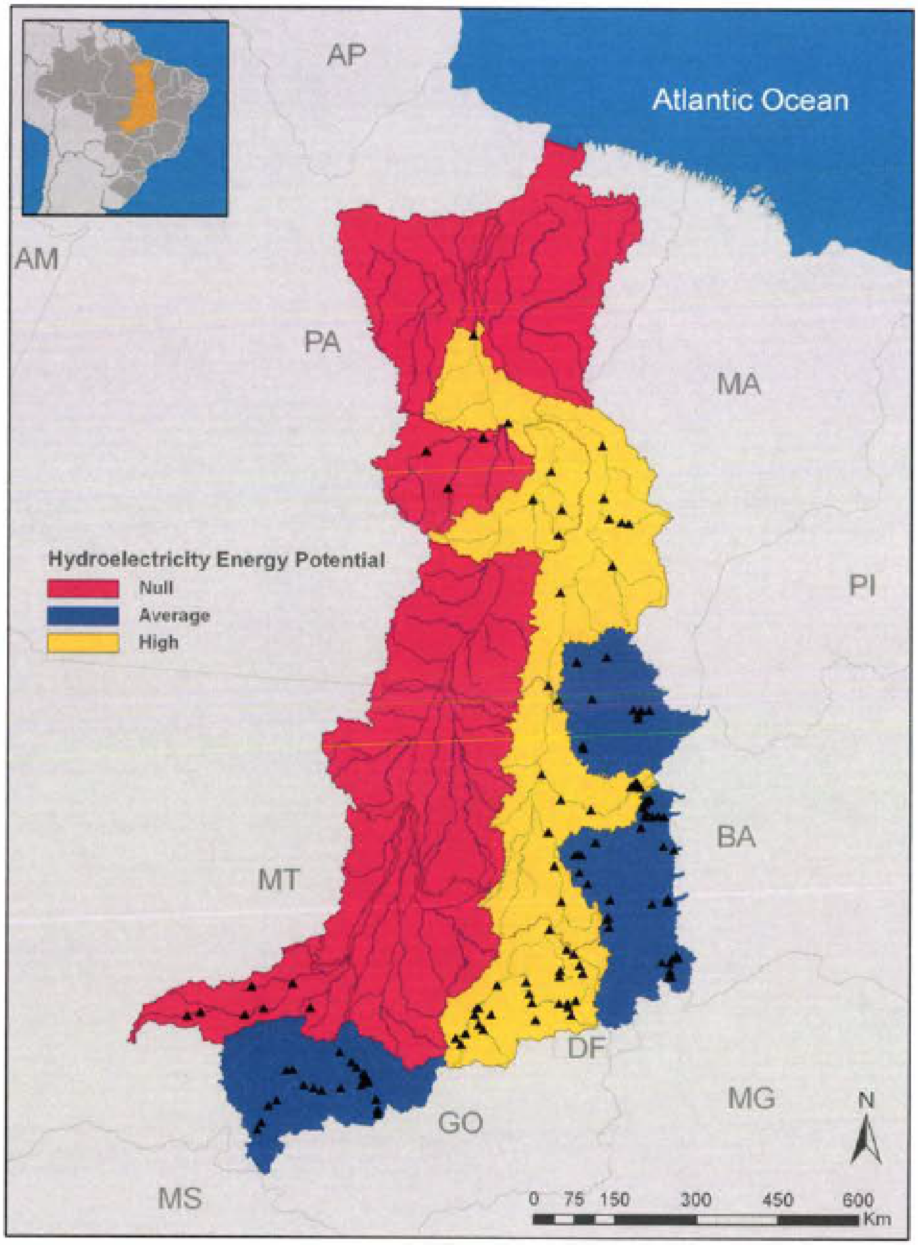


Figure 5.38. Hydroelectricity Energy Potential Map (Source: Elaborated by the author, with data from ANA, 2009)

14. Navigation (Figure 5.39), which represents the major waterways existing in the river basin. Some of the seventeen planning regions were selected according to the existence of significant waterways in their territories;

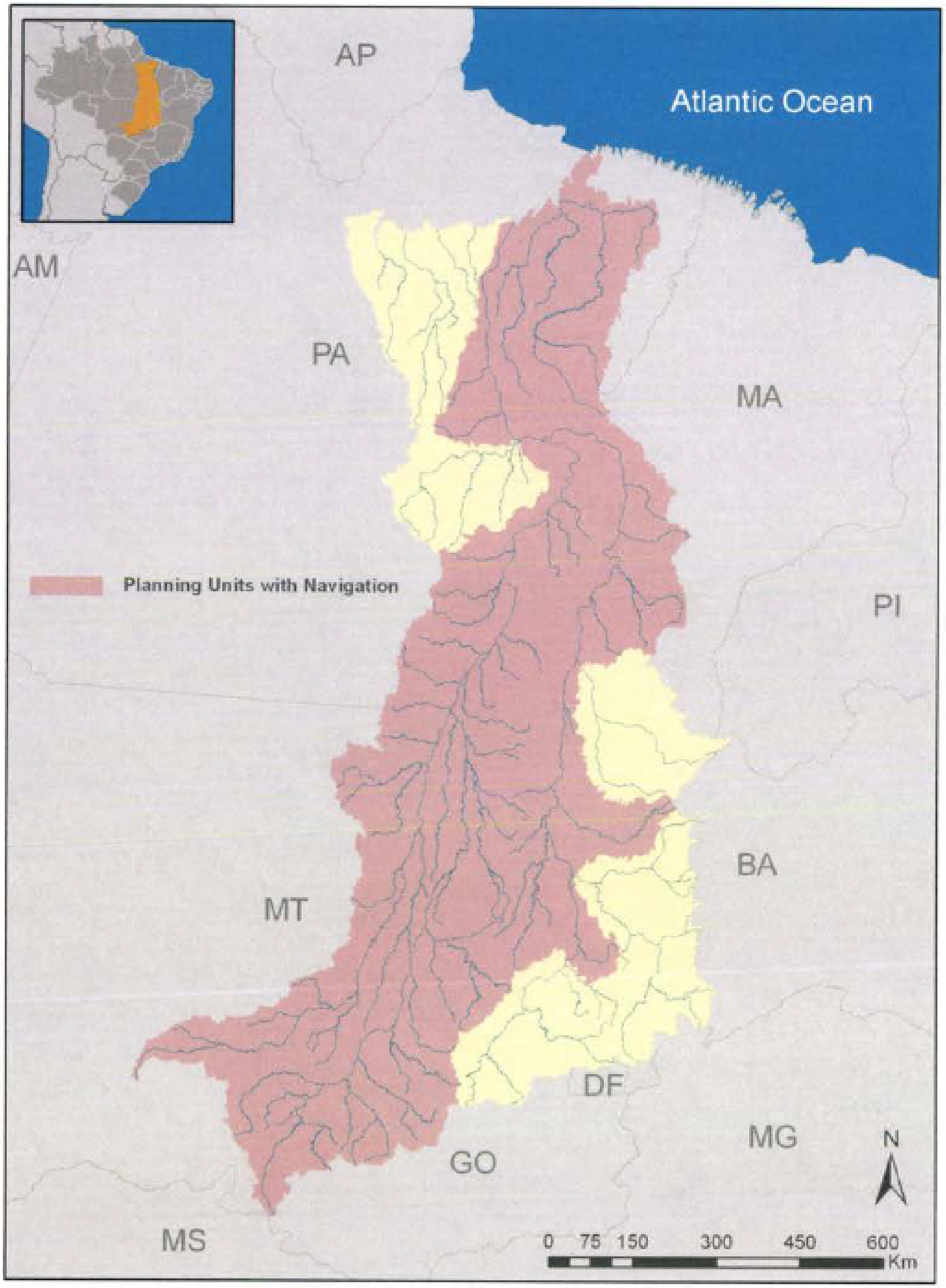


Figure 5.39. Navigation Map (Source: Elaborated by the author, with data from ANA, 2007a)

15. Sugar Cane Expansion (Figure 5.40), which represent areas under the pressure of sugar cane cropping expansion. This is the result of the growing international demand for renewable energy. In the south of the Tocantins-Araguaia region, there are significant projected investments because of cheaper lands, water availability, and tax exemptions created by the government;

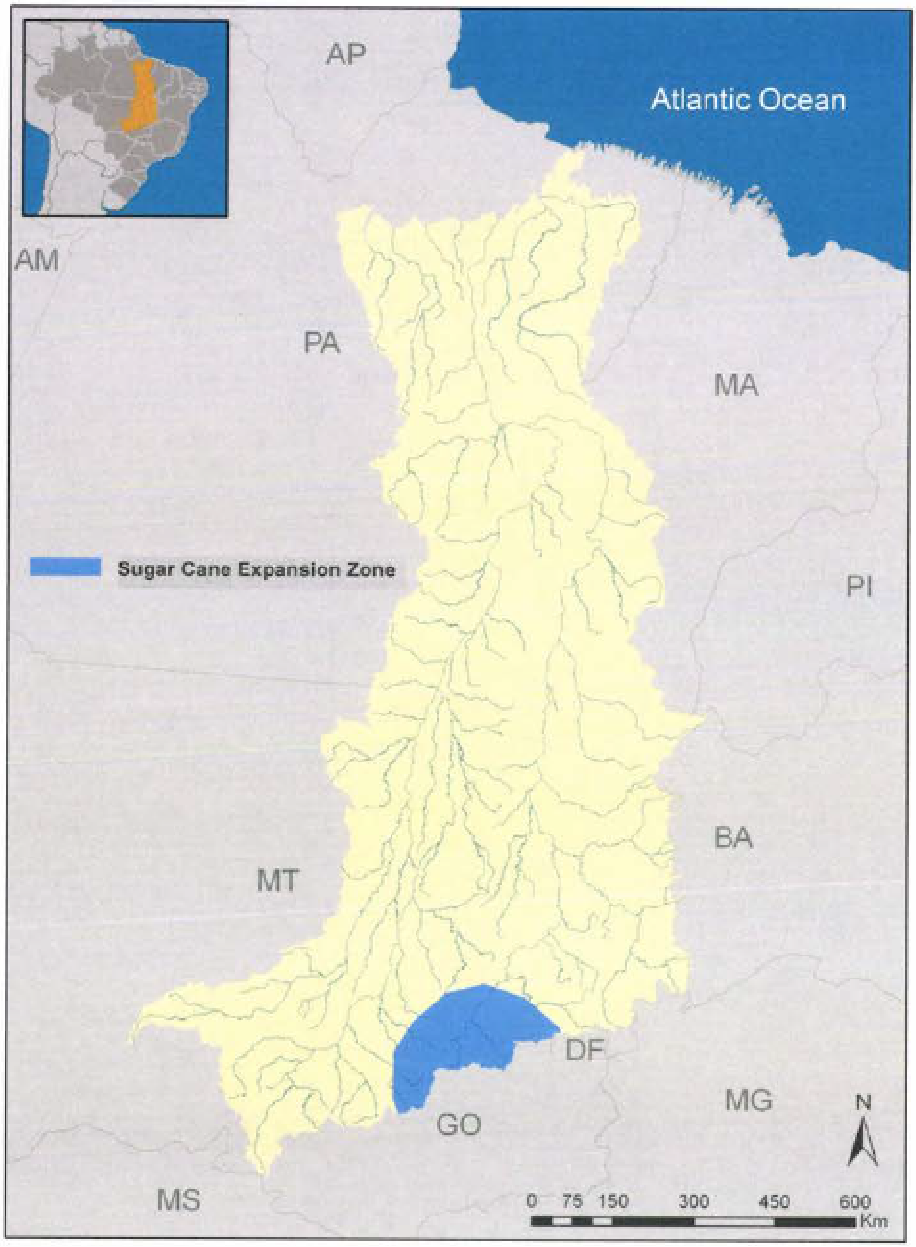


Figure 5.40. Sugar Cane Expansion Zone Map (Source: Elaborated by the author, with data from ANA, 2007d)

16. *Problemshed* (Figure 5.41), which summarizes significant problems that can be specialized in the river basin, such as critical events areas—droughts and floods—, soil erosion and siltation, water quality issues, special protection zones against structural interventions, and new water demands (ANA, 2009);

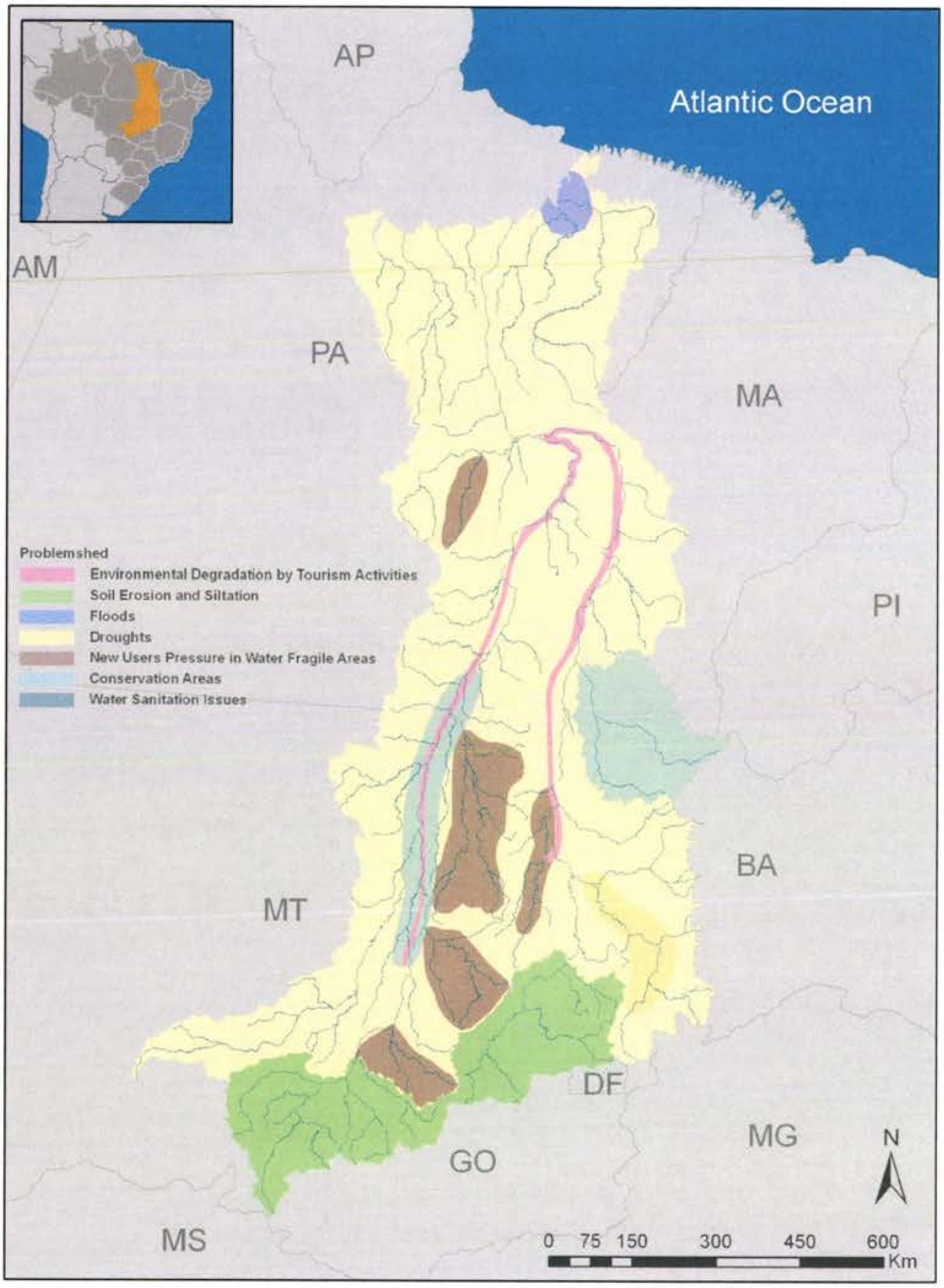


Figure 5.41. *Problemshed* Map (Source: Elaborated by the author, with data from ANA, 2009)

17. Social Organizations, which represent existing river basin committees in the region or any related form of water social organizations. There is only one official river basin committee created in the region in 1997, named CBH dos Ribeirões Sapé e Várzea Grande (ANA, 2010b). It has local authority and does not have significant regional influence. Therefore, it was not considered in this analysis.

5.3. Combining Criteria and Basis and Weighting Criteria

After defining the basis and criteria, it is time to start the algorithm. As described before, the first module of the algorithm actually performs the intersection between chosen criteria and the basis. The overlapping areas of each criterion over basis' units are calculated. Then, the set of weights must be defined in order to calculate the measure of closeness for each adjacent pair in the basis. For this case study the criteria are organized into four categories: physical-environmental, political-administrative, hydrographic and socioeconomic. Different simulations were performed, giving different weights to each category. Each individual aspect has the same weight in each of the four categories.

Figure 5.42 illustrates the process of combining criteria and basis, using ArcGIS Intersection functionality, as well as defining the list of adjacent pairs of the basis, using ArcGIS Polygon to Line functionality. In the sequence, the L2-norm subset of compromise programming and the cluster analysis are performed, as described before. Different grouping alternatives are generated according to the users preferences. In this study, different weights are assigned to represent each category importance.

Even though the algorithm is calibrated to give best possible solutions, no direct calibration or validation of the results is performed. The results are evaluated according to the users' preferences, who can choose different sets of weights, a maximum number of elements (basis' units) per cluster, different threshold values for the hierarchical agglomerative cluster option, or different numbers of groups for the partitioning cluster option. This is a qualitative simulation model that includes judgment and preferences. Therefore, each individual analysis may lead to different results.

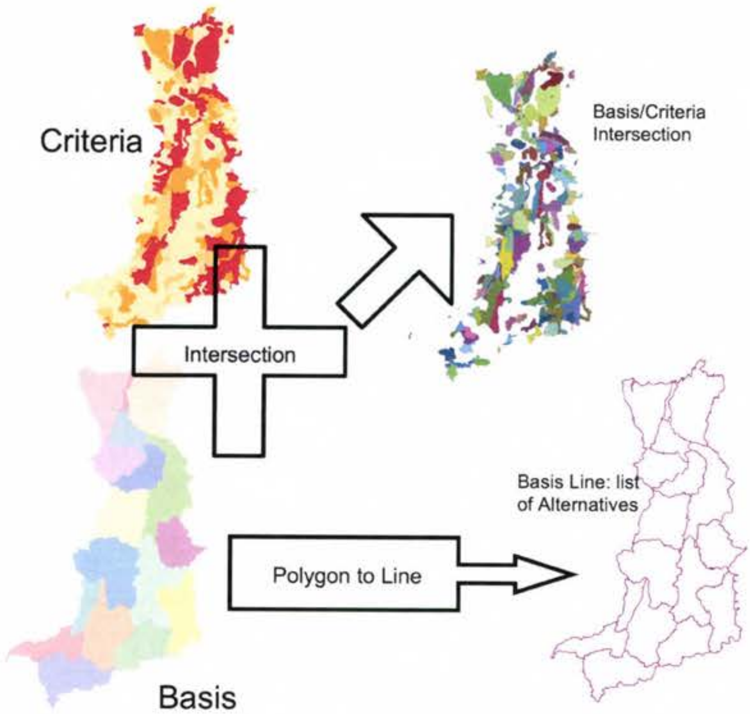


Figure 5.42. Illustration of the GIS operations

5.4. Simulated Results

The following figures present different simulated results. Selected parameters are specified in each figure, such as different sets of weights, different threshold values for the hierarchical agglomerative cluster option, or different numbers of groups for the partitioning cluster option. The first scenario considers identical weights for all categories of criteria. According to the results of the simulation, the optimum number of clusters is six, containing six, three, two, two, two and two elements (Figure 5.43). The optimum benefit, considering the inter-cluster measure of homogeneity is equal to 0.347. In this 6-cluster scenario, there is a contrast between one big group, with six elements, and the other groups, which may not be considered an ideal solution. In this case, the optimum number of clusters may not be the 'best ideal' solution. Scenarios 01a, 01b and 01c (Figure 5.43) present the sub-optimum solutions of the same simulation, containing five, seven and eight clusters respectively. As observed in Table 5.1, which presents the summary of the results from Scenario 01, the difference in the return benefit between the different number of cluster options is relatively not significant.

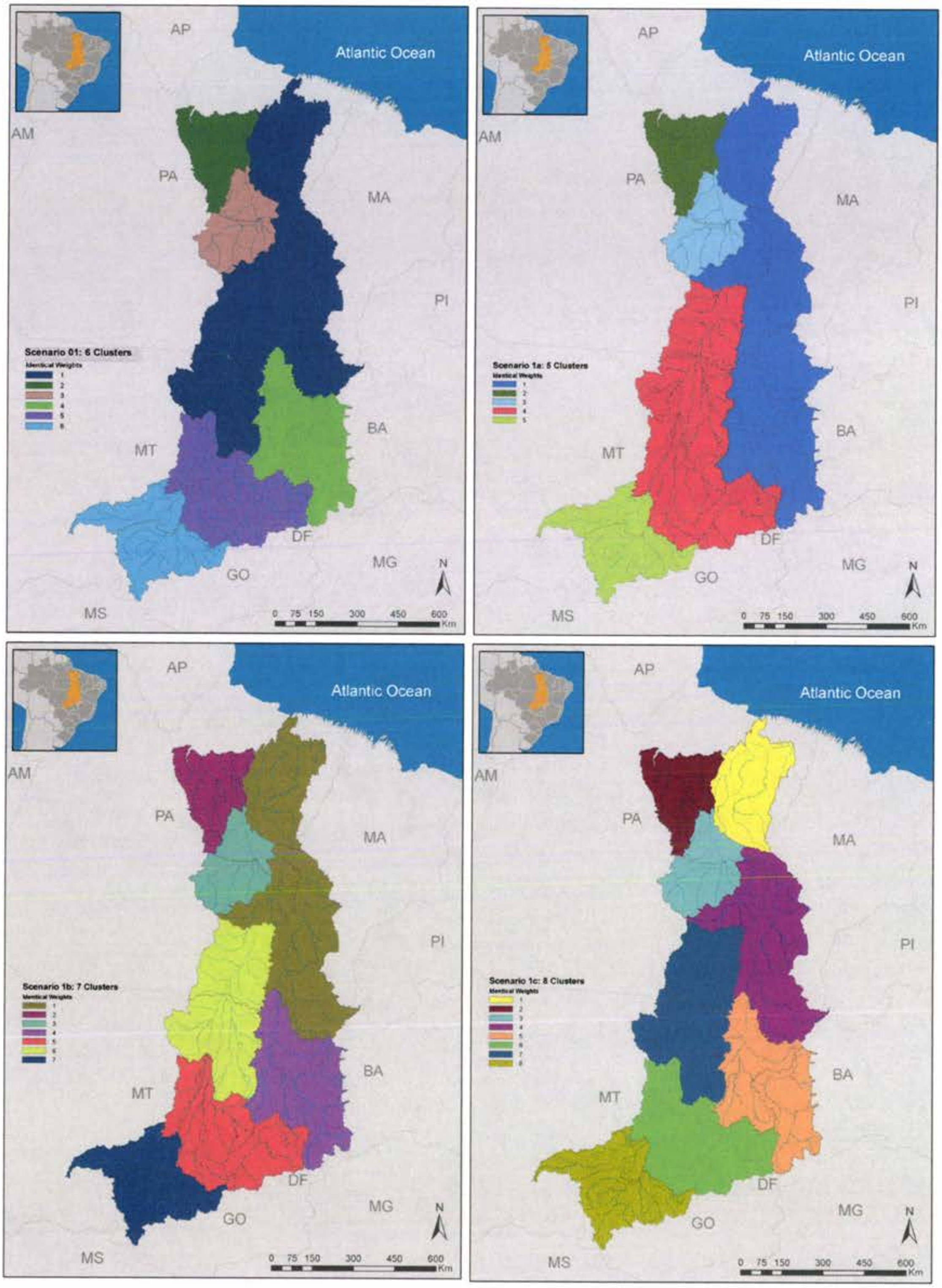


Figure 5.43. Illustration of Scenarios 01, 01a, 01b and 01c: comparison between different numbers of clusters

Table 5.1. Results of Scenario 01: Identical Weights for All Aspects

Scenario 01—Summary of Results

Category of Aspects	*Assigned Weights*
Political-administrative	1
Physical-environmental	1
Hydrographic	1
Socioeconomic	1

Number of Clusters	*Return Benefit*	*Number of Elements per Cluster*
5	0.328	6, 5, 2, 2, 2
6	0.347	4, 3, 2, 2, 2, 2, 2
7	0.337	6, 3, 2, 2, 2, 2
8	0.306	3, 3, 2, 2, 2, 2, 2, 1

In addition, according to the knowledge-rules associated with the results (Figure 5.44), it is possible to observe that physical-environmental aspects were the leading factor in creating the biggest cluster, cluster #1. Its area is equal to 399,918 square kilometers. Clusters #2 and #3 were defined mainly because of political-administrative aspects. Clusters #5 and #6 were delineated mainly because of socioeconomic aspects. Cluster #4 was defined because of hydrographic aspects. As mentioned before, the knowledge rules, which are part of the KBS, provide, automatically, additional information to the users, regarding the clusters created in each simulation.

Cluster #1 is formed by 6 elements.
The most significant aspects considered to delineate this cluster are the Physical-Environmental Aspects .
Its total area is equal to: 399,918 square kilometers.
The units contained in this cluster are: 5, 6, 7, 11, 12, 17 .

Cluster #2 is formed by 2 elements.
The most significant aspects considered to delineate this cluster are the Political-Administrative Aspects .
Its total area is equal to: 66,422 square kilometers.
The units contained in this cluster are: 15, 16 .

Cluster #3 is formed by 2 elements.
The most significant aspects considered to delineate this cluster are the Political-Administrative Aspects .
Its total area is equal to: 68,066 square kilometers.
The units contained in this cluster are: 13, 14 .

Cluster #4 is formed by 2 elements.
The most significant aspects considered to delineate this cluster are the Hydrographic Aspects .
Its total area is equal to: 132,601 square kilometers.
The units contained in this cluster are: 9, 10 .

Cluster #5 is formed by 3 elements.
The most significant aspects considered to delineate this cluster are the Socioeconomic Aspects .
Its total area is equal to: 142,587 square kilometers.
The units contained in this cluster are: 3, 4, 8 .

Cluster #6 is formed by 2 elements.
The most significant aspects considered to delineate this cluster are the Socioeconomic Aspects .
Its total area is equal to: 102,795 square kilometers.
The units contained in this cluster are: 1, 2 .

Figure 5.44. Knowledge Rules for Scenario 01

Another analysis automatically performed in the DSS is the calculation of the fuzzy membership value of each element to the assigned cluster, as well as to other adjacent clusters.

The objective function of this ill-structured problem is considered subjective, especially because of the uncertainty associated with it, as well as qualitative judgments related to the solutions and imprecise knowledge. It is clear, in this context, that the elements have a continuous grade of membership within clusters, representing the situations that do not completely fulfill the quantitative results, or that have no sharp boundaries. As part of the solution, Table 5.2 is generated in each simulation, providing the fuzzy membership value for each element clustered. For instance, Element 17 belongs 9% to Cluster #1, 47% to Cluster #2 and 44% to Cluster #3. In the optimum solution, it is assigned to Cluster #1 because if element 17 is assigned to Cluster #2, the return total benefit is reduced from 0.347 to 0.321, and if it is assigned to Cluster #3, the return total benefit is reduced to 0.317. The way the benefit function is calculated, considering the intra-cluster measure of homogeneity, seems to favor the clustering of one object to bigger clusters (for instance, element 17 to Cluster #1) than to smaller ones (for instance, element 17 to Clusters #2 or #3).

Table 5.2. Fuzzy membership values (FMF) of each element to respective Clusters

Elem	Cluster	FMF	Elem	Cluster	FMF	Elem	Cluster	FMF	Elem	Cluster	FMF
1	6	81.5%	5	1	46.8%	10	4	78.0%	14	3	84.8%
	5	18.5%		4	30.0%		1	13.5%		1	5.7%
2	6	83.3%		5	23.3%		5	8.6%		2	9.5%
	5	16.7%	6	1	98.9%	11	1	49.2%	15	2	66.3%
3	5	63.4%		4	1.1%		4	50.8%		1	26.3%
	1	9.2%	7	1	70.4%	12	1	92.9%		3	7.4%
	6	27.4%		3	29.6%		3	2.4%	16	2	90.7%
4	5	51.6%	8	5	62.5%		4	4.7%		1	0.0%
	1	35.5%		4	33.3%	13	3	75.8%		3	9.3%
	4	1.9%		6	4.2%		1	24.1%	17	1	9.0%
	6	11.0%	9	4	86.6%		2	0.1%		2	46.8%
				5	13.4%					3	44.2%

A summary of the relative importance of each category of aspects in the six clusters defined in Scenario 01 is presented below (Table 5.3). As observed, each category has a similar contribution, in general, to the results.

In order to test this affirmation, and the relative influence of each category of aspects, next scenarios (Scenario 02 to Scenario 05) weight each category in a different way (Figure 5.45). Scenario 02 emphasizes political-administrative aspects, which are weighted equal to five, while the other aspects are equal to 1. Scenario 03 emphasizes hydrographic aspects, Scenario 04 emphasizes socioeconomic aspects, and Scenario 05 emphasizes physical-environmental aspects. As observed in Figure 5.45, only Scenario 02, which emphasizes political-administrative aspects and is detailed in Table 5.4, has a different clustering alternative than Scenario 01. It seems that the same pre-defined clusters dominate the results. These simulations reinforce the fact that, in general, the aspects have similar contribution to the final solution.

Table 5.3. Relative importance of each category of aspects

Aspects	Political-administrative	Hydrographic	Socioeconomic	Physical-environmental
Cluster #1	19.8%	27.0%	24.9%	28.3%
Cluster #2	40.7%	21.7%	14.2%	23.5%
Cluster #3	45.3%	18.7%	14.0%	22.0%
Cluster #4	24.3%	30.9%	15.3%	29.4%
Cluster #5	18.4%	23.2%	30.9%	27.6%
Cluster #6	7.6%	27.9%	33.9%	30.6%
Total	26.0%	24.9%	22.2%	26.9%

Table 5.4. Results of Scenario 02: Emphasis on Political-administrative Aspects

Scenario 02—Summary of Results

Category of Aspects	*Assigned Weights*
Political-administrative	5
Physical-environmental	1
Hydrographic	1
Socioeconomic	1

Number of Clusters	*Return Benefit*	*Number of Elements per Cluster*
5	0.403	5, 2, 2, 2, 6

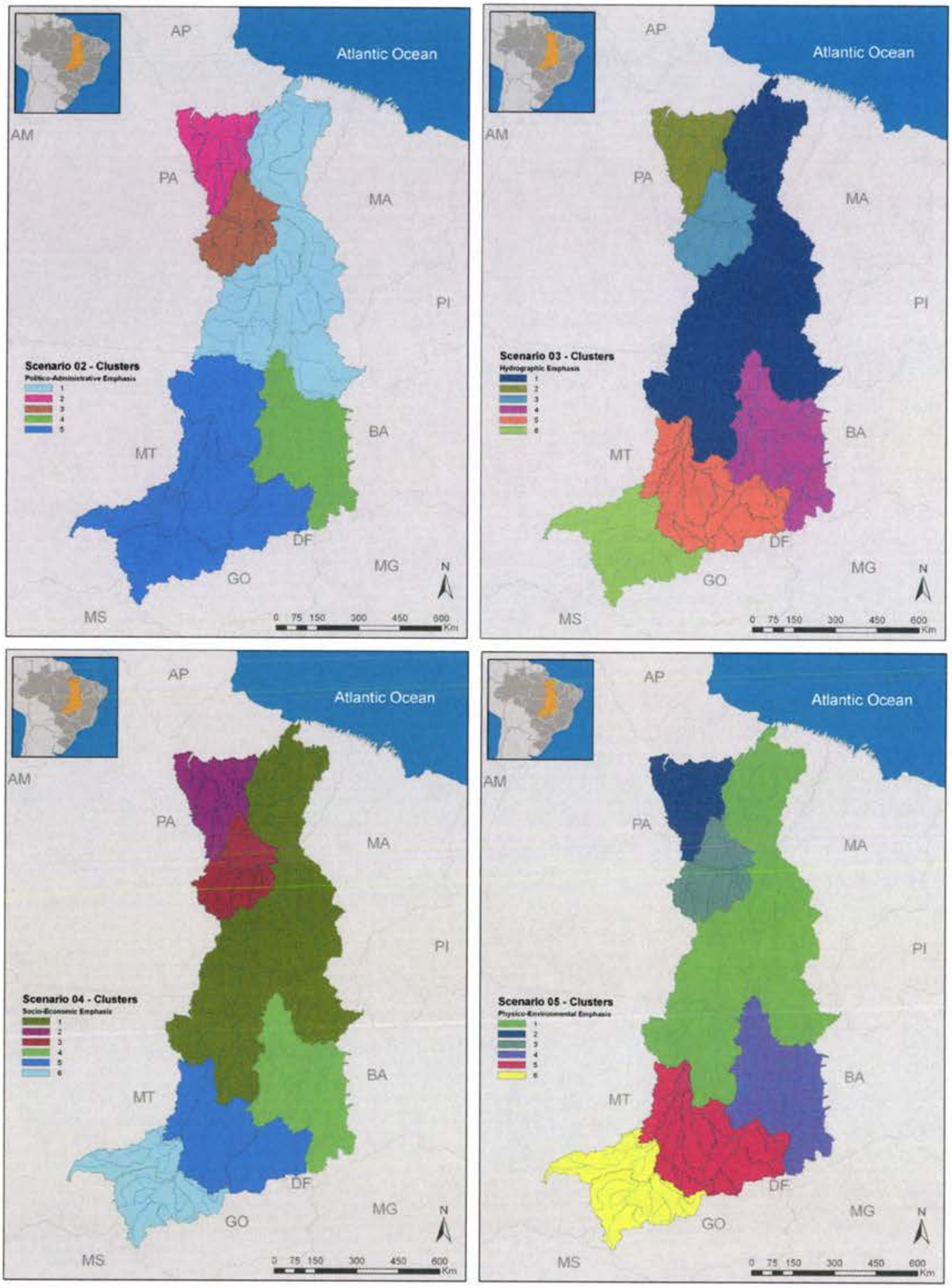


Figure 5.45. Illustration of the Results of Scenarios 02 to 05: comparison between different emphasis

Another set of simulations (Figure 5.46) weights each category of aspects independently.

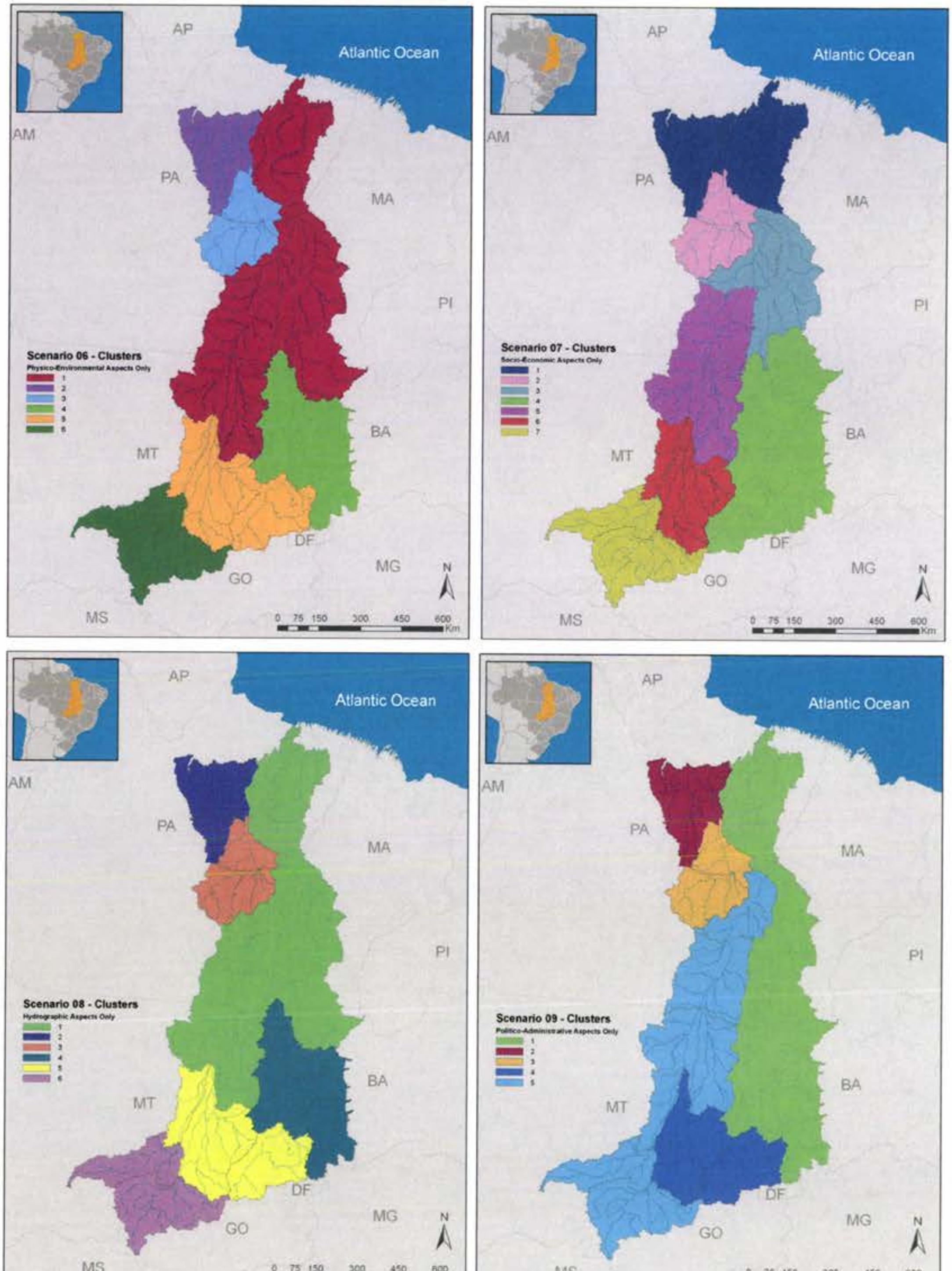


Figure 5.46. Illustration of the Results of Scenarios 06 to 09: comparison between independent aspects

In these simulations, each category of aspect was weighted independently in order to verify the influence of each set of aspects separately form the others. For instance, in Scenario 06, physical-environmental aspects were weighted equal to one and all other aspects equal to 0. Scenario 07 considers socioeconomic aspects only, Scenario 08 considers hydrographic aspects only, and Scenario 09 considers political-administrative aspects only. As observed in Figure 5.46, only Scenarios 07 and 09, which are detailed in Tables 5.5 and 5.6, have different clustering alternatives than Scenario 01. Scenario 07 presents seven clusters as the optimum solution, containing three, two, two, four, two, two, and two elements respectively. It is the most homogeneous solution, in terms of the number of elements per clusters. Scenario 09 presents five clusters as the optimum solution, containing five, two, two, two and six elements respectively.

Table 5.5. Results of Scenario 07: Socioeconomic Aspects Only

Scenario 07—Summary of Results

Category of Aspects	*Assigned Weights*
Political-administrative	0
Physical-environmental	0
Hydrographic	0
Socioeconomic	1

Number of Clusters	*Return Benefit*	*Number of Elements per Cluster*
7	0.284	3, 2, 2, 4, 2, 2, 2

Table 5.6. Results of Scenario 09: Political-administrative Aspects Only

Scenario 09—Summary of Results

Category of Aspects	*Assigned Weights*
Political-administrative	1
Physical-environmental	0
Hydrographic	0
Socioeconomic	0

Number of Clusters	*Return Benefit*	*Number of Elements per Cluster*
5	0.433	5, 2, 2, 2, 6

Despite the fact that the same pre-defined clusters dominate the results, the weighting of criteria has a direct impact on the alternatives. For example, Scenarios 02 and 09 emphasize political-administrative aspects, which are possibly the dominant aspects. Both scenarios have five clusters as the optimum solution. However, the clustering alternatives are notably different, according to the different weights, as repeated in Figure 5.47.

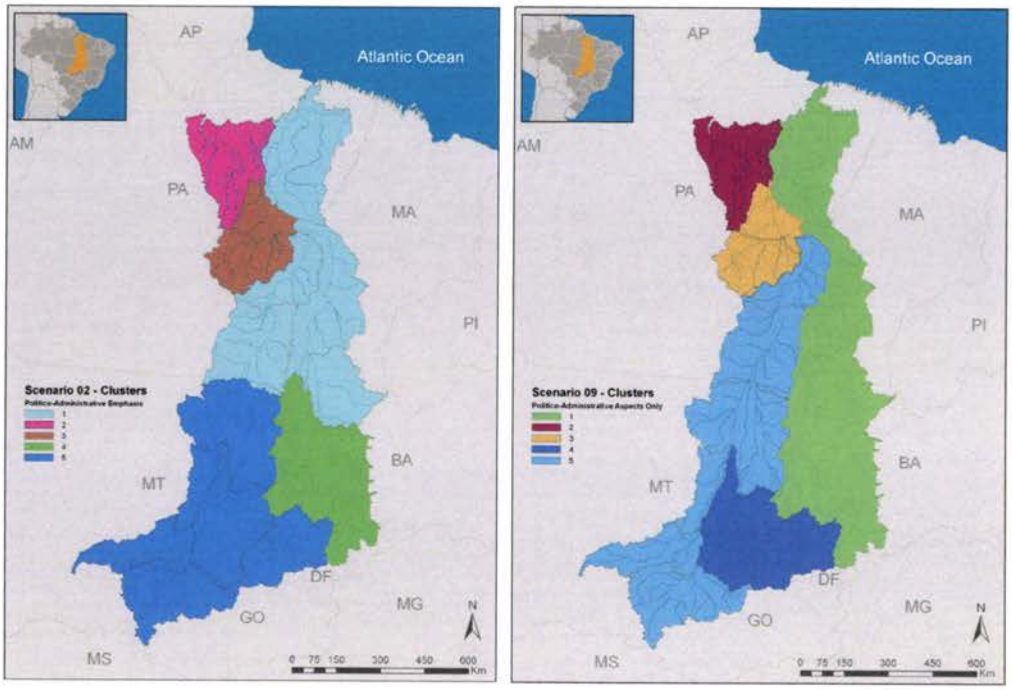


Figure 5.47. Illustration of the Results of Scenarios 02 and 09: comparison between different weights

In order to address the large variance in the number of elements among clusters, one alternative provided by the DSS is to limit the number of elements per cluster. The next set of simulations limits the number of elements per cluster to four (Scenario 01d) and to five (Scenario 01e). As described before, the users can easily pre-define a maximum number of elements per cluster. This is directly related to the size of the clusters to be defined and distance limits, according to the heuristic knowledge rules detailed in Chapter 4. As observed in Figure 5.48, more homogeneous sets of clusters, in terms of size, are created by limiting the number of elements in each cluster and by breaking bigger clusters into smaller ones. In addition, the difference in the return benefit, as presented in Table 5.7, is relatively small: from 0.347 to 0.344, when limiting to five and from 0.347 to 0.337, when limiting to four. Therefore, this is an important feature of the model, allowing the users to test different clustering alternatives, according to their own preferences.

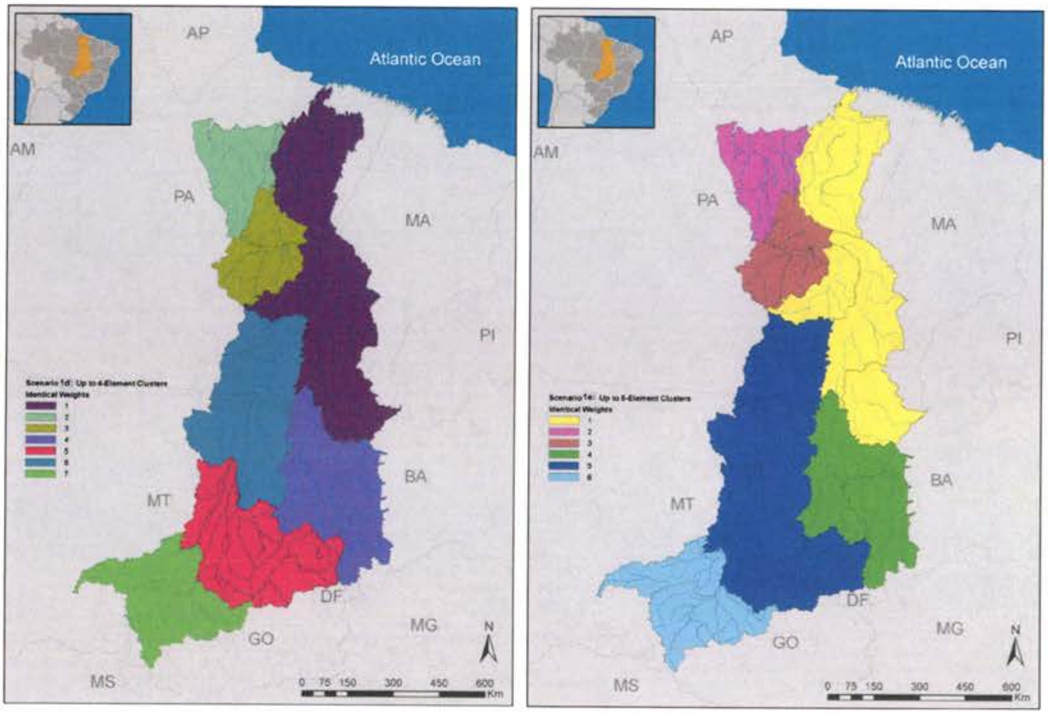


Figure 5.48. Illustration of the Results of Scenarios 01d and 01e: limiting the number of elements per cluster

Table 5.7. Results of Scenarios 01d and 01e: Limiting the number of Elements per Cluster

Scenarios 01d and 01e—Summary of Results				
Category of Aspects	*Assigned Weights*	*Number of Clusters*	*Return Benefit*	*Number of Elements per Cluster*
Political-administrative	1	7 (SC01d)	0.337	4, 2, 2, 2, 3, 2, 2
Physical-environmental	1	*Number of Clusters*	*Return Benefit*	*Number of Elements per Cluster*
Hydrographic	1			
Socioeconomic	1	6 (SC01e)	0.344	4, 2, 2, 2, 5, 2

The same simulation, limiting the number of elements per cluster up to four, is also demonstrated in Scenarios 06b to 09b, considering each category of criteria individually. Again, as observed in Figure 5.49, only Scenarios 07b and 09b, which represent socioeconomic and political-administrative aspects respectively, have different clustering alternatives than Scenario 01d, which weigh all aspects equal to one and limit the number of elements per cluster up to four. The results reinforce the fact that, in general, the aspects have similar contribution to the final solution. In this simulation, the clustering alternatives are, in general, more homogeneous in terms of size than previous ones. The return benefits vary from 0.362 to 0.355 for Scenario 06b, considering physical-environmental aspects only; from 0.343 to 0.340 for Scenario 08b, considering hydrographic aspects only; and from 0.433 to 0.427 for Scenario 09b, considering political-administrative aspects only. Scenario 07 is identical to Scenario 07b because clusters with up to four elements were defined.

Finally, the comparison between the hierarchical agglomerative and partitioning clustering methods is demonstrated in Figure 5.50. Three simulations were performed using three different threshold values for the hierarchical agglomerative clustering method as described in Chapter 4, and considering identical weights for all the aspects. Scenario 10, with 39% threshold value, results in five clusters; Scenario 11, with 40% threshold value, results in six clusters; and Scenario 12, with 42% threshold value, presents seven clusters. The hierarchical method results in less homogeneous clusters in terms of size and form, in comparison to the partitioning method, illustrated in Scenario 01. The method results, also, in extreme variance of the number of elements among groups, from one to eight. As expected, the results of the partitioning method are better.

No specific analysis, in terms of evaluating each delineated region independently, was performed. Actual users of the DSS will have the capability of performing this analysis, identifying the most important characteristics that bring those regions together. In addition, WARPLAM can be used to derive the underlying logic behind already established regions. For instance, the seventeen planning units existing at Tocantins-Araguaia River Basin might be evaluated in order to understand which aspects were emphasized in the delineation process. Even though there might be a non-unique set of weights, that is, non-dominant solutions, to derive those regions, it is possible to perform a sensitivity analysis to understand the influence of different aspects and to understand possible trade-offs.

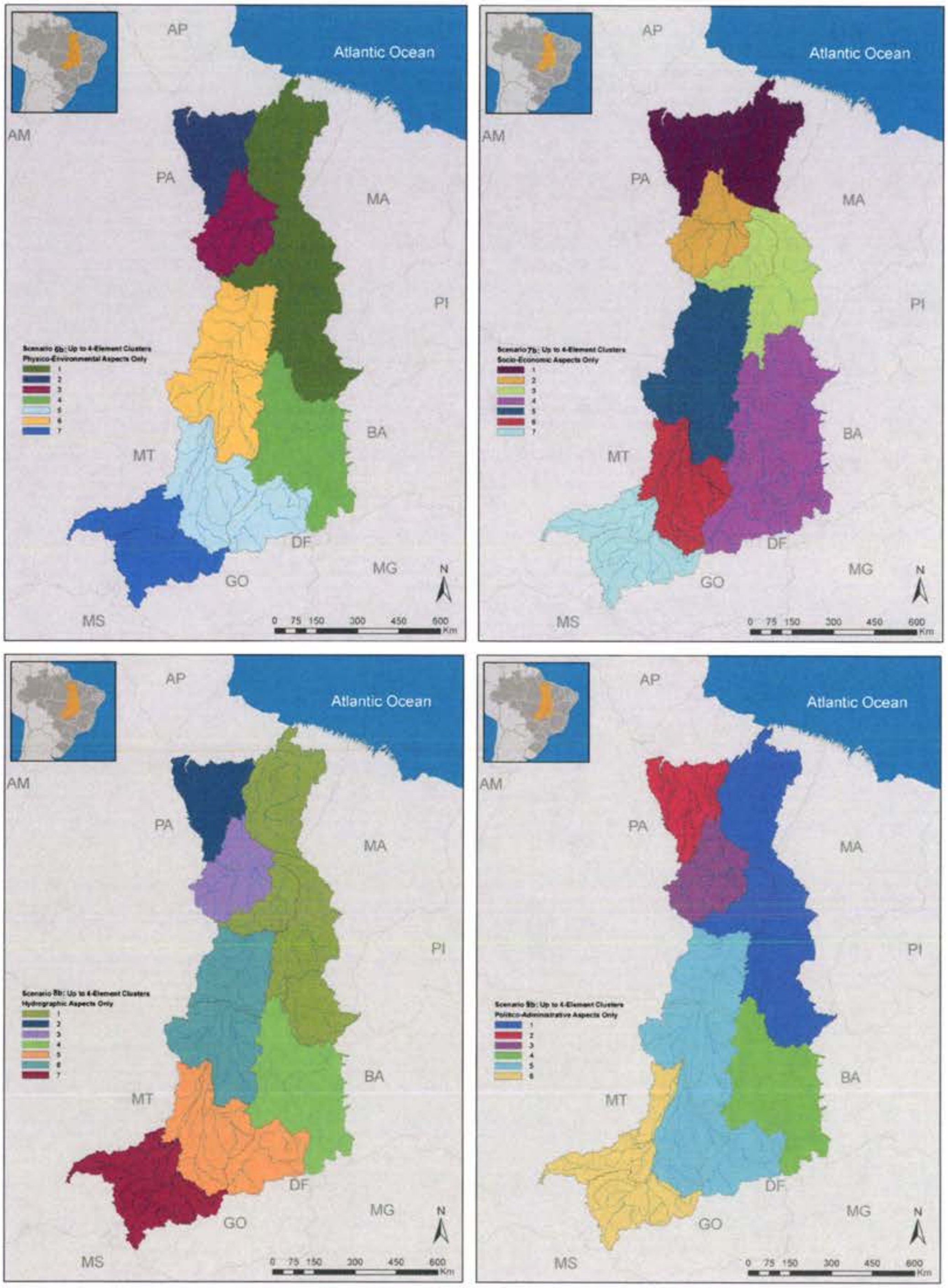


Figure 5.49. Illustration of the Results of Scenarios 06b to 09b: comparison between different aspects

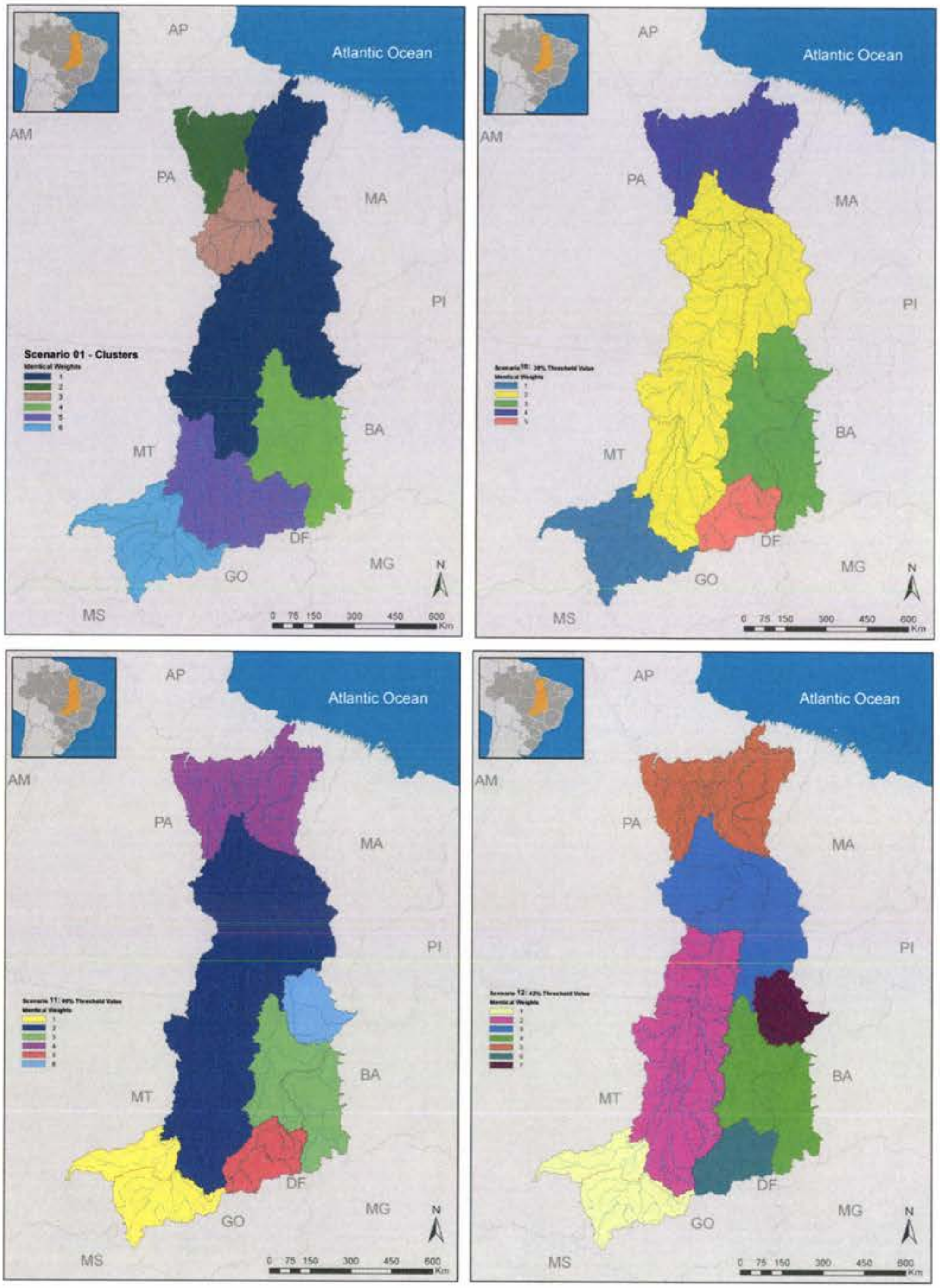


Figure 5.50. Illustration of Scenarios 01, 10, 11, 12: comparison between partitioning and hierarchical methods

6. CONCLUSIONS AND RECOMMENDATIONS

The process of delineating integrated water resources planning and management regions—the main subject of this study—is ill structured. As discussed throughout, it is imperative to define appropriate territorial units, considering the capacity, articulation and needs of the existing institutional structure. The establishment of water resources institutions encompasses political judgment about the scale on which one can manage water resources. This is a fundamental step to promote IWRM practices and coherent action, as advocated by the EU WFD, in its first goal: to delineate RBDs.

WARPLAM DSS has been introduced in this study as a solution to address this problem. In addition, considering that poor governance is one of the main obstacles to sustainable development, the proposed DSS offers some guidance for future related systematic decision-making processes, and improved water governance. According to Correia (2007), investments in governance are increasingly recognized as an important way to address water management issues.

The present study has also reinforced the importance of IWRM principles and has demonstrated that the proposed DSS can support multiple interests and multiple users; facilitate capacity building and access to knowledge from prior experiences; allow human judgment and preferences; and provide flexibility in adapting to regional circumstances and multiple levels of subsidiarity. Many authors (Mostert et al., 2008; Costa, 2003; Barraqué, 2000a; Barraqué, 2003) suggest that multiple levels of integration or multi-level governance, with adequate connections between them, should be established. For example, in a country as expansive as Brazil, the central government does not have the capacity to deal in detail with local issues directly. If multiple levels of integration are promoted, appropriate intermediate structures can be determined. According to Braga (2009), the implementation of the Brazilian Water Resources Management System still requires a solution to the issue of harmonizing river basin limits with the dual jurisdiction of Brazilian rivers. In this context, the present approach can support the selection of an appropriate level of subsidiarity, sensitive and responsive to local conditions, and, at the same time, strengthen the connection amongst various levels of governance.

Another important characteristic of the proposed approach, as demonstrated, is the recognition of more comprehensive aspects, beyond river basin limits, such as political-administrative, socioeconomic and environmental aspects. Considering that other policy sectors, such as energy, navigation, and spatial planning, are extremely dependent on the water sector, their boundaries should be combined with the water resources boundaries in order to optimize planning and management actions, avoid overlapping structures and the proliferation of institutional arrangements, as well as competing and conflicting planning strategies and tactics.

In summary, this study reviewed the state of the art in international thinking about establishing water management regions and developed a DSS to help decision makers analyze a vast array of options to delineate water resources regions, with varying sets of priorities, in a reasonable amount of time. The vast number of possibilities for creating such regions could not be evaluated without the use of a systematic approach, as illustrated.

Phase 1 of this study presented the identification of aspects, beyond river basin limits, that were considered in defining water resources regions adopted in the selected countries. The relatively large number of examples assessed in this analysis attempted to ensure that a wide variety of criteria and the set of recognized aspects are relevant for application in this and other future studies. Despite the fact that some collected data may be subject to different interpretation, the results can be considered valid because of the multiple sources and variety of examples selected in this study. Future studies might consider a deeper geographical analysis to potentially aggregate additional aspects. In addition, further reflections about good water governance may also bring new inputs and suggestions in the field of territorial and non-territorial regions.

Phase 2, in particular, emphasized a coherent DSS approach in order to address the necessity of defining water resources regions and multiple levels of water governance. As demonstrated, such an approach and direction involves the utilization of human intuition, experience and judgment, such as what occurs in the subjective criteria selection and weighting processes. Through a user-end focus, it also provides easy access to information; interaction, which is supported by visualization of criteria; flexibility, since it is open to aggregate other criteria in order to consider new aspects; and participation, by allowing multiple users to balance their interests and serving as an arena of focused disagreements. In addition, it constitutes a learning process because decision makers can better understand the many and varied aspects related to water resources regions delineation, using the KBS. The building and operating of the DSS into an integrated system between ArcGIS and Excel is presented as an efficient solution to address all users' needs. Thus, the proposed DSS can be used by users around the world who have ArcGIS and Excel software available. Further information about how to access WARPLAM DSS is available by contacting the author.

DP has proven to increase the efficiency of the algorithm, especially when compared to the exhaustive enumeration method. According to the results of the simulations tested, for a data set containing five elements, there are 24 intra-cluster and 48 inter-cluster measures of homogeneity that can be found in exhaustive enumeration. DP one-dimensional algorithm analyzes only 16 inter-cluster measures of homogeneity. For the given 9-element dataset presented in this study, 90 intra-cluster and more than 1,300 inter-cluster measures of homogeneity can be found in exhaustive enumeration. DP one-dimensional algorithm analyzes approximately 240 inter-cluster measures of homogeneity. The optimization of the number of groups can be incorporated into the analysis, according to users' preferences. However, it is important to highlight that the objective of the DSS is not to guarantee the optimum number of groups. Instead, the benefit of the tool is to allow different simulations of grouping alternatives, which are most important to the decision makers in order to develop a solution.

The key to the cluster analysis method is to define *real groups* instead of *imposed groups* (Aldenderfer and Blashfield, 1984). In this case, the combination of cluster analysis with optimization techniques and the adopted 'closeness measure' guarantees 'ideal' solutions based upon inputs of the users. The combination of GIS with cluster analysis is advantageous because the GIS structure easily provides the valid pairs of alternatives and the adjacency property, which is useful to facilitate the definition and solution of the cluster algorithm and increase its efficiency. The use of GIS has proven to be fundamental in the five steps of the decision analysis process, in order to support the users interaction with the process. The partitioning clustering method has improved results compared to the hierarchical agglomerative clustering method. The genetic algorithm was assessed and considered less efficient than the DP approach. In addition, the algorithm incorporates fuzzy analysis concepts in order to represent the uncertainty associated with this process. Considering this is a subjective process, based upon qualitative input, it is valid to illustrate the strength of the clusters and the risks associated with the quantitative analysis. Another advantage of the cluster partitioning method is that it allows the representation of the results based upon fuzzy logic. The combination of all presented techniques is the innovation proposed in this work.

Future studies might consider additional optimization approaches, including a more detailed analysis of the genetic algorithm. The inter-cluster measure of homogeneity may also be adjusted to incorporate the variety in the number of elements per cluster, in order to avoid one element being preferably clustered to a bigger cluster instead of a smaller one. Considering the variance of the measure of closeness, instead of the mean, to calculate the inter-cluster and/or intra-cluster measure of homogeneity may improve the clustering results and deal better with ordinal data. In addition, it is possible to include one step in these calculations to ensure each element is grouped with the closest hard cluster in which it has the largest fuzzy membership values.

Phase 3 of this study presented the potentials and the results of the proposed approach. As demonstrated, the DSS can easily incorporate a set of criteria and respective weights, and perform multiple simulations in order to support the decision analysis process by multiple users. In the Tocantins-Araguaia case study, several criteria were used in order to present the full potential of the model. In real-world simulations, it is recommended that fewer aspects be prioritized, according to users' preferences. Another alternative is to try each aspect independently, as a sensitivity analysis, in order to test its importance among the general results.

This analysis may also be utilized to support the selection of the scope of negotiations and related stakeholders to be invited to participate in the decision.

In addition, the sequence of simulations are presented in order to enhance the decision analysis process. Instead of confusing, it intends to provide a strong basis for the decision making, giving necessary information to the user. Also, the simulations demonstrated that different regions can be defined as unique solutions, considering each case's particularities, instead of generalized solutions. For that reason, the calibration of the final results is potentially subject to users' preferences and judgments. Despite being subjective, the results are considered transparent and visible to the users as opposed to a typical black-box-like simulation. Finally, the results obtained through the simulation may be true, as real water resources regions, if preferences and weights are set up accordingly and further implementation steps are performed. Among existing implementation steps, Costa (2003) suggests that after mapping the water resources regions, a group dynamics should be performed for evaluating and legitimizing the proposed regions, according to main conflicting areas.

Future studies might incorporate conflict resolution approaches in WARPLAM DSS. The use of weights supports the generation of a range of solutions so that it is possible to look for potential areas of agreement or disagreement among users. However, the process of setting various weights may result in increasing conflicts between multiple interest groups. Therefore, it is important to enable different decision makers to use the DSS to reach some kind of consensus or to clarify the disagreements. The capability of storing and comparing different scenarios, with different sets of criteria and weights, is easily included, considering users already have the capability of exploring various criteria and weights to look for a common pattern or a common set of regions that address their needs. In addition, using GIS functionalities, it is possible to identify areas of agreement or disagreement for future refinement.

Furthermore, it is important to emphasize that the process of delineating water resources regions should be dynamic. Considering that climate changes may impose new challenges for water resources planning and management, combined with the inherent complexity and uncertainty of this problem, an adaptive process must be established. Despite the fact that the establishment of water resources regions may begin by considering physical boundaries, the process quickly becomes political, and thus, subject to changes and modifications in terms of spatial and non-spatial dimensions. Recognizing the cross-boundary aspects that bring regions together represent the increasing need to more holistic and interdisciplinary approaches. According to Mostert (2006), it is possible to affirm that IWRM is political and context-specific, as well as subject to political priorities when considering all aspects and all functions related to water. Therefore, it is suggested that *flexible* water resources regions should be established, according to relevant functional relationships.

The 2nd UN World Water Development Report: *Water, a shared responsibility* pointed out the need for an integrated and holistic approach to water resources management, highlighting the benefits from IWRM: 1) multiple uses and cooperation between different sectors; 2) coordinated management and development of land, water and other resources; and 3) balanced social, environmental and economic benefits (UNESCO, 2006). Therefore, to integrate existing political divisions within river basin units is one of the biggest challenges. Still, according to this report, the difficulties of IWRM are directly related to the fact that political boundaries are not always coincident with natural river basins.

As demonstrated throughout the study, among other possible existing alternatives, WARPLAM DSS provides a multi-faceted and comprehensive solution to the extremely complex issue of delineating water resources regions. Future related decisions will have increased quality using the proposed approach. The innovative aspects presented herein establish a method whereby a more objective solution and improved evaluations can be generated in a relatively short amount of time, unlike the manner in which these decisions were previously made. In addition, the proposed methodology can be extended to other areas, such as the variable geometry concept, utilized in the field of geographical analyses. Finally, using the proposed DSS, one can get closer to delineating true integrated water resources planning and management regions that promote effective planning and management, lessen political boundary effects, encourage cross-boundary cooperation and interdisciplinarity, and represent multiple users' interests.

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APPENDIX 1: SURVEY

1. Introduction

You were selected as an expert decision maker on water resources planning and/or management. Your particular experience is extremely relevant for this study and I invite you to share your knowledge through this survey.

The survey focuses on regions for planning and/or management of water resources. Its objective is to identify the important aspects considered in establishing regions for water resources planning and/or management at regional, national and international levels. The purpose of this survey is to understand how river basin limits and other socio-economic, political and environmental aspects are considered when delineating regions for planning and management of water resources and how, in practice, these regions promote Integrated Water Resources Management (IWRM).

This survey is part of my Ph.D. dissertation that focuses on the formulation of a decision support system (DSS) to support the process of delineating regions for comprehensive water resources planning and management. The knowledge acquired from this survey is going to become part of an Expert System as part of the DSS, in order to increase the quality of future decisions related to this issue.

For example in some countries, the regions for water resources planning and management are not integrated. One of the reasons for that is because different governmental institutions are responsible for different competences related to water resources planning and management. Also, in some cases, these regions may reflect the historical interests of dominant sectors instead of multiple interests. In such cases, disagreements may arise and IWRM is more difficult to achieve. A harmonized division into regions may promote IWRM and prevent conflicts.

According to the proposed approach, please answer the following questions, considering the information available to you. Your experience in dealing with this issue, according to your country particularities, is really important. Therefore, try to provide as much detail as possible, since this will be really important for my study conclusions.

After that, I will be traveling to selected countries in order to meet with a random sample of experts for more elaborate arguments and to acquire additional relevant information.

Finally, if you are interested, I will be more than happy to send you the results from this analysis and an invitation to participate at the formal discussion and presentation of the results.

Your help is extremely valuable. I really appreciate your effort. Thank you!

Ana Carolina Coelho
Ph.D. Candidate
Colorado State University
Civil and Environmental Engineering Department
Water Resources Planning and Management Program

Water Resources Specialist
National Water Agency of Brazil (ANA)

PS: If you have questions or want to send me additional material, i.e. reports, maps, etc., do not hesitate to contact me at: coelho@engr.colostate.edu or at anacarolina@ana.gov.br.

2. Institutional Aspects

1. Is your institution engaged in planning and/or management of water resources?
Yes

No
2. What sector do you work in? Please select all that apply
Government and Policy
Regulation
Water supply and or Wastewater
Energy
Irrigation
Navigation
Other

3. How would you classify your institution's emphasis in dealing with water resources planning and/or management?
Planning
Management
Both
Other
4. Please briefly describe its competences, especially if other is selected.

3. Existence of Regions
1. Are there established regions for water resources planning and/or management?
Yes, there is a clearly defined map of regions for water resources planning and/or management. (go to 4)
Some resemblance of regions for planning and/or management. (go to 4)
No particular regions are defined. (go to 33)

4. Purposes of the Regions
1. Please select one of the following alternatives about the division of regions for water resources planning and/or management in your country:
a) There is only one division for both planning and management purposes. (go to 5)
b) There are different divisions for planning and for management purposes. (go to 9)
c) There is one division for planning purposes mainly. (go to 17)
d) There is one division for management purposes mainly. (go to 21)
e) There are regions defined for different purposes. (go to 25)

5. Levels of Regions for Planning AND Management purposes
1. Are there more than one level of regions for planning and management purposes? For example, are there multiple divisions into local, regional, national and international levels?
Yes
No

6. Top Level of Regions for Planning AND Management Purposes
1. For the top level of the division, how many regions are established?
2. Please, list these regions and briefly describe their main general characteristics?
3. What are the main emphases of these regions?
(please select all that apply)
Data Management
Water Permits Sharing
Water Use Charges
Water Quality Control
Water Use Control and/or Regulation
Water Resources Monitoring
Other (please specify)
4. If other(s), please specify:
5. Which aspects were considered when delineating these regions?
(please select all that apply)
River Basin Limits
Political Divisions
Administrative Regions
Metropolitan Regions
Cultural Aspects
Historical Aspects
Water Transfer Projects
Reservoirs, Dams, Channels, etc.
Environmental Protection Areas
Socio-Economic Areas

Census Divisions Other (please specify)

6. If other(s), please specify:

7. Please describe, as best as you can, how these aspects were important when delineating the regions in terms of promoting IWRM?

8. Are there any commissions established for these regions (e.g. River Basin Committees, Water Resources Councils, etc.)? If yes, please list them and briefly describe their general competences and composition?

(These intermediate questions are similar to the previous ones, just varies according to some particularities)

26. Integrated Water Resources Management (only if 4a or 4e is selected)

1. Do you believe one comprehensive division for planning and management purposes is important to promote Integrated Water Resources Management? How is it possible to be accomplished in real practice?

27. Integrated Water Resources Management and Different Regions for Planning and Management Purposes (only if 4b is selected)

1. Are water resources planning and management practices integrated and harmonized, considering there are different regions for that? Do you believe one comprehensive division for planning and management purposes is important to promote Integrated Water Resources Management? How is it possible to be accomplished in real practice?

28. Integrated Water Resources Management and Regions for Planning Purposes Only (only if 4c is selected)

1. How are management activities organized at regional and/or local levels if there is not a particular delineation of regions for that? Do you believe one comprehensive division for planning and management purposes is important to promote Integrated Water Resources Management? How is it possible to be accomplished in real practice?

29. Integrated Water Resources Management and Regions for Management Purposes Only (only if 4d is selected)

1. How are planning activities organized at regional and/or local levels if there is not a particular delineation of regions for that? Do you believe one comprehensive division for planning and management purposes is important to promote Integrated Water Resources Management? How is it possible to be accomplished in real practice?

30. River Basin Commissions

1. If the regions are established at river basin levels, do you consider there are effective planning and/or management at the river basin level? Why?

2. Is this process participatory? How?

31. Form and System of Government

1. Do you think the form/system of the Central Government interferes with the delineation of water resources planning and/or management regions? How?

2. It your Country a Federative Country?

Yes

No

32. Federative Units and Regions for Water Resources Planning and/or Management...

1. How do the Federative Units coexist with the Regions for Planning and/or Management of Water Resources? Is there any kind of cooperation or agreement in order to integrate water resources planning

and/or management activities between the Central Government and the Federative Units' Governments? What else can be done to improve IWRM in Federative Countries?

33. International River Basins

1. Are there International River Basin Commissions? If yes, please list them and briefly describe their general competences and composition?

34. Conclusion and General Comments

1. Please, insert any additional comments or suggestions, if desired.

2. Please insert your name, institution and contact information.
(for confirmation purposes only)

3. Would you like to indicate someone else that may be interested in this survey? Please include name, institution and contact information.

APPENDIX 2: LIST OF SPECIALISTS THAT PARTICIPATED AT THE ONLINE SURVEY AND/OR PERSONAL INTERVIEWS

Country	First name	Last name	Institution
Belgium	Jorge	Rodriguez Romero	European Commission, Directorate General of Environment
	Philippe	Quevauviller	European Commission, Research Directorate-General
	Panagiotis	Balabanis	European Commission, Research Directorate-General
United Kingdom	John	Aldrick	Environment Agency UK
	Tony	Allan	King's College London - School of Oriental and African Studies
	Alan	JENKINS	Center for Ecology & Hydrology CEH Wallingford
	Helen	Chapman	Thames Water
France	Alain	Bernard	Office International de l'Eau (OIEAU)
	Bernard	Barraqué	AgroParisTech École Nationale du Génie Rural, des Eaux et des Forets
	Léna	Salamé	UNESCO
	Marc	Collet	Agence de l'eau SEINE NORMANDIE
	Vincent	Frey	Ministère de l'Agriculture et de la Pêche/Secrétariat Général
Germany	Andreas	Kraemer	Ecologic Institute
	Cornelius	Laaser	Ecologic Institute
	Jens	Götzinger	LAWA Bund/Länder-Arbeitsgemeinschaft Wasser
	Fritz	Holzwarth	Federal Ministy for the Environment, Nature Conservation and Nuclear Safety
	Heide	Jekel	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit
	Volker	Mohaupt	Federal Environmental Agency Umweltbundesamt
Netherlands	Erik	Mostert	Centre TU Delft
	Herman	Havekes	Association of Dutch Water Authorities
	Jeroen	Aerts	Institute for Environmental Studies at VU University Amsterdam
Portugal	Adérito	Mendes	Instituto da Agua de Portugal INAG Comissão para a Aplicação e Desenvolvimento do Convênio de Albufeira (CADC)
	António	Brito	Administração da Região Hidrográfica do Norte
	Antonio	Eira Leitao	Conselho Nacional da Água
	Francisco	Nunes Correia	Ministerio do Ambiente, do Ordenamento do Território e do Desenvol. Regional

Country	First name	Last name	Institution
Portugal	Simone	Pio	Administração da Região Hidrográfica do Tejo
	João	Rocha	Laboratório Nacional de Engenharia Civil LNEC
	Graça	Saraiva	Ministerio do Ambiente, do Ordenamento do Território e do Desenvol. Regional
	Andre	Matoso	Administração da Região Hidrográfica do Alentejo
	Rodrigo	Maia	Universidade do Porto
Spain	Antonio	Embid Irujo	Universidade de Zaragoza
	Fernando	Octávio de Toledo	Ministerio de Medio Ambiente y Medio Rural y Marino Comision para la Aplicacion y Desarrollo del Convenio de Albufeira (CADC)
	José Ángel	Rodríguez Cabellos	Conferación Hidrográfica del Guadiana
	Tatiana	Ortega	Conferación Hidrográfica del Júcar
	Elena	Lopez-Gunn	Water Observatory, Fundacion M. Botin, Complutense University
	Lucia	De Stefano	WWF/Adena
	Leandro	Del Moral	Fundación Nueva Cultura del Agua
	Joaquin	Andreu	Universidad Politecnica de Valencia
Greece	Elpida	Kolokytha	Aristotle University of Thessaloniki
	Maria	A. Mimikou	National Technical University of Athens
United States	Eugene	Stakhiv	Corp of Engineers IWR / ICIWaRM
	Leo	Eisel	Brown and Caldwell
Brazil	João G.	Lotufo	Agência Nacional de Águas
	Wilde	Cardoso Gontijo	Agência Nacional de Águas
	Joaquin	Gondim	Agência Nacional de Águas
	Francisco	Lobato Costa	Agência Nacional de Águas - Consultant
	Benedito	Braga	Agência Nacional de Águas
	Ricardo	Toledo Silva	Secretaria de Saneamento e Energia do Estado de São Paulo
Mexico	Jaime Ivan	Ordoñez	Universidad Nacional de Colombia
	German	Poveda Jaramillo	Universidad Nacional de Colombia
	Mario	López Pérez	Comisión Nacional del Agua
	Ricardo	Martínez Lagunes	Comisión Nacional del Agua
	Ivan	Rivas Acosta	Mexican Institute of Water Technology Hydrology and River Mechanics

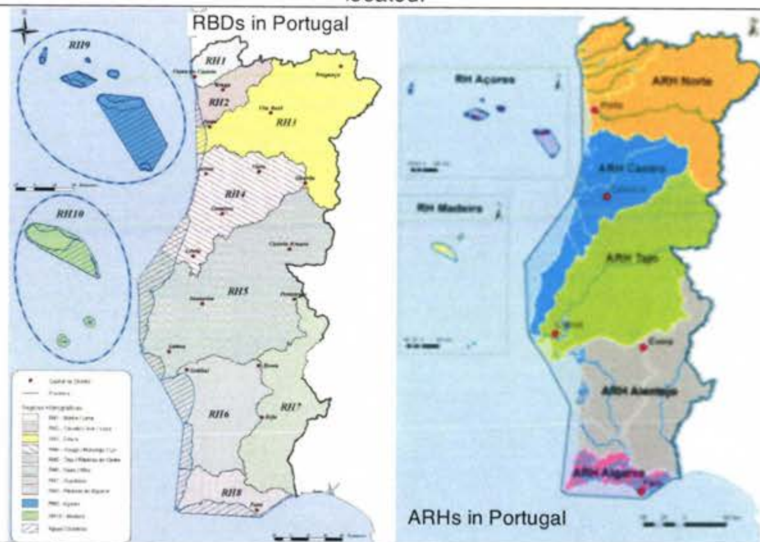
APPENDIX 3: GENERAL OVERVIEW OF THE RESULTS OF THE COMPARISON ANALYSIS IN 11 COUNTRIES

Analysis of Water Resources Planning and Management Regions in Portugal

	**PORTUGAL**
Form / System of Government	Unitary Republic Parliamentary
Water Resources Regions	Ten River Basin Districts (RBDs), Under WFD (eight continental including groundwater and adjacent costal waters and two regional archipelagos including groundwater and costal waters in all islands)—RH1: Minho and Lima; RH2: Cávado, Ave, Leça and Ribeiras da Costa; RH3: Douro; RH4: Vouga, Mondego, Lis and Ribeiras do Oeste; RH5: Tejo; RH6: Sado and Mira; RH7: Guadiana; RH8: Ribeiras do Algarve; RH9: Açores; RH10: Madeira
Purposes	Mainly planning according to the WFD strategy.
Criteria considered when delineating water resources regions	Mainly Hydrographic Political: consideration of transboundary river basins (international x national). The corresponding international RBDs are in accordance with the Spanish ones. Historical: Portugal has a long tradition in water resources planning and management. Prior planning processes: Fifteen river basin plans were defined by law in 1994 and approved in 2000 and 2001. The bidding process was organized in order to group some smaller river basins. In cases where the river basin was national, the plan was elaborated by the respective regional entity; if international, the plan was elaborated by the INAG. Size: combination of smaller river basins, according to WFD strategy.
Other Established Regions	Five Hydrographic Region Administrations—ARH (continental): ARH-Norte (embracing RH1, RH2 and RH3), ARH-Centro (RH4), ARH-Tejo (RH 5), ARH-Alentejo (embracing RH6 and RH7), ARH-Algarve (RH8). The two Portuguese autonomous regions—archipelago of Azores and Madeira—do not follow this model because they are under the jurisdiction of regional governments, and their territory is composed of relatively small islands. They were established in 2008 as the water resources competencies were separated from the Regional Development Coordination Commissions—CCDRs structure—in order to empower the regional water resources management process at the river basin level.
Purposes	Management and Planning The ARHs are responsible for water quality, data management, licensing, supervision, water use charges (including economic analysis), monitoring, planning (execution of river basin plans and specific plans for water management), river basin organizations and applying the program of measures established at the planning process (implementation). They are also responsible for coastal water and groundwater management. In cases where there is a common aquifer, the responsibility is shared among the ARHs. The dominant responsible party is the ARH where the aquifer is under pressure and affects considerably the superficial water resources. In addition, the ARH has the important task of harmonizing and coordinating the general environmental information exchange between the CCDR under their respective territories. For example, the ARH-Tejo has three different CCDRs in its territory, representing the most significant case that justifies the importance of the ARH.
Criteria	Mainly Hydrographic, including the RBDs delimitation established for the WFD. Political Jurisdictions: transboundary basins and municipal councils that are significant. Historical: Algarve, for example, is historically well delineated. Prior Plans: the 2002 National Water Plan has important references on regional organization.

	**PORTUGAL**
Criteria (cont.)	Administrative/Institutional: consideration of prior institutional structures. In 1886, there were four hydraulic divisions: North until Douro, Douro to Lis, Lis to Tejo, and Tejo until South. In 1892 there were only two subdivisions: North until Lis, Lis until South. Then, from 1949 until 1992, there were five Hydraulic Services Regional Directions: Douro, Mondego, Tejo, Sul e Algarve. Later, five CCDRs—Norte, Centro, Lisboa, Alentejo, Algarve—become responsible for the environment and spatial planning, including water resources. The CCDRs, however, do not have the river basin concept, and the water resources were not the focus of their competencies. Therefore, the ARHs resumed the specific water focus, largely based upon the river basin concept and adopting divisions that are similar to the 1949—1992 ones, representing historical aspects. Financial Efficacy: Avoid excessive institutional structures that may result in additional costs. Hydraulic Connectivity: some river basins depend on each other for water resources planning and management. For example, the Alqueva Reservoir connects Guadiana River Basin with Sado River Basin. Water Quantity and Quality aspects: recognizes the territory asymmetry in terms of spatial and temporal variability of water quantity and quality. Similar Kinds of Problems: Problems occur, for example, when two adjacent small river basins suffer from drought events. It is related to the concept of *problemshed.* Many times the problems are not distributed harmoniously within the population or natural regions. Social: similar human occupation process, for instance at the three RBDs of ARH-Norte. Geological/Geomorphological: similar characteristics, for instance Mira and Sado. Economical: similar conditions, for instance, Mira and Sado have traditional agriculture activity, rural areas not well developed, and suffer tourism pressures in the coastal area. Regional Planning Regions and the Territorial Units for Statistical Purposes—NUTs: the second level (NUTII) was considered when defining the ARHs. They represent similar socioeconomic profiles, corresponding to the CCDRs, and are used for macro planning purposes. Geographical Distances: According to the *2005 Water Law*, Tejo RBD does not include the Ribeiras do Oeste region, which is part of the Lis/Mondego/Vouga RBD. However, water resources planning and management of this region—Ribeiras do Oeste—is part of the ARH Tejo by delegation of the ARH Centro, which is responsible for the Lis/Mondego/Vouga RBD. Ribeiras do Oeste region is more centrally located within the Tejo RBD than the Lis/Mondego/Vouga RBD. It represents the Atlantic border of the Tejo River Basin and has much more adjacency to it than to Lis/Mondego/Vouga RBD. The population living in this area has a greater proximity to Lisboa, where the coordination of ARH Tejo is located. One justification for the fact that the Ribeiras do Oeste region is not included in Tejo RBD is that Tejo River Basin is international. A similar arrangement occurs at the Algarve Region, in which two important tributaries of the Guadiana RBD (RH7) are administered by the ARH-Algarve. The possibility of delegation is considered in the legislation in order to accommodate some singularities and allows flexibility. Communication Distances: reinforces the geographical distance criteria
Committees	RBD Councils are the consultative bodies of the ARH, comprised of public administrators, municipalities, users, and other technical, scientific and non-governmental authorities. They support the elaboration of river basin plans and discuss main water issues in each RBD included in their territories.

	**PORTUGAL**
Public Participation	Yes, through the RBD Councils and also during the river basin plans elaboration process (public participation happens six months before the final report of the plans). Local authorities (Municipal Councils and Municipal Assemblies) are also very vocal, politically influential, and considered to be very representative of the citizens. These institutions are active in all water related matters and participate in the RBD Councils.
Real Planning and/or Management at River Basin Level	Yes, despite the fact that Portugal has a strong tradition of centralized administration and decision-making processes. Despite the conviction that they will be effective, the existence of the ARHs is recent; therefore, more experience is necessary in order to evaluate the real planning and management efforts at the river basin level.
International River Basin Commissions	The Albufeira Agreement is the most recent bilateral agreement between Portugal and Spain, signed in 1998 and effective in 2000. It supports coordination at the four international river basins, including superficial and groundwater: Minho-Lima, Douro, Guadiana and Tejo. It establishes, also, a Commission for the Implementation and Development of the Agreement (CADC), under the dependence of the Foreign Affaires Ministry but with participation of INAG and ARH, which is responsible for coordinating the information change process, evaluating projects that may cause impacts for any side, helping to implement the WFD, overseeing the program of measures implementation process, and maintaining the minimum flows regime. Both countries have agreed on RBDs and corresponding competent authorities—ARHs in Portugal and *Confederaciones Hidrograficas* in Spain—to put the WFD into practice. The first planning process for the WFD is being performed separately in these international RBDs. Some decision makers believe that the second planning process should be performed jointly, having one single plan for each of the four RBDs, although this is controversial for political reasons. There is a debate between <u>*joint planning*</u> versus <u>*coordinated planning*</u>, with the later prevailing.
General Comments and Questions	It is important to emphasize that Portugal and Spain have a long tradition of international collaboration and signed agreements in water resources issues, dating back to 1864. The Water Institute (INAG) is the national water authority, responsible for water resources planning and management at the national level, coordinating and harmonizing procedures, guaranteeing the effective implementation of the water law, ensuring the execution of the national policies, and dealing with international questions as the EC interlocutor. The National Water Council is the consultative body of the government for water resources issues that promotes the integration of sectors' interests through it representatives. There is a significant effort to integrate spatial planning into water resources planning and management in Portugal, as this is considered essential to the implementation of effective policies. The *2005 Water Law* is the most updated legislation dealing with water resources in Portugal and represents the transposition of WFD principles to Portuguese legislation. It establishes an important institutional reform, ensuring the integration of management and planning is performed throughout the different levels, from the regional to the national level. This law has also grouped the 15 existing river basins into eight RBDs. The prior 15 river basin plans are being considered as the basis for the preparation of the new plans, in accordance with the WFD strategy.

	**PORTUGAL**
General Comments and Questions (cont.)	ARHs have financial independence because they are in charge of water use fees. However, these fees may be too low in some ARHs to promote solid independence. ARHs can create regional departments with a specific council to focus on more problematic subbasins; for example, the Aveeiro River and the Ria de Aveiro (lagoon). For that, they should develop a specific water management plan, as established in the *2005 Water Law*. ARHs need to work in agreement with CCDRs in order to promote the necessary integration with environmental and spatial planning components. Depending on a specific situation, one ARH can delegate all water resources management functions, in a specific region, to another ARH. This is the case of two tributaries of the Guadiana River Basin, located in the territory assigned to the Alentejo ARH, but belonging to the Algarve Region. This river basin has been historically administrated by the Algarve Regional Authorities. The Algarve region also utilizes the water resources of those tributaries of the Guadiana River Basin on a large scale, including some existing water transfer infrastructure and an interconnected drainage system. The problems are similar between those two tributaries and the other rivers in the Algarve, included in the Algarve ARH, including droughts and floods. There is also a greater proximity of the population to this ARH than is the case with the Alentejo. Ribeiras do Oeste is another example of delegation that brings some flexibility to a hydrographic criteria. It is a group of small rivers that are included in ARH-Centro in strict hydrographic terms, but it would be completely artificial to have water users dealing with the administration in Coimbra instead of Lisbon where ARH-Tejo is located.
Map of the Water Resources Regions	
References	Correia, 2000; EC, 2002; MAIA, 2003; CNA, 2005; INAG, 2005; Silva, 2005; Brito, 2007; INAG, 2007; MAOTDR, 2007a & 2007b; INAG, 2008; MAOTDR, 2008a, 2008b & 2008c; MFAP and MAOTDR, 2008; Rodrigues, 2008; ARH Alentejo, 2009a; ARH Alentejo, 2009b; ARH Norte, 2009; Brito, 2009; Correia, 2009; EC, 2009b; Eira Leitão, 2009; Maia, 2009; Matoso, 2009; MCOTA, 2002; Mendes, 2009; Pio, 2009; Rocha, 2009; Saraiva, 2009.

Analysis of Water Resources Planning and Management Regions in Spain

	**SPAIN**
Form / System of Government	Unitary, quasi-federal (17 Autonomous Communities/Regions, two Autonomous Cities) Monarchy Parliamentary
Water Resources Regions	Twenty-five RBDs under the WFD (15 in Spain-Continental, including coastal waters, eight islands, and two in African Continent): Nine intercomunitary districts: Gualdaquivir, Segura & Jucar (in Spain), Minho-Sil, Cantabrico, Duero, Tajo, Guadiana and Ebro (international districts); 14 intracomunitary districts: Galicia-Costa, Cuencas Internas del Pais Vasco, Cuencas Internas de Cataluna, Cuenca Mediterranea Andaluza, Guadalete-Barbate & Tinto-Odiel-Piedras (prior Cuenca Atlantica Andaluza), Islas Baleares and Canarias (seven districts); two districts in Africa: Ceuta and Melilla. The intercomunitary districts are basins containing rivers that cross regional boundaries and are managed by river authorities controlled by the Central State. The intracomunitary districts are basins contained within a single autonomous community. The formal designation of RBDs and respective authorities is still being reviewed in Spain. The division of powers between the Central State and the autonomous communities is not clearly defined in some regions. Some of the most recent Statutes, in respect to the division of powers and new regional competences of water resources, are under review by the Constitutional Court. There is a current prevailing tendency towards smaller regional water management units. In addition, some coastal areas were not assigned yet, according to WFD Art. 3 requirements, due in 2003. The 2007 Royal Decree does not fulfill those requirements, according to the Expediente de Infraccion (infringement case) being filed in the EC.
Purposes	Planning and Management Some districts have a strong tradition in integrated water resources planning and management. Others are taking the initial steps to implement integrated planning and management. Among the intercomunitary districts, the competences are the same, but they can be different at the autonomous regions. WFD requirements are more focused on planning. Their competencies include data management, reservoir operation (including flood risk management), water permits (licensing), water use charges, water quality control (pollution control), water use control / allocation (water quantity control), water resources monitoring, water resources plans, building and maintenance of hydraulic works, river basin organizations, land use planning and/or management, environmental protection, harmonization of regional and state projects (multiagencies coordination), and natural resources planning and/or management, in general. As a common rule, management of water must be subject to the planning, which must be approved for all hydrographic basins. There are, basically, two different models of water authority organization in Spain: *Confederaciones Hidrograficas* in intercomunitary districts, and *Agencias del Agua* of Autonomous Regions, in intracomunitary districts, as part of the regional descentralization process. Legal responsibilities of *Confederaciones Hidrograficas* and Agencies are similar. For instance, the Cataluna Water Agency is a different organizational model than *Confederaciones Hidrograficas* because it is not under the Central State, but legal responsibilities are similar because of the National Water Law requirements. The traditional structure and legal personality of these organizations is mostly for inland waters (rivers and aquifers). They need to be adjusted to WFD requirements.

	**SPAIN**
Criteria considered when delineating water resources regions	Hydrographic, Political (transboundary basins between Autonomous Communities and Countries) and Historical. Considering hydrographic aspects, according to WFD implementation strategy, these districts are comprised by one river basin or adjacent river basins and associated transitional waters, costal waters, and groundwater. Considering political aspects, some smaller river basins or subbasins are being dissociated from larger regions if they are completely located in only one autonomous region. The decentralization process is a recent tendency in Spain because the autonomous regions want to exercise their authority over water resources, independently from the Central State. Central and regional governments are still defining the WFD district borders. The inclusion of coastal water under the authority of RBD, as required by the WFD, puts additional pressure on this process because coastal waters were traditionally managed by the autonomous regions. In 1993 the authority over water at the Galicia-Costa region was transferred to the Galicia Autonomous Region. In 2006 a similar process occurred at Cuencas Internas del Pais Vasco. The prior *Confederacion Hidrografica* del Pirineo Oriental also became Cuencas Internas de Cataluna. In 2006, the Andaluza Autonomous Region required its authority over Atlantica Andaluza (previous part of *Confederacion Hidrografica del Guadiana* and *Confederacion* Hidrografica *del Guadalquivir*) and Mediterranea Andaluza Regions (previous *Confederacion Hidrografica del Sur*). In 2009, the same region required its authority over the whole *Confederacion Hidrografica del Gualdaquivir* because 98 percent of its territory is located inside its boundaries. Since January 2009, the Andaluza Autonomous Region, through the Andaluza Water Agency, has been responsible for the Andaluza part of Guadalquivir River Basin. The *Confederacion Hidrografica del Guadalquivir* is responsible for the part of the river basin located in the Castilla La Mancha, Murcia, and Extremadura Autonomous Regions. In 2008, the *Confederacion Hidrografica del Norte* was subdivided in two: Minho- Sil and Cantabrico, based upon the fact that these districts flow to different oceans. In 2009, the Atlantica Andaluza was subdivided into two RBDs: Guadalete-Barbate & Tinto-Odiel-Piedras. At *Confederacion Hidrografica del Jucar*, some intracomunitary subbasins which were combined with the Jucar region are also requiring their independence: Cenia-Maestrazgo, Marina Alta, Marina Baja and Vinalopó Alicantí. In these cases, Valencia Autonomous Community does not want to assume the responsibility for the small coastal river basins because it does not want to give full authority over the *Confederacion Hidrografica del Jucar* to Castilla La Mancha Autonomous Region. As a result, river basin planning processes are still ongoing at the Jucar River Basin. Also considering political aspects, in accordance with WFD requirements, regions were delineated based upon the transboundary river basins. For example, Minho-Sil region has two main river basins that are shared between Portugal and Spaln: Minho and Lima. They constitute one RBD mainly because of this condition and together with historical aspects that also have great influence.
Other Established Regions	There are subbasins established in each RBD. These subdivisions cover particular aspects of each individual district. For instance, at *Confederacion Hidrografica del Jucar*, there are nine subbasins (exploitation-systems): Cenia-Maestrazgo, Mijares-Plana Castellón, Palencia-Los Valles, Turia, Júcar, Serpis, Marina Alta, Marina Baja, Vinalopó Alicantí. In terms of historical aspects, the first attempt to organize water resources management in river basin units dates back to 1865. Spain pioneered the establishment of river basin authorities. *Confederacion Hidrografica del Ebro* was created in 1926 (*Real Decreto de 5 de marzo de 1926 de su Majestad el rey Alfonso XIII*). In the following years, Gualdaquivir, Segura, Jucar, Norte, Duero, Tajo, Guadiana, Catalana, Pireneo Oriental and Sur were created. Five of these

	**SPAIN**
Other Established Regions (cont.)	were implemented between 1926 and 1929; one was during the Second Republic (1934); and the remaining four were established between 1948 and 1961. *Confederaciones Hidrograficas* boost the concept of hydrographic basins as the territorial basis for water management. They had a strong influence over territorial development in Spain. Their antecedents are the *Confederaciones Sindicales Hidrograficas* or *Sindicatos Centrales*, responsible for managing water as determined by the *Water Act of 1879.* Different periods of Spanish history lead to different levels of authority of the *Confederaciones Hidrograficas.* They were reinforced by the *1985 Water Act* and by the RBD concept, as defined in the Royal Decree 125/2007. However, their current situation is challenged by the regionalization process discussions and also due to the fact that its original hydraulic paradigm is weakened. Currently, *Confederaciones Hidrograficas* constitute RBDs, as described in the previous topics.
Purposes	Planning and Management purposes of the subbasins. The historic *Confederaciones Hidrograficas* responsibilities varied in different regions of the country and in different periods of time. Its role in building and exploitation of hydraulic works until 1985 was very important. Since then, it has been a comprehensive part of river management. Since the 1950s, parallel institutions in each river basin, named *Comisarias de Aguas*, were responsible for quality control, licensing, and allocation. They were integrated in new *Confederaciones Hidrograficas* after the new law in 1985.
Criteria	Mainly Hydrographic for the subbasins. For the *Confederaciones Hidrograficas*: hydrographic aspects, political jurisdictions, administrative regions, size limits, geographic features, territorial organization, user participation and historical-social processes. The river basin has been considered as the suitable level for water resources management. The engineering community was initially responsible for defending the natural integrated water flow as a unit for water management. Today, users' associations, environmental organizations, and professionals, among others, support this concept. In addition, it was reinforced by an historical allocation process that was based upon the population that comprises each region. The 'Sindicatos Centrales' were originally created as a way to integrate all interests of the communities located in a river body, and later expanded to the whole valley. Therefore, each *Confederacion Hidrografica* was being created according to the priorities established at that time.
Committees	Each district has an administrative institution: *Confederacion Hidrografica* (Central Government, intercomunitary) or Water Agency (autonomous regions, usually intracomunitary). In each of these administrative institutions, there are five organizational levels: 1) Exploitation Councils (*juntas de explotacion*)—a group of licensed users that sets the water tariffs and discusses and coordinates infrastructure needs; 2) Water Management Boards (*Comisiones de desembalse*)—the users' assembly responsible for coordinating water resources allocation among the users; 3) A Water Council or River Basin Council—representing the general administration of the State, autonomous communities and local users, and ecologist associations and other organizations responsible for proposing and revising the river basin management plan; 4) A Competent Authorities Committee—including national and regional authorities responsible for the coordination of their water actions; 5) A Governing Council (*Junta de Gobierno*)—representing administrations and users who are responsible for approving the plans and for general management. This is the only body with decision and governmental authority, while others are consultative. There is also the National Water Council, which is the central consultative body.

	**SPAIN**
Public Participation	Yes. Mainly through the Water Councils, Exploitation Councils, Water Management Boards and Governing Councils in each *Confederacion Hidrografica* and/or Water Agency and also through the participatory processes required by the WFD. The planning phase of the WFD requires active public participation; it has been happening since 2009 and is ongoing in 2010. The *Confederaciones Hidrograficas* were created in order to emphasize local participation and regional approaches. However, they became technocratic institutions under the strong hydraulic paradigm that dominated water policies in Spain for more than six decades and delineated a national unitary territory for water management. The traditional approach (formal participation through councils and boards) is characterized by a technocratic model, with strong cooperation between the big water users and technical corps. Advocacy coalitions, policy changes, an increase in environmental concerns, and European Commission regulations are the main leading factors influencing changes in authority levels and acceptance of new actors. The new public participation approach promoted by the WFD is still deficient is some regions, due to some skepticism and weak civil society organizations, mainly.
Real Planning and/or Management at River Basin Level	Yes. Spain has competent water management and planning authorities at the river basin level and legally binding river basin management plans developed by the river basin authority in every district. Transitional and coastal waters were not among the managing responsibilities of the *Confederaciones Hidrograficas* or the agencies. They should be included in planning processes, as required by the WFD. The new planning process introduced by the WFD also requires the analysis of water quality aspects in addition to the traditional definition of available water resources and their division among the demands, as well as the integration with groundwater. The Competent Authorities Committee is working for the inclusion of coastal and transitional waters. *Confederacion Hidrografica del Ebro* is a good example of the successful implementation of water resources management at river basin levels. There are nine Autonomous regions that harmoniously share the water through efficient permitting and conservation systems.
International River Basin Commissions	The Albufeira Agreement is the most recent bilateral agreement between Portugal and Spain, signed in 1998 and effective in 2000. It supports the coordination at the four international river basins, including superficial and groundwater: Minho-Lima, Duero, Guadiana, and Tajo. It establishes, also, the Commission for the Implementation and Development of the Agreement (CADC) responsible for coordinating the information change process, evaluating projects that may cause impacts for any side, helping to implement the WFD, overseeing the program of measures implementation process, and maintaining the minimum flows regime. Both countries have agreed on RBDs and corresponding competent authorities—ARHs in Portugal and *Confederaciones Hidrograficas* in Spain—to put the WFD into practice. The first planning process for the WFD is being performed separately in these international RBDs. It is expected that the second planning process will be performed in an integrated manner, having one single plan for each of the four international RBDs. It is important to emphasize that Portugal and Spain have a long tradition of international collaboration and signed agreements in water resources issues, dating back to 1864.
General Comments and Questions	The Water Authority is the Ministry of Environment (Central State) when rivers flow through more than one autonomous region; otherwise, it is the respective autonomous region. adapt to these new demands and priorities.

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<tr><td></td><td>SPAIN</td></tr>
<tr><td>General Comments and Questions (cont.)</td><td>Legislation is now being improved to promote coordination between central and autonomous governments. As mentioned above, the power of the autonomous regions in the Confederaciones Hidrograficas is under review, in order to represent their interests, according to their territorial representation. Decentralization is a new and strong paradigm in Spain, promoted both by the WFD (top-down) and by the growing importance of territory and water, at a regional scale (bottom-up). The WFD requires special attention to the management and maintenance of hydraulic works. Considering that Confederaciones Hidrograficas used to be efficient in planning and executing these works, they might need to</td></tr>
<tr><td>Map of the Water Resources Regions</td><td>

RBDs in Spain</td></tr>
<tr><td>References</td><td>Loras, 2008; Barnes et al., 2003; EC, 2002; CEC, 2007; Rodriguez-Cabellos, 2009; Toledo, 2009; Lopez-Gunn, 2009a; Lopez-Gunn, 2009b; De Stefano, 2009; CIRCA, 2009; EC, 2009a; Margeli et al., 2008; Costeja et al., 2004; FNCA, 2007a; FNCA 2007b; Barreira, 2008; Irujo, 2002; Irujo, 2008; Irujo, 2009; Del Moral, 2008; Rozados, 2007; Real Decreto 266/2008; Real Decreto 2130/2004; Real Decreto 125/2007; Retortillo Baques, 1958; Hispagua, 2007; Andreu, 2009; Gomez, 2009; MARM, 2009; Agencia Andaluza del Agua, 2009; Ministry of the Environment, 2001; Agencia Catalana de l'Aigua, 2008; Del Moral, 2009.</td></tr>
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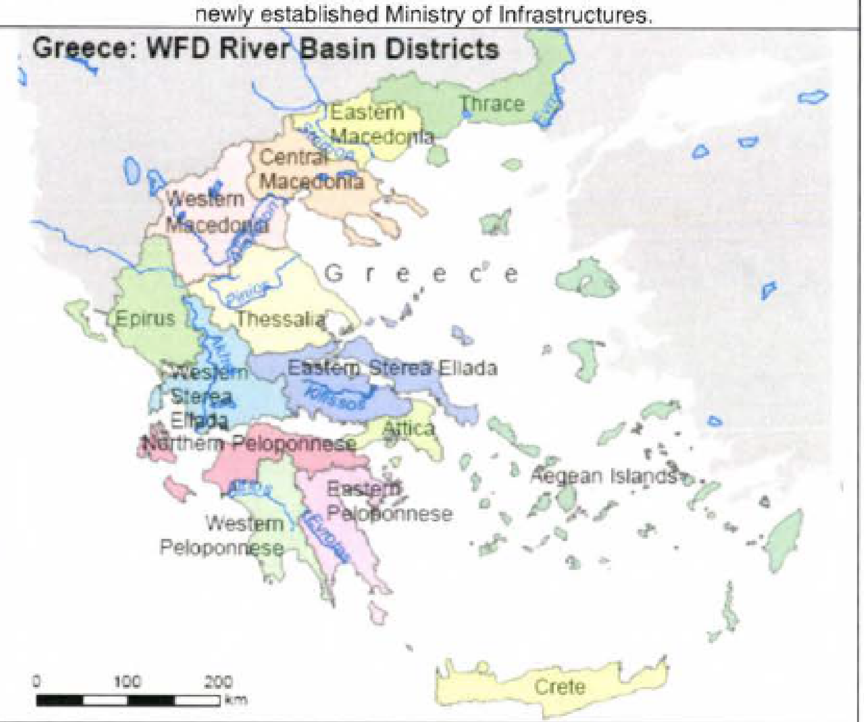
Analysis of Water Resources Planning and Management Regions in Greece

	**GREECE**
Form / System of Government	Unitary (13 administrative regions established in 1997) Republic Parliamentary
Water Resources Regions	Fourteen RBDs under WFD, established by the legal transposition of the Directive into *National Law* in 2003 *(Law #3199)* and 2007 (*Presidential Decree #51*). The *2007 Law* also established 45 River Basins (RBs). The 14 regions were originally defined by the *1987 Water Law* and respective Regional Water Management Departments (RWMDs) + Advisory Bodies. In 1997, during the decentralization reform, the RWMDs were transferred to the 13 administrative regions of the country. The 13 newly established RWMDs were given administrative oversight for specific water districts. Most RWMDs have different territories of oversight from these of the regions because the 14 water districts do not always coincide with the boundaries of the 13 regions.
Purposes	Mainly Planning, under WFD. According to the *1987 Law*, RWMDs' responsibilities include: monitoring and managing water resources, adjusting national water policy to regional conditions, calculating water balances, developing water development programs and necessary studies. RWMDs were also given responsibility for issuing water permits (for energy production and multiple water uses). Currently, despite their establishment in the entire country, the RWMDs have a marginal role in water management. In practice, their responsibility for water planning and programming never became fully operational, being mostly bureaucratic and restricted to their involvement in water permitting procedures and the formulation of guidelines and regulations for measures on surface and groundwater quantitative use. As a result, their role in coordinating water management across administrative levels and water uses was minimal, while water management remains largely centrally dominated. The RWMDs are not financially independent and do not manage funds for water projects.
Criteria considered when delineating water resources regions	Hydrographic. The pre-established 14 water districts follow, in general, the WFD guidelines: considering main river basins and combining small units considering climatic aspects, environmental aspects, socioeconomic aspects and administrative aspects. According to the *1987 Law*, hydrogeology was used as the basis for the 14 water districts, grouping water basins with similar hydrological—hydrogeological conditions.
Other Established Regions	The *2003 Water Law* established administrative responsibilities for water resources management, in accordance with the regional administrative system of Greece (13 regional administrations). Thirteen Regional Water Agencies (RWAs) were established in each administrative region. Each of these RWAs has exclusive administrative responsibility for a water district (WD) (established by the *1987 Water Law*) if the WD is totally in the administrative area of the RWA. In case the WD lays in more than one RWA, the administrative responsibility is shared between the RWAs and the WD. The 13 RWAs were placed under Mandate 13 Secretaries General of the 13 Administrative Regions of the country, as introduced by the *2003 Water Law* (article 5) and realized by a Ministerial Decision in December 2005. According to the planning reform of the administrative system in Greece, which will be in power in January 2011, the 13 RWAs will keep their territorial responsibilities, but so far, it is not absolutely clear whether they will remain under the administrative mandate of the 13 Secretaries General or whether they will be put under the mandate of the central government. The *2007 Water Law* established 14 RBDs and 45 River Basins (RBs), managed by 13 RWAs.

	**GREECE**
Purposes	Management mainly, including protection and management of all river basins within the region's boundaries. In cases of river basins crossing the boundaries of two or more regions, the RWAs' responsibilities should be exercised in common, but the National Water Committee can also determine a single competent RWA. Each RWA should develop and implement a management plan for all river basins and respective programs under its authority to measure, monitor water resources, and register protected areas. It should also report annually to the Central Water Agency. Concerning the financial instruments of each RWA, apart from the national budget, they can finance their projects by international funds. They have no additional income sources of their own.
Criteria	Political Administrative. According to the *2003 Water Law*, RWAs were established at the level of regional administrative region boundaries instead of river basins.
Committees	According to the *1987 Water Law*, Regional Water Committees should be implemented, one in each water district, to consult over water district development programs. They were established in 2000, and only a few of the established committees have been activated. In general, no significant water management issues have been discussed. According to the *2003 Water Law*, Regional Water Councils should run consultations on the river basin management plans.
Public Participation	Yes. The *1987 Law* established the participation of representatives of the relevant regions and prefectures, farmers' unions, local self-administration and the Technical Chamber of Greece. The *2003 Law* established consultations on the river basin management plans. Compared to the 1987 Regional Committees, a broader group of stakeholders can participate, following WFD guidelines.
Real River Basin Level	No. Carried out mostly along administrative boundaries.
International River Basin Commissions	At Aoos/Vijose River Basin, there is no special agreement between Greece and Albania for the Aoos River, apart from a memorandum of understanding and collaboration in environmental issues, signed in 2005, and a common committee established for the inland transboundary waters of the two countries. At Macro and Micro Prespa Lake, there is no special agreement apart from a declaration of understanding and collaboration for the Prespa Region between Greece-Albania-FYR of Macedonia, signed in 2000. There is also a common committee established for the inland transboundary waters of Greece and Albania. At Axios/Vardar River Basin, two agreements were signed in 1959 and 1970 and ratified between Greece and Yugoslavia. Currently, however, there is no formal agreement, and there has not been one since the separation of FYROM from Yugoslavia in 1991. At Strimon/Struma River Basin, there is no special agreement with Bulgaria, apart from an agreement on general issues, signed in 1991, including some articles that present the will of collaboration between the two countries for water issues. In this same area, there is no agreement between Greece and FYROM. At Evros/Meric/Maritsa Rivers, and their tributary Ardas, there is no considerable agreement between Greece and Bulgaria or Turkey, apart from an old agreement with Turkey, signed in 1934, and numerous protocols, signed mainly during the 1960s, concerning technical and protection measures. Recently, a will for collaboration for Evros and its tributaries has been expressed by the politicians of all involved countries and especially those of Greece and Bulgaria. At Nestos/Mesta, an agreement was signed and ratified in 1995 between Greece and Bulgaria. This agreement consists of the most considerable agreement between Greece and its neighboring countries for transboundary inland waters issues.

<table>
<tr><td></td><td>GREECE</td></tr>
<tr><td>General Comments and Questions</td><td>From the mid-1960s until the mid-1980s, water policy developed into a fragmented mosaic of overlapping regulations on specific aspects of water management in specific geographical areas. In the early 1980s, the Greek government announced plans for a framework water law to coordinate legislation and institutional arrangements. The 1987 Water Law is the first attempt to promote integration. In December 2003, Greece transposed the EU WFD by adopting the new Law on the Protection and Management of Water (MEPPW, L.3199). It is now considered important to harmonize the water management systems and tools in accordance with EU WFD reporting requirements. Greece delayed in providing complete information on the definition of its RBDs and their competent authorities and in submitting reports on the current state of its RBDs to EU.
In administrative terms, the 2003 Water Law required setting up several administrative and advisory bodies, with similarities and differences to those established in 1987. A National Water Council, headed by the Ministry of Environment, Energy, and Climate Change (MEPPW), should be set up to assess and give its expert opinion on water policy and law implementation. The law also required the establishment of a Central Water Agency at the MEPPW as the principal national competent authority for water protection and management. The agency should draw up national water programs and prepare annual reports on water status, law implementation and EU compliance.
In October 2009, the MEPPW was renamed as Ministry of Environment, Energy and Climate Change (MEECC), giving the responsibility for public works to the newly established Ministry of Infrastructures.</td></tr>
<tr><td>Map of the Water Resources Regions</td><td>
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<tr><td>References</td><td>Kampa and Bressers, 2008; Mylopoulos and Kolokytha, 2008a; EC, 2002; Mylopoulos and Kolokytha, 2008b; Kolokytha, 2008; Kolokytha, 2010; Mimikou, 2005; Mimikou, 2010.</td></tr>
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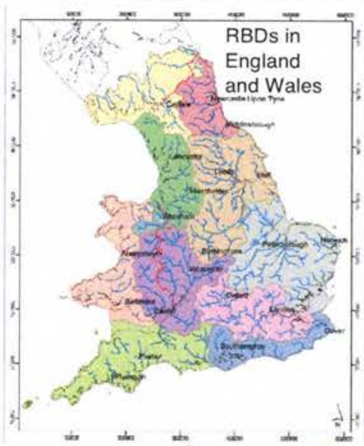
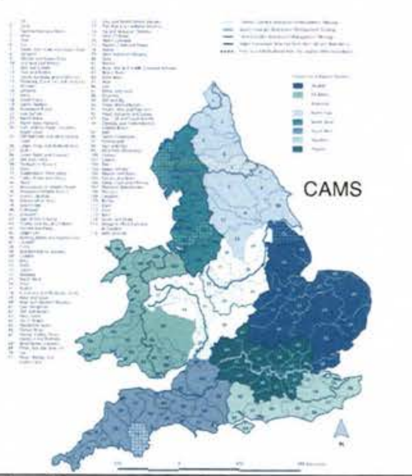
Analysis of Water Resources Planning and Management Regions in United Kingdom

	**UNITED KINGDOM**
Form / System of Government	Unitary Monarchy Parliamentary
Water Resources Regions	Eleven RBDs under the EU WFD Six entirely in England (Anglian, Humber, North West, South East, South West, Thames districts); One entirely in Wales (Western Wales district); Two cross the border with England and Wales (Dee and Severn districts); Two cross the border with England and Scotland (Northumbria and Solway Tweed districts)
Purposes	Mainly Planning, in accordance with the EU WFD guidelines. Planning is not legally binding.
Criteria considered when delineating water resources regions	Hydrographic.
Other Established Regions	There are 129 Catchment Abstraction Management Strategies (CAMS), and eight Regions of the Environment Agency: Anglian, Midlands, North East, North West, South West, Southern, Thames, Wales.
Purposes	Planning and Management CAMS' responsibilities include: assessing water resources availability, licensing water abstraction, and managing time-limiting licenses with a sustainable and consistent strategy, based upon a catchment scale. In accordance with the eight regions of the Environment Agency, the emphasis of these regions is data management, water quality control, water use and allocation, monitoring, planning, river basin organizations, and environmental protection. In addition, CAMS should provide a clearer methodology and increase transparency to the general public regarding the licensing process, as well as to balance water uses and environmental needs. They also promote the involvement of stakeholders.
Criteria	CAMS: Mainly surface water catchments (hydrographic including: river basins, catchments and sub-catchments), but some consider the boundaries of groundwater and aquifers. Other factors considered are: tidal waters, estuary regions and coastal areas, significant abstractions, and historical aspects. In urban areas, it is also difficult to split planning and management process into many small catchments or to consider solely the limits of the river basins. In addition, there are several large reservoirs and water transfers in England and Wales, which make the situation quite complex. Artificial watersheds may be considered in these situations. In recent years, some catchment units have been merged to create larger CAMS and represent the link between surface water and groundwater. In addition, some areas are being refined to bring the CAMS in line with the WFD objectives and to help its implementation. Beyond the size criteria, the continuous merging process intends to reduce administrative structures and improve efficiency. It is expected that the total number of CAMs will be reduced from 129 to 101 by 2014. In addition, it is important to understand how abstractions affect superficial flow, however it is a difficult task to accomplish, especially in cases where CAMS do not match well the groundwater limits. In such cases, it is necessary to analyze bigger blocks of CAMS. For instance, at Severn River Basin, there are many CAMS, but the watershed is managed as a whole using the concept of corridor CAMS. Regarding the eight Regions of the Environment Agency, they do not follow watershed limits completely, but their boundaries are mainly based upon hydrographic criteria, by grouping CAMS. History also plays an important role.

	**UNITED KINGDOM**
Criteria (cont.)	For more than 100 years, water resources management has been based upon a catchment-level approach. In 1948, there were 32 River Boards based upon drainage boundaries. In 1968, there were 29 River Authorities. In 1973, ten multipurpose regional water and sewage authorities were created, centralizing the functions of multiple water management units, such as local government water authorities, river authorities, and local authority sewage works, in order to get people, power, and financial resources together. These authorities were also responsible for the abstract license process and for integrating water supply, sewage, and water quality aspects. In 1989, the water services functions of these authorities were privatized into ten companies. The boundaries of the water authorities and subsequent water companies had always been based upon hydrographic criteria, and they were considered when defining the eight regions of the Environment Agency. These regions were reduced in number in order to optimize administrative structures, but no specific criteria were defined other than distinct river basin areas.
Committees	There are liaison panels, at the river basin level, that cover whole river basin areas. They are similar to the CAMS structure in their stakeholder involvement processes. The Environment Agency coordinates this practice.
Public Participation	Stakeholder and public participation is not organized by individual CAMS but through the river basin planning process within the WFD. There are situations where additional small focus groups are set up to discuss specific issues. Participation is restricted to key stakeholders, and not open to the general public. The WFD promises to be an important process to improve public participation.
Real Planning and/or Management at River Basin Level	The WFD is promoting real planning at the river basin level, and the Environment Agency is coordinating this process, grouping the contributions coming also from the water companies. In addition, the licensing process is being performed at the river basin level through the CAMS, including the participation of several stakeholders.
International River Basin Commissions	The United Kingdom comprises four unified bodies: England, Wales, Scotland and Northern Ireland. There are four transboundary basins among these unified bodies: two cross the border with England and Wales (Dee and Severn districts); two cross the border with England and Scotland (Northumbria and Solway Tweed districts). In England and Wales, there are cross-border arrangements. The truly international basins are between the UK (Northern Ireland) and the Republic of Ireland: Foyle/Erne/Melvin & Neagh/ Bann/Dundalk. There are no political issues and no administrative tensions over water management in the minor streams that cross the border.
General Comments and Questions	Traditionally, the government has been centralized. It has a strong central frame based upon national regulation and privatization policies. The power of the local authorities is limited, requiring that policies, legislation, and regulation be coordinated at the national level. WFD was transposed into UK law by December 2003. The Environment Agency has been designated as the sole 'competent authority' for implementing the WFD. OFWAT is responsible for economic regulation of the water services industry; Water UK represents the regulated water and wastewater industries; Defra deals with all aspects of water policy in England, including water supply and resources, and the regulatory systems for the water environment and the water industry. The National Rivers Authority (NRA) was established in 1989 to manage water resources and take over some functions of the former ten regional water authorities that were being privatized. In 1996, the NRA was replaced by the Environment Agency, which is the current environmental regulator for England and Wales. It manages water resources and enforces water quality standards and licenses water abstraction at the national and regional levels and coordinates the water companies' local planning process.

<table>
<tr><td></td><td>UNITED KINGDOM</td></tr>
<tr><td>General Comments and Questions (cont.)</td><td>Local Environment Agency plans have been carried out in England and Wales since 1995. They include comprehensive environmental questions balancing different needs within a watershed and integrating local planning processes. They are not legally binding, but they are based upon a wide public consultation. The WFD River Basin Management Plans—RBMP have impacted the LEAP process. It is expected that LEAPs are used as subbasin plans for the RBMP, considering that these WFD plans can be supplemented by more detailed plans. It is possible that the existing water resources units may suffer some adjustments depending on the results of these river basin plans being executed as part of the WFD.</td></tr>
<tr><td>Map of the Water Resources Regions</td><td>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<tr><td>References</td><td>EC, 2002; Zabel and Rees, 2000; Zabel and Rees, 1999; Environment Agency, 2002; Environment Agency, 2004; Environment Agency, 2005; Environment Agency, 2006; Environment Agency, 2008a; Environment Agency, 2008b; Environment Agency, 2008c; Environment Agency, 2008d; Environment Agency, 2008e; Johnes, 2006; Environment Agency, 2008f; Environment Agency, 2008g; Defra, 2008a; Defra, 2008b; CIWEM, 1996; CIWEN, 2008; Water UK, 2008; Orr et al., 2007; Shelton,f 1981; Wheater and Peach, 2004; Page, 2003; McMahon and Postle, 2000; Aldrick, 2009; Chapman, 2009; Williams, 2001; Jenkins, 2010; Watson et al., 2009.</td></tr>
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Analysis of Water Resources Planning and Management Regions in Netherlands

	**NETHERLANDS**
Form / System of Government	Unitary (National, provincial and municipal level)
	Monarchy (Constitutional)
	Parliamentary
Water Resources Regions	Four International RBDs under WFD: Ems, Rhine, Meuse and the Schelde basins (designated on the basis of the *Water Management Act*). The Dutch part of the Rhine RBD is subdivided into four areas for practical purposes. Within these areas there is cooperation among state agencies, provinces, water boards, and some municipalities.
Purposes	Mainly Planning (mostly cooperation/coordination because they have no authority)
Criteria	Hydrographic
Other Established Regions	Twenty-six Water Boards (*Waterschappen*) are bottom-up governmental institutions that are elected/appointed by the main water user categories, levy their own taxes, and have legal and administrative powers.
Purposes	Management (planning is mainly carried out at the Provincial level) The first water boards (*Waterschap*) were created in the twelfth and thirteenth centuries, During the Middle Ages, farmers began to organize themselves at a local level to improve the management of dikes and polders. The Dutch *Constitution of 1848* introduced the term *Waterschap*. Only in the Twentieth Century was the whole country divided into water resources regions. The first water boards were responsible only for dikes and drainage. Collection and treatment systems are more recent tasks. Some of the water boards carried out several water management tasks. Currently, all the water boards incorporate the full scope of water management, including water quality, operational management plans and regional surface waters management, as well as regulating most groundwater abstractions. More specifically, their tasks include policy development, local and regional quantitative and qualitative water management, data management, monitoring, flood risk management, treating urban wastewater, granting water permits and establishing usage charges. Regarding land use planning and management, water boards act as advisors. They are not very active in the environmental field in general, only when water is related, for instance, in water emissions. The water boards have a constitutional position equivalent to municipalities but are under the supervision of the regional provinces and the central government. The Dutch Association of Water Boards—*Unie van Waterschappen*—was created in 1927 to promote the water boards' interests at national, and later, at international levels.
Criteria	Mainly Hydrographic. Because The Netherlands is a hydrologically complex area, the concept of a river basin might be adapted. Half of the country is a single water system according to system analysis and 60 percent of the land is below sea level. The dike rings are areas with risk of inundation protected by a ring of dikes and also by higher grounds. The Netherlands can be subdivided into five areas according to hydrological aspects: coastal, rivers, lake, higher parts, and lower parts. The areas for water management up to 800 A.D. were divided In: peat reclamation area, the Schelde delta, the area of the rivers and the tidal salt marsh area in the north. From 800 to 1250 A.D., there were no separate governing bodies; local governments were responsible for water management and drainage while some regional water boards were being defined. From 1250 to about 1600 A.D., the organization of the water boards was part of the governmental structure in many districts; this is

	NETHERLANDS
Criteria (cont.)	reflected in the 20th Century model. From 1600 to about 1800 A.D., the provincial government was becoming increasingly responsible for water management. Between 1800 and 1950 A.D., The Netherlands had thousands of water boards. From 1800 to the present, the country has been divided into five districts that represent the regional directorates and the basis of the organization of the central government. The water boards are primarily determined by hydraulic aspects such as subcatchment basins and water systems or groups of water systems, for instance, dike rings, pumping and storage areas, polders or drainage basins. They are also partly based upon river basins, combined with administrative regions. Many existing water boards are inter-provincial. Coordination is guaranteed at the river basin level, especially through the WFD international RBDs. Some additional aspects considered include: coastal water and estuaries; groundwater; artificial structures such as reservoirs, channels, and water transfers projects; climatic characteristics; environmental protection areas; socioeconomic areas and agriculture lands; political jurisdictions; metropolitan regions; geographic features; census divisions; historical development and cultural factors; size and distance limits; and pragmatic considerations. The wide range of criteria being considered for defining regions leads to a good level of integration with other public fields, such as environment and spatial planning. After 1950, a transformation in the water board model started to happen. On February 1st 1953, there was a large tidal flood disaster that accelerated the process of administrative concentration of the water boards. Lack of central coordination and the need for a broader scope were the leading motivation factors. Many clustering of small and middle-sized water boards started to take place. From 1950 onwards, an increasing number of water boards got water quality management as a task, which required more specialized expertise. In such a case, bigger water boards could attract personnel with this expertise. In addition, the government policy of implementing IWRM started in 1985, and especially the integration of water quality and quantity management into the water boards resulted in a significant decrease in numbers and increase in size of these water boards. The need for expertise resulted in an increase in financial need, which also contributed to the process. Furthermore, in 1996, the Association of Water Boards took an official position in favor of the integration. More recently, the main principles of the WFD have influenced the delineation of water boards. In 1985, there were 255 water boards. In 2004, there were 56 water boards. In the time between 1950 and now, the total number of water boards decreased from more than 2600 to 26. Changes also included the organization of tasks, funding, and composition and election of the boards. The boards became modern professional organizations with an important role in regional water management. It is possible that further reduction in the number is necessary, getting closer to the twenty water authorities predicted by the Water Authorities Research Committee in 1974 and seventeen administrative river basins envisaged by the Committee for Water Management in 2000. Moreover, the water boards may lose their independence and become branches of provincial government, according to the program of several political parties that want to abolish them in order to simplify water management, increase municipal and provincial integration, and reduce costs.
Committees	The water boards might be considered committees, considering that different representatives are elected once every four years, having legal responsibilities for water management.
Public Participation	Yes. Similar to other governments, the water boards have formal consultation processes. Their representatives are directly elected or appointed by user groups, and many also organize more active forms of participation.

	**NETHERLANDS**
Public Participation (cont.)	According to the principle of 'the unity of pay, say and interest', these stakeholders that have an interest in water management pay for the operational costs of the water authorities and compose its board. In the beginning, the interest was linked to land property, and the boards were dominated by landowners. Currently, it is related to a wider variety of aspects and regulations, including several stakeholders in this process, which are democratically elected and can be involved in the decision-making process at early stages.
Real Planning and/or Management at River Basin Level	Yes. The Netherlands is, in legal terms, a 'decentralized unitary state', and this is especially reflected in water management. Cooperation between different water authorities at river basin level is considered relatively effective; cooperation between the water authorities and other policy sectors, such as agriculture and special planning, is more problematic. The WFD implementation process has been reinforcing the management process at the river basin level. For most areas, there are still a couple of water policy plans, a couple of water management plans, some land use plans, environmental plans and so on. Despite the fact that there are different plans on different levels, there is a structure designed to reach integration and coordination of water management.
International River Basin Commissions	International Commissions for the Protection of the Rhine, Meuse, Sheldt and Ems. They have limited competencies and instead have a coordinating function and knowledge exchange. In addition, there are smaller not so active commissions for some small transboundary rivers.
General Comments and Questions	The Netherlands is known for its public water management and its water board system. In addition to the water boards, twelve provinces are responsible for regional water management plans and environmental and land use plans; supervision of local water and wastewater management; licensing groundwater abstractions; and formulation of strategic water management policy. The central government—State Water Management Agency (*Rijkswaterstaat*)—is responsible for the strategic national water management plan and for the management of the main water system in the country. Water policies and legislation are the responsibility of the Minister of Transport, Public Works and Water Management, including coordinating river basin management plans, submitting information and reports for the WFD, and integrating water boards with RBDs. The Water Boards' model is considered relatively compatible with the WFD objectives, regarding its similarity to the RBD model, its appropriate field of public participation, and its adequate institutional structure. However, to reach good chemical and ecological status of water, as required by the WFD, it is necessary to develop the necessary coordination among water boards and the agricultural sector, which is responsible for the diffuse pollution, one of the main current problems in the Netherlands. Another issue is related to the morphological changes and need for more natural ecosystems that are required by the WFD. Considering that heavily modified bodies are the vast majority of the bodies in the Netherlands, additional space is necessary to address this issue. Therefore, better coordination among the water boards and the spatial planning sector is also necessary.

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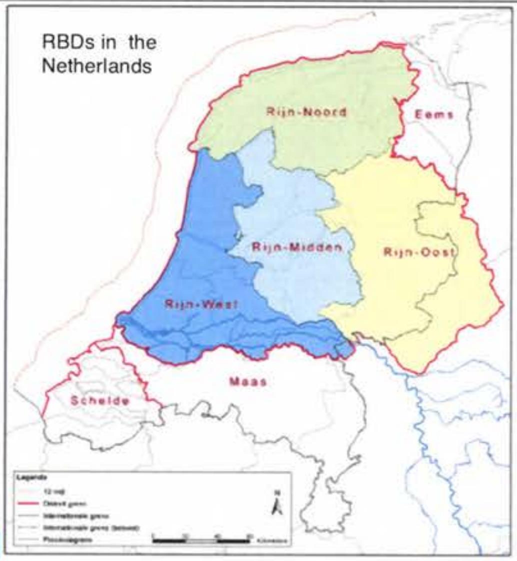
<tr><td></td><td>NETHERLANDS</td></tr>
<tr><td>Map of the Water Resources Regions</td><td>

Water Boards
</td></tr>
<tr><td>References</td><td>Grijp and Oslthoorn, 2001; Brugge and Rotmans, 2007; Rijswick, 2004; Mostert, 2000b; EC, 2002; Aerts, 2009; Havekes, 2009; Mostert, 2009; Ven, 2004; Havekes et al., 2008; Mostert, 2006; Havekes, 2008; Ministry of Transport, Public Works and Water Management, 2009; Kuks, 2004; Uitenboogaart, 2009; Junier, 2009.</td></tr>
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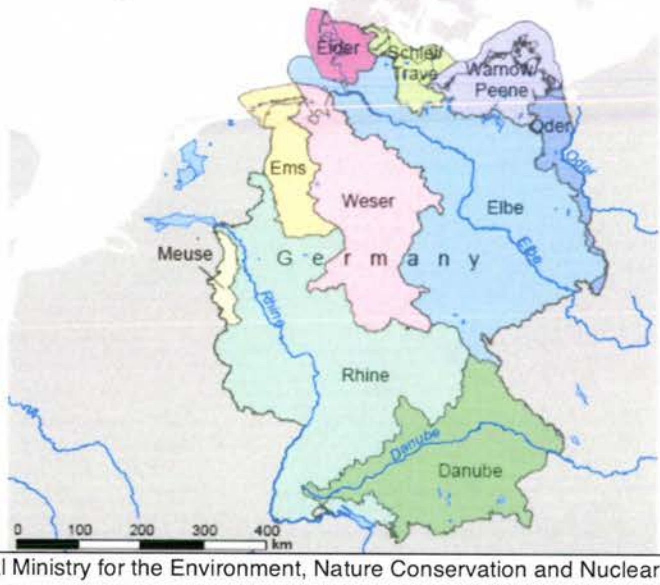
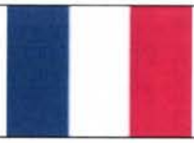
Analysis of Water Resources Planning and Management Regions in Germany

	GERMANY
Form / System of Government	Federalism (16 States or Landers) Republic Parliamentary
Water Resources Regions	Ten RBDs Under WFD (*Flussgebietseinheiten*—FGE): River Danube; River Eider; River Elbe; River Ems; River Meuse; River Oder; River Rhine; Schlei/Trave; Warnow/Peene; River Weser. Seven are major rivers, and three are smaller tributaries. From these, eight are part of international RBDs: Danube, Eider, Elbe, Ems, Meuse, Oder, Rhine and Schlei/Trave.
Purposes	Mainly Planning and coordination of the River Basin Management Plans and other activities in accordance with the WFD. Their purposes also include: data management, river basin organizations' set up, harmonization of federal and state projects (Multiagencies Coordination), and environmental protection.
Criteria considered when delineating water resources regions	Hydrographic + Ecoregions + Size Limits First, the catchment of six major river systems are considered: Rhine, Ems, Weser and Elbe, which flow into the North Sea; the Oder, which flows into the Baltic Sea; and the Danube, whose tributaries lead to the Black Sea. It also includes their coastal regions. Then, size limits and ecoregions are considered in order to define additional water resources regions, especially in coastal areas that contain several small river basins. Ecoregions is a classification procedure elaborated for the whole of Europe, considering topographical features. In Germany, there are five regions: the North German Plain, the Central Upland Range, the terrace panorama of the Southwest, the Alpine Foothills in the south and the Bavarian Alps. In order to refine these districts, some other important criteria are analyzed, such as landscape type, small administrative borders, and comparable types of problems. Finally, coastal areas, which are dry during low tide and wet during high tide, were also delineated as part of RBDs depending on the direction in which the water flows to main rivers between periods. This is an historical process for the international river basins and some domestic river basins in Germany. The entire system of environmental management in Germany is formed by administrative traditions and its political and economic situation.
Other Established Regions	In each river basin, the Landers have created several sub-regions for coordinated water management. These sub-regions are also the basis for state water authorities' working groups.
Purposes	Management. The Landers have established cooperation procedures among them, such as for the purpose of coordinated river basin management. The responsibility for water management is located on the Lander level. Interstate cooperation for coordinated river basin management is partially institutionalized in the form of working groups of state water authorities for each of the major river systems. These working groups are responsible for producing river basin management plans and programs of measures which are not legally binding, focusing on improving water quality, in accordance with the provisions of the WFD. The Landers are responsible for data management, reservoir operation, water permits, water use charges, water quality control, monitoring, land use planning and/or management, and environmental protection. In addition, Landers have some legislative power in the management of water resources due to the latest amendment of the *German Constitution.* One of the oldest coordination bodies was established in 1956 and is called *Bund/Länder-Arbeitsgemeinschaft Wasser* (LAWA—German Working Group on water issues of the Federal States and the Federal Government represented by the Federal Environment Ministry). LAWA is a subgroup of the Environmental Ministerial Conference. It is composed of the water management authorities from the Landers

	GERMANY
Purposes (cont.)	and the federal government. LAWA works specifically with water resources issues but does not have legal power. LAWA itself has two levels: 1) the management level, constituted by the heads of the water departments/authorities of the Landers and 2) federal environment ministries and the working groups. There are four working groups to support more scientific questions: Surface Water, Groundwater, Water Law, and Hydrology and Flood. It is interesting to note that these working groups and River Basin Commissions have, in many cases, the same representatives, and consequently, overlapping questions are discussed; which is good for integration.
Criteria	Water management is traditionally organized around political-administrative units. Subbasin limits are considered for state water authorities' working groups and/or river basin committees or communities.
Committees	River Basin Communities exist in several national river basins and national parts of international river basins in order to improve coordination for planning and management activities. They are steered by a ministerial council and have a president and a secretariat sponsored by the involved Landers. They are formed by the representatives of the Landers. Representatives of the federal government are usually welcome guests. In the Elbe Community, the federal government is a member. Every international river basin also has an international commission or some kind of international working organization, with a similar structure and purpose as the river basin communities. Some of these river basin communities existed in the early 1950s and 1960s, for example, the Rhine. Others are more recent.
Public Participation	The general public must be given the opportunity to voice its opinion early at all relevant stages during the formulation of river basin management plans according to the provisions of the WFD. The process is more open to stakeholders than to the general public. Furthermore, the WFD requires public participation during the River Basin Plans elaboration, which is coordinated by the Landers. It is performed by allowing different kinds of contributions and suggestions during a six-month period. Each Lander utilizes different approaches, varying from formal big stakeholders meetings to more local workshops where citizens can participate at the local level. The Landers have adapted their plans if necessary, and in several of the Landers there have been intensive evaluations and feedback. As a general evaluation, the process of public participation is improving in Germany. Adaptive IWRM, polycentric governance and broader stakeholder participation is replacing old governance structures with limited stakeholder participation.
Real Planning and/or Management at River Basin Level	Currently, river basin management exists in Germany, but it is limited by political-administrative territories. Water Resources planning and management is mostly performed by the Landers, following administrative boundaries. Motivated by the WFD, the Landers are working together to elaborate river basin management plans. Instead of individual plans, the Landers are now trying to create more integrated plans. For many of the big river basins, comprehensive plans have been elaborated, such as for Weser, Oder, and Elbe. They have been discussed and coordinated in the river basin communities. In parallel, separate plans for the territory of the Landers exist due to legal and financial autonomy. Plans are legally binding for administrations, but not legally binding for third persons. The federal government is supporting these planning processes. In the future, it is expected that these RBDs will be managed with greater harmonization and better coordination by the neighboring states (Landers). In the last ten years, Europe, as a whole, has moved towards river basin coordination and has focused international attention on IWRM at the river basin level. It is improving substantially, but some more time is necessary to be able to evaluate the effectiveness of the new regulations.

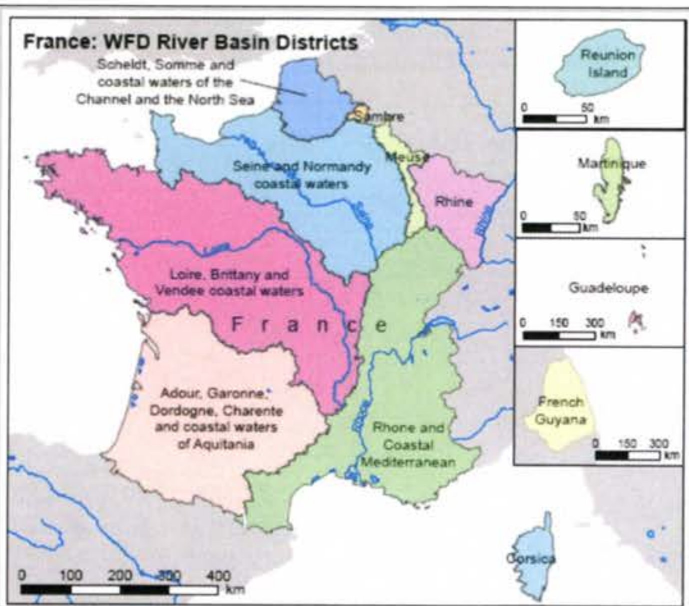
	GERMANY
International River Basin Commissions	Because Germany is centrally located in Europe, the majorityf its river basins are transboundary. The international river basin commissions are: International Commission for the Protection of the Rhine (IKSR), since 1950; International Commission for the Protection of the Elbe (IKSE), since 1991; International Commission for the Protection of the Danube River (ICPDR), since 1998; International Commission of the Meuse (IMK), since 2002; International Commission for the Mosel and Saar (IKSMS), since 1961—as part of the Rhine; International Commission for the Oder (IKSO), since 1990; International Commission for the Ems, since 2006. Inside these Commissions, Germany is represented by a delegation formed by one member from each Lander and one head from the central government. For instance, at Lake Constance, Germany also cooperates with several of its neighbors in bilateral transboundary water commissions. Almost all transboundary river basins have some institutionalized form of cooperation. At the eight International RBDs, neighbor countries are working together to submit joint overall reports for each transboundary RBD, as part of the WFD goals. At Eider and Schlei//Trave there are no formal commissions, but there is coordination between Germany and Denmark for information exchange.
General Comments and Questions	The federal government has few responsibilities for water resources management and limited administrative power. The most significant responsibilities are to manage navigable rivers and to operate locks and gates. The municipal level has autonomy on the questions of local interest. Federalism and the application of the subsidiarity principle are the most prominent features of water management in Germany. Given the importance of political-administrative territories to water management, the WFD implementation process constitutes a challenge. The current competent authorities for the WFD RBDs are the Landers' Environmental Ministries.
Map of the Water Resources Regions	**Germany: WFD River Basin Districts** 
References	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, 2006a; Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, 2006b; Winnegge and Maurer, 2002; Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, 2001; EC, 2002; Kraemer, 2000; LAWA, 2009; Götzinger, 2009; Mohaupt, 2009; Kraemer, 2009; Holzwarth, 2009; Herman, 2003; Rolke et al., 2007; EC, 2004; EC, 2005; Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, 2005; Laaser, 2010; Jekel, 2010.

Analysis of Water Resources Planning and Management Regions in France

	**FRANCE**
Form / System of Government	Unitary (36,680 Communes, 101 Departments, and 26 Regions) Semi-Presidential Republic Executive & Parliamentary
Water Resources Regions	Twelve RBDs Under WFD: six in France-continental: Rhône-Méditerranée, Loire-Bretagne, Rhin-Meuse, Seine-Normandie, Artois-Picardie, Adour-Garonne; five islands: Martinique, Guadeloupe, Réunion, Mayotte, Corse; and, one overseas: Guyane (America). These RBDs correspond to River Basin Authorities (twelve *Comités de Bassin*), Water Agencies (six *Agences de l'Eau*: Rhône-Méditerranée et Corse, Loire-Bretagne, Rhin-Meuse, Seine-Normandie, Artois-Picardie, Adour-Garonne) and Water Offices (four *Offices de L'eau*: Martinique, Guadeloupe, Réunion, and Guyane located at the *Départements d'outre mer*). These institutions were established according to the *1964 Water Law*, and the most recent French legislation, formalized in 2002 and 2006, which reflect decentralization efforts at the river basin level.
Purposes	Mainly Planning, for the 12 RBDs. According to the WFD, each district needs to elaborate the SDAGE (General Water Management Plan). The SDAGE is elaborated by the River Basin Committees and approved by the central state. For those RBDs that comprise a water agency, some management responsibilities are included, such as data management, water use charges, water quality control, monitoring, and environmental protection. The main challenges related to water management are agriculture diffuse pollution and floods.
Criteria considered when delineating water resources regions	Mainly Hydrographic and Administrative Units. *Base Communale*: grouping the smallest administrative units closest to river basins or groups of river basins. The limits of the communes are adopted in order to avoid different fees (executed by different agencies) being applied in the same commune. Some additional criteria were also considered when grouping river basins, such as culture, history (e.g., Rhône-Méditerranée long history tradition), geology (e.g., sedimentary basins in Adour-Garonne), socioeconomy (e.g., population versus GDP and industrial regions in Artois-Picardie), geography (e.g., estuary region in Rhine-Meuse), scaling revenue generation (e.g., Seine-Normandie and Loire-Bretagne), and size limits (big enough in terms of population and economic aspects to have enough money to fund more attractive projects). The water agency model resulted from a study performed by a special Secretary created in 1961. This Secretary defined 16 hydrological regions and elaborated the water law proposal, approved in 1964. It established six associations of technical missions as part of the Secretary organization, which resulted in the creation of six respective water agencies. The *1964 Law* did not establish the number of agencies to be created. A political criterion was also considered when delineating the water agencies in France. They were evenly assigned to the three existing Corps of Engineers at that time: The Corps of Roads and Bridges; The Corps of Rural Engineering, Water and Forestry; and The Corps of Mining. These had responsibilities related to water resources management. Currently, there are new situations that pose some challenges to the agencies' delineation. For instance, the Bretagne River Basin is formed mainly by cattle farms and has completely different problems than the Loire River Basin, which is mostly dealing with flood risks. Rhône-Méditerranée and Corse are two RBDs, which are grouped in one water agency. It was originally one single River Basin Committee, but it was divided into two in 2003 in order to: 1) reinforce the Corse island's autonomy, especially in terms of planning; 2) make it a distinct basin; and, 3) allows the creation of Corse's River Committee.

	**FRANCE**
Other Established Regions	In order to integrate the departments, regions, and communes into water resources management, as well as to deal more closely with local problems, some subbasins are also delineated in France. For example, at Seine-Normandie River Basin, there are six geographic commissions (*commissions géographiques de bassin*): Vallées de Marne, Seine Amont, Riviéres d'Ile-de France, Seine Aval, Vallées d'Oise et Bocages Normands. In this RBD, the SDAGE's program of measures is organized by each hydrographic unit. Those subbasins may comprise Local Water Commissions (*Commission Locale de l'Eau*—CLE) and/or River Basin Territorial Public Establishments (*Établissement public territorial de bassin*—EPTB) into a multi-level governance system. The EPTBs are the official actors of the water policy at the subbasin level and constitute a public establishment for the cooperation of the regions, departments, and communes. They were first created in 1997 and were officially recognized by *Law #699* in 2003. There were nineteen EPTB officially recognized in France in 2009. There were 167 SAGE in France as of May 2010, covering approximately half of its territory. Of the total, 88 are being developed; 43 are under the first review; 8 are being implemented; 19 new territories are emerging, and 9 have their perimeters under investigation.
Purposes	Planning, management, and regulation at a lower territorial level (smaller river basins). There are155 CLEs are responsible for the elaboration of SAGE and/or River Contracts in coordination with the territorial collectivities (communes, departments and regions). The SAGE (Water Management Plan) and the River Contracts fix the general objectives to manage water resources at the subbasin level or other determined territory (e.g., estuary or aquifer system) and are responsible for executing these objectives. They are voluntary instruments and must be compatible with the SDAGE. River Contracts are usually more specific action plans, but they can evolve to SAGE. Together, both instruments help to implement the WFD objectives. CLEs are also responsible for implementing the SDAGE's and SAGE's program of measures. It can implement these plans through the EPTBs. The territorial collectivities provide these local authorities with technical and financial resources. In such cases, for instance, EPTBs might also be responsible for flood and drought prevention, reservoir operations, water supply, territorial organization, and environmental protection.
Criteria	Small river basins (hydrographic) or water systems (estuary, aquifer, etc.)
Committees	River Basin Authorities (*Comités de Bassin*) and Local Water Commissions (*Commission Locale de l'Eau*). These entities are constituted by representatives from territorial collectivities, government administrations, water users and NGOs (tripartite).
Public Participation	France has a long tradition in the field of public participation. SDAGE, SAGE and River Contracts introduced negotiation and participatory processes in planning. In addition, according to the WFD principles, public participation is required during the elaboration of the river basin plans (inform and consult). There are different sorts of committees and watershed partnerships in France. However, at the River Basin Authorities level, despite the creation of multipartite entities, real public participation, including the general public, is restricted. It is more effective at the subbasin level and during the implementation of local projects and programs. For instance, SAGE's elaboration process is usually dependent on the existing political articulation/capacity at the local level.
Real Planning and/or	Yes, France has competent water management and planning authorities at river

	**FRANCE**
Management at River Basin Level	basin level, including legally binding river basin management plans developed by the river basin authority. Multiple legislations reinforce the responsibility of the River Basin Committees, but the territorial collectivities and central state still play an important role.
International River Basin Commissions	Six RBDs are international: Artois-Picardie (Sheldt) and Seine-Normandie with Belgium, Rhine-Meuse with Germany, Luxemburg and Belgium, Rhône-Méditerranée with Italy and Switzerland, Adour-Garonne with Spain and Guyane with Brazil and Suriname. The existing International River Basin Commissions are Garonne Joint Commission, the International Commission for the Protection of the Rhine (ICPR), the International Meuse Commission (IMC), the International commission for the protection of Lake Geneva (CIPEL), and the International Scheldt Commission (ICBS). These organizations, generally, do not have strong planning powers but do have coordination and mutual funding. They are also responsible for guaranteeing the necessary coordination of water resources plans among riparian countries, in accordance with WFD principles.
General Comments and Questions	In France, there is the National Water Committee (NWC) that includes representatives of water users, associations (NGOs), territorial collectivities, central state's government administrations, recognized professionals and the presidents of the River Basin Committees. The *1964 Water Law* created water agencies and river basin committees in France. Among other efforts, the *1992 Water Law* created two planning procedures—SDAGE and SAGE—in order to assure a decentralized and participative action, to harmonize water use, to protect ecosystems and to increase the number of stakeholders involved in the decision-making process. They also establish a link among multiple planning levels, in order to relate local and regional problems. The most recent water law is from December 30, 2006. It was established mainly to regulate the WFD in France. This law also addresses an important question related to the constitutional legitimacy of the water agencies to charge for water use. The water fees, which constitute a significant amount of financial resources, were being questioned because they were not directly controlled by the Parliament. The necessary arrangements were regulated by the *2006 Water Law*, restoring the legitimacy of the water fees. According to this law, the Parliament defines the priority directions of the multiyear intervention program of the water agencies and sets a limit for its expenses. Territory management is historically dominated by the confrontation between the central state and the local authorities because of France's traditional strong centralized administrative system. Since 1987, there have been more significant efforts towards decentralized systems. The initial proposal for the creation of the water agencies would have given them more authority, similar to contractor agencies like German *Ruhrverband* or Spanish *Confederaciones Hidrograficas de Cuenca* models. Instead, the Parliament decided to give them technical and financial responsibility only. The financial function of the agency is significant because it charges for water use and elaborates almost one hundred budgets for the necessary investments in each river basin. The multi-level government system existing in France needs a clear allocation of the competencies, especially when considering that EPTBs and water agencies may have conflicting responsibilities.

<table>
<tr><td></td><td>FRANCE</td></tr>
<tr><td>Map</td><td>

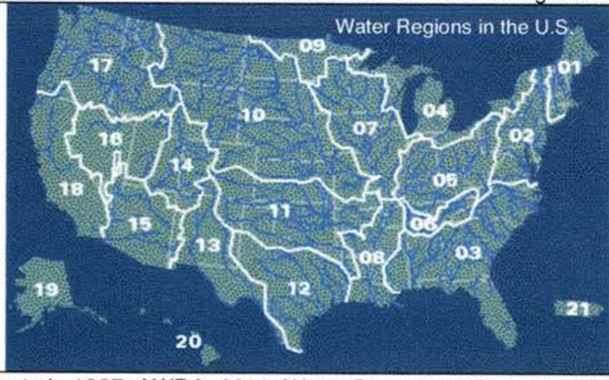
EPTBs

SAGEs/CLEs
</td></tr>
<tr><td>References</td><td>Piégay et al., 2002; Piégay, 2006; Barraqué, 2000a; Barraqué, 2000b; Hubert et al, 2002; MED, 2003; Allain, 2002; Wasson et al., 2003: EC, 2002; Salamé, 2009; Collet, 2009; Frey, 2009; Barraqué, 2009; Bernard, 2009; Barraqué, 1995; Sangaré and Larrue, 2004; Martinez, 2007; Agence de l'eau Seine-Normandie, 2008a; Agence de l'eau Seine-Normandie, 2008b; Agence de l'eau Seine-Normandie, 2008c; Agence de l'eau Rhône Méditerranée & Corse, 2009; Office International de l'Eau (2009); +1(?AB); Donzier, 2005; Bouleau, 2007; Bakker et al., 2009; Gest'eau, 2009; GWP and INBO, 2009; Association Française des EPTB, 2010, Gest'Eau, 2010; Ministère de L'Écologie, de L'Énergie, du Développement Durable et de la Mer, 2010.</td></tr>
</table>

Analysis of Water Resources Planning and Management Regions in United States

	**UNITED STATES**
Form / System of Government	Federalism Republic Executive
Water Resources Regions	Four levels defined in 1977: 21 Regions, 222 Subregions, 378 Accounting Units, and 2264 Cataloging Units.
Purposes	Data Management, Monitoring, Water Rights Inventory (originally was focused on planning at National Level. Currently, there are planning activities at the State Level only.) 21 Regions were originally created by the Water Resources Council in 1970 to help planning activities (in 1968, there were 20 regions and 110 subregions for the 1st National Assessment; in 1970 there were 21 regions for the 2nd National Assessment. The North Atlantic region was subdivided into the New England Region and the Middle Atlantic region due to political reasons) In order to harmonize different delineations being used by federal, state and local agencies (previously using incompatible criteria for names, codes, and river basin boundaries), a huge process of reviewing the established units was initiated. The Nationwide Standardization of Hydrologic Units was a national project to establish uniform hydrologic boundaries that began in 1972. The Hydrologic Unit Map Series was developed by USGS in cooperation with the U.S. Water Resources Council in order to define water resources units as the basis for the National Water Resources Assessment Reports. These maps were approved between 1974 and 1977. The fourth level, or eight-digit, hydrologic unit codes (or HUCs) were originally published as 1:500,000-scale statewide paper map products. An intense and extensive formal review process happened between 1977 and 1987, including federal, regional and state water resources agencies. It was approved by the National Planning and Assessment Committee of the Water Resources Council. Nowadays, as a result of this process, at least the data management is standardized between the EPA, the Forest Service, the U.S. Fish and Wildlife Service, the USGS, the National Park Service, the Bureau of Land Management, the Department of Energy, the Weather Service, and the Bureau of Commerce.
Criteria considered when delineating water resources regions	Hydrographic (natural or human-made stream-drainage area of major rivers or combination of small drainage areas with adjacent larger unit) + Political + Cultural + Jurisdiction. In addition: existing reservoirs; interbasin flow and continuous flow diversions; major cities and state lines; standard metropolitan statistical areas; economic areas; land resources areas; tidal or backwater effects; strategic hydrologic, political, or cultural points; minimum size of drainage areas, equal to 700 square miles (almost all cataloging units are larger than that); bays and estuaries; coastal islands & coastal areas. Groundwater areas were not considered. Because the boundaries of the cataloging units and accounting units are hydrologic in nature, they can be extended into Mexico and Canada. Some characteristics of the current Watershed Boundary Dataset (WBD) include a reference range for the number of watersheds per subbasin or subwatersheds per watershed (fiver to fifteen) and the nested subdivision of established subbasins (formerly Cataloging Units). In addition, the WBD consider adjacent state lines and forests, such as Yellowstone Lake, which illustrates the issue of being consistent with the hierarchical order of the WBD. In general, the subregional delineations defined by the U.S. Water Resources Council (1970) were used as the principal geographic units during the 1977 process, with the following exceptions: at a major lake or reservoir, the boundary was placed at the outlet of the impoundment rather than at its head. The location of boundaries

	**UNITED STATES**
Criteria considered when delineating water resources regions (cont.)	at gauging stations, major cities, state lines, tidal or backwater effects, or other so-called strategic hydrologic, political, or cultural points was deemphasized. The cataloging units are thus more hydrographic than true hydrologic entities. Interbasin flow was not considered if it occurs only during flood conditions.
Other Established Regions	There are several local, state, regional, Interstate Compacts, Federal Interstate Compacts and other established regions. Major examples include: the Tennessee Valley Authority (TVA) (Federal Administration Institution with comprehensive powers across state boundaries), the Brandywine Valley Association and the Delaware River Basin Commission; Florida Water Management Districts (unique institutional framework based upon hydrologic boundaries, involving land management, ecosystem, and water rights); Minnesota's 46 Watershed Districts (government entities, created in 1955, that monitor and regulate the use of water; its board of managers is appointed in each county by commissions). There are no harmonized water resources regions for the entire country because water resources planning and management is the responsibility of the states. Water law is entirely at the state level, and they do not want to share their authority.
Purposes	The emphasis of the different models of regions varies among river basins. It might include planning and management (association, districts, etc.), reservoir operation (including flood risk management), water permits, water use charges, water quality and quantity control, and others. Compacts are fairly static with time and usually have limited purposes and no integration between water quality and quantity. Therefore, they might not be used for management of routine activities, but serve mostly as a reference because there is no comprehensive water management for the whole country. Each state, in general, plans and manages its own water individually, and there are no federal water allocation laws in the U.S. Each state has the right to have its own set of water laws that it uses for allocation of water. This is the main reason why the U.S. has little effective river basin and interstate water planning.
Criteria	Hydrographic. Usually river basin limits in critical river basin areas. In Minnesota, it is the watershed limits. However, it varies among the different delineated regions.
Committees	Watershed groups in some parts of the country. There are some watershed groups being created in planning processes, but they are not recognized by U.S. federal law. At the federal level, there are many independent agencies, subcommittees, departments, and offices that have jurisdiction of water resource policy and funding.
Public Participation	Limited. Mostly at local levels and watershed groups; the public might participate, but it is not regulated.
Real Planning and/or Management at River Basin Level	No. Water resources planning and management are conducted at the state level. The U.S. Water Resources Planning and Management model is decentralized to the states and is not based upon river basin management, in practice. In shared river basins, some compacts were established in order to organize water allocation between states. River basin planning is not common, being restricted to some major watersheds.
International River Basin Commissions	The International Water and Boundary Commission (IBWC) is responsible for administering the transboundary treaties between the United States and Mexico, as well as resolving disputes related to the use of water. It involves the Rio Grande, Colorado, Tijuana and Yaqui rivers. The International Joint Commission (IJC) was established in 1909 by the *Boundary Waters Treaty*. It is responsible for administering the treaties between Canada and the United States, including necessary advising, protection measures, regulation, and conflict resolution processes. It has a long tradition of successful negotiation processes. It involves Alsek, Chilkat, Columbia, Firth, Fraser, Mississipi, Nelson-Saskatchewan, Skagit, St. Croix, St. John, St. Lawrence, Stikine, Taku, Whiting and Yukon Rivers.

	**UNITED STATES**
International River Basin Commissions (cont.)	Among the existing international river basin commissions, there is also the *Columbia River Treaty*, signed in 1964 in order to address some of the disagreements about the sharing of downstream benefits between Canada and the U.S. The implicated states from both countries had different power authorities, which made the negotiation process more challenging. Finally, the Great Lakes Commission is responsible for management and protection of the Great Lakes—St. Lawrence system, including water, land, and other natural resources.
General Comments and Questions	Jurisdiction over water resources policy is fragmented among more than 50 federal entities and nearly 53,000 water agencies in the United States. Water resources planning and management are largely conducted at the state level, and there are no harmonized or coordinated regions and no data sharing to attain an integrated vision of the entire river basin. There is no effective water resources planning and management at the river basin level in the U.S. Considering that several river basins are shared between the states in the U.S., coordination should be improved. The first comprehensive national effort to assess the nation's water resources was carried out by the Water Resources Committee of the Natural Resources Committee between 1935 and 1937. The Water Resources Council was established by the *Water Resources Planning Act of 1965*, to be responsible for a) maintaining a continuing study and preparing an assessment biennially of the adequacy of supplies of water necessary to meet the water requirements in each water resource region in the U.S.; and b) maintaining a continuing study of the relation of regional or river basin plans and programs to the requirement of larger regions of the nation and of the adequacy of administrative and statutory means for the coordination of water and related land resources policies and programs of the several federal agencies. The council recognized the need for standard geographic and hydrographic bases. One of the first tasks in preparing the second assessment was the delineation of geographic areas. In January 2010, the American Water Resources Association lauched a converstion about the need for a national water resources policy, plan or vision in the United States. Different groups have opposing opinions and there is no consensus (AWRA, 2010). According to the author, past attempts to develop national and/or regional water strategies were overcome by disputes over state versus federal dominance. In 1879, Powell discussed the possibility of the delineation of the U.S. using river basins, watershed, or hydrologic planning units. Natural features were used to define state boundaries because there was no advanced mapping technology available. Delaware's state boundaries, which were defined using surveying techniques, demonstrate the difficulties for modern water resources management practices.
Map of the Water Resources Regions	
References	Seaber et al., 1987; AWRA, 2010; Water Resources Council, 1968; Water Resources Council, 1970a; Water Resources Council, 1970b; Water Resources Council, 1980; Matthews and Germain, 2007; Duram et al., 2008; Ruhl, 1999; Deason et al., 2001; Kauffman, 2002; Berelson et al., 2004; PWCMT, 2010; Muckleston, 2003; Eisel, 2009; IBM, 2009.

Analysis of Water Resources Planning and Management Regions in Colombia

	**COLOMBIA**
Form / System of Government	Unitary Republic Executive
Water Resources Regions	Thirty-three *Corporaciones Autonomas Regionales* (CARs), or Regional Environmental Authorities.
Purposes	Management (including land, water and natural resources in general, in a multisectoral and integrated approach). The first CAR was created in 1954, following the U.S. TVA model. During the next 50 years, all 33 CARs were established in Colombia. Because they were created during different periods, they have different organizational structures. CAR is the highest authority for national resources, including water resources management. They are also responsible for implementing national policies and regulations. They are public institutions, composed of public and private territorial entities, including NGOs, business and communities, and representatives of the ministry and presidency. The main functions of CARs in relation to water resources are: 1) allocating water resources to users; 2) controlling water pollution for point and non-point sources; 3) formulating, approving and adopting Watershed Ordering and Management Plans; and, 4) designing, financing and implementing activities for the protection of ecosystems. CARs are also responsible for the conservation of forests and other ecosystems, such as wetlands, related to the hydrologic cycle. Water resources planning, in general, is not a regional or national priority. CARs generate their own financial resources, mainly though property tax and other taxes applied in their territory. They are not completely independent because they also have some funding from the national budget, which results in some political disputes.
Criteria considered when delineating water resources regions	Biogeography, Hydro-geographic and Geopolitical CARs, in general, follow the hydrographic (river basin) limits, in accordance with regional department boundaries. In addition, political jurisdictions, administrative regions and environmental protection areas are considered. For instance, at Rio Grande Madalegna, the river and its tributaries are grouped in one CAR because of the similarity of the problems.
Committees	CARs are autonomous, consisting of a regional board that appoints the director and approves the budget. However, there is no permanent River Basin Committee in Colombia.
Public Participation	The Regional Board is composed of a majority of regional representatives (department, municipal, NGO, business sector, and ethnic communities) and representatives from the national government (Ministry of the Environment and the President). In addition, for big projects' approval, there is public participation and discussions required by law.
Real Planning and/or Management at River Basin Level	Not always. The municipal authorities have strong political power. Therefore, when CARs are located near or contain a big city (e.g., greater than 250K in population), their power might be less than the municipality, especially for managing water resources. In these cases, CARs may not exercise full authority. Big cities have their own water utilities and manage most aspects of the water resources as independent units.
International River Basin Commissions	The *Organization of the Amazon Cooperation Treaty* (OTCA) promotes transboundary cooperation for the conservation and rational utilization of natural resources and the preservation of the environment in the Amazon territory.

	**COLOMBIA**
General Comments and Questions	There are five drainage basins in Colombia: Caribbean, Pacific, Orinoquia, Amazonia, Catatumbo. Colombia has a unique institutional framework in .Latin America, with decentralized environmental authorities and a market-based regulation for potable water and electricity utilities. The central government plays an important role through the Ministry of Environment. However, the water resources area, specifically, needs to improve its IWRM goals because, at present, current mechanisms are insufficient to implement the law and to guarantee efficient and equitable water resources management.
Map of the Water Resources Regions	
References	Blanco, 2008; Wikipedia, 2008; Instituto Humboldt, 2008; Ordoñez, 2009; Grigg, 2008; Poveda, 2009.

Analysis of Water Resources Planning and Management Regions in Mexico

	**MEXICO**
Form / System of Government	Federalism, 31 Federative Entities
	Republic
	Executive
Water Resources Regions	According to the *2004 Law on National Waters*, Mexico is divided into 13 administrative river basins regions or decentralized CONAGUA (Mexico's National Water Council) regions. The thirteen river basin regions and the respective localization of its basin organism's offices are: I. Península de Baja California (Mexicali, Baja California). II. Noroeste (Hermosillo, Sonora). III. Pacífico Norte (Culiacán, Sinaloa). IV. Balsas (Cuernavaca, Morelos). V. Pacífico Sur (Oaxaca, Oaxaca). VI. Río Bravo (Monterrey, Nuevo León). VII. Cuencas Centrales del Norte (Torreón, Coahuila). VIII. Lerma Santiago Pacífico (Guadalajara, Jalisco). IX. Golfo Norte (Ciudad Victoria, Tamaulipas). X. Golfo Centro (Jalapa, Veracruz). XI. Frontera Sur (Tuxtla Gutiérrez, Chiapas). XII. Península de Yucatán (Mérida, Yucatán). XIII. Aguas del Valle de México y Cutzamala System (México, Distrito Federal).
Purposes	Management, in general, including water quantity control and water supply, groundwater preservation, sustainable development, water quality, revenues, permits, water use culture, floodplain management, hydraulic infrastructure operation, data management and monitoring, water permits, planning and river basin organizations, and multiagencies coordination.
Criteria considered when delineating water resources regions	Hydrographic (drainage areas' limits, natural, and physical) and Administrative (municipal limits, political jurisdictions, and local councils). The approach considers both aspects, considering that the best water management unit for IWRM is the basin, but remembering that Mexican development planning, budgeting, and programs implementation has political boundaries (municipal, state, and federal). The combination of these aspects make it possible to comply with IWRM needs, as well as governmental structures and financial resources application.
Other Established Regions	There are 102 sub-regions, 314 hydrological basins, 37 hydrological regions
Purposes	Regional planning programs can be planned at the sub-regional level. State Management Units focus on local problems, user's relationships, and municipal questions. The 37 Hydrological Regions are mainly used for surface water quantification, including data management and monitoring, as well as the establishment of river basin commissions.
Criteria	Sub-regions are based upon political jurisdictions, and each sub-region includes a number of municipalities of the same state, so that regional programs can be planned at the sub-regional level. The Hydrologic Regions are coincident with river basin areas (hydrographic).
Committees	25 River Basin Councils, which promote coordination among federative units, the federal government, and water users and constitute an arena for public participation. Some of the River Basin Councils are not yet functional for all practical purposes and for promoting IWRM at a regional level. In every region, there is one Federal Basin Organism (decentralized CONAGUA) and one or more River Basin Council, River Basin Committee and Groundwater Technical Committee (COTA). The River Basin Councils and the River Basin Committees are composed of governmental representatives (federal, state and municipal), stakeholders, and society representatives. The COTAS are composed mainly of groundwater stakeholders of the same aquifer. The River Basin Councils correspond to hydrologic basins, and the River Basin Committees correspond to subbasins, microbasins and coastal areas. There are 17 River Basin Commissions that function in sub-river basins, 22 in micro-river basins, and there are 31 clean beaches committees. There are 76 COTAS covering one or more aquifers.

	**MEXICO**
Public Participation	CONAGUA is trying to improve public participation at regional and local levels in order to incorporate civil society interests, including the private sector, citizens' groups, and others. The River Basin Councils include the participation of water users and authorities at different levels, but the level of participation is different in each region. There is a special focus on planning processes and multi-sector agreements in order to increase the chances of complying with the goals established in these plans. The country recognizes that it is necessary to consider the opinion of the stakeholders and to involve them extensively when making decisions. However, it takes more time to make public participation more effective.
Real Planning and/or Management at River Basin Level	Mostly yes. A better balance between the central government and the regions is necessary, in order to involve all multi-sector regional stakeholders and focus on more technical and less political decisions.
International River Basin Commissions	The Mexico U.S. International Boundary and Water Commission (IBWC), or Commission International of Limits y Aguas (CILA), is responsible for helping to apply U.S.—Mexico Water treaties, as well as in the general allocation of transboundary waters at the Rio Grande (Rio Bravo), Colorado, Yaqui and Tijuana rivers. Mexico shares four river basins with Guatemala (Grijalva-Usumacinta, Suchiate, Coatán and Candelaria), and one with Belize and Guatemala (Río Hondo).The Guatemala, Belize and Mexico IBWC duties are related to monitoring the international rivers and solving water issues. Because there is plenty of water, there is no specific water allocation agreement in this case.
General Comments and Questions	CONAGUA, or Water National Commission (CNA), was created in 1989 and is responsible for the overall planning, management, monitoring, and development of water resources, as well as water policy design and implementation. Water is of federal domain in Mexico; therefore, CAN is also responsible for the promotion, regulation, and construction of hydraulic infrastructure for irrigation, water supply, and sanitation and flood control. In 1992, the *Law of the Nation's Waters* (*Ley de Aguas Nacionales*, LAN) was established, describing the role of CONAGUA, the structure and functioning of river basin councils, and public participation. States and Administrative River Basin Regions are in constant dispute over water management. In the course of history, many tensions were present because of the stronger power of these regions, compared to the states. Basin level water management institutions were started in the 1940s, when large-scale development projects were the priority, such as hydropower and irrigation. In the 1960s the power of river basin authorities was diminished because exportation or irrigated projects were reduced. Authorities were re-established in 1976 to coordinate water resources plans and policies. Their responsibilities included flood control, hydropower, irrigation projects, rural development, communications, and navigation. In 1982, the water management responsibilities were transferred to the state, and the river basin commissions disappeared. In 1992, the River Basin Councils were back, but not completely autonomous from the central state. Regarding some regional characteristics in Mexico, the northern and central regions are mostly dependant on groundwater and on the Pacific coasts on surface water. Most of the regions are water scarce and present important surface water deficits as well as aquifer overexploitation. The southern Gulf of Mexico coastal regions and the Yucatán Peninsula have the greatest runoff of the country, and floods are common. In the Yucatán, water demands are attended by a huge aquifer. All the regions suffer from water pollution due to insufficient wastewater treatment facilities.

MEXICO

Map of the Water Resources Regions

References

CNA, 2002; CNA, 2007; Scott and Banister, 2008; Biswas, 2008; Tortajada and Contreras-Moreno, 2005; Tortajada, 2001; Perez, 2009; Acosta, 2009; Lagunes, 2009; SEMARNAT, 2008.

Analysis of Water Resources Planning and Management Regions in Brazil

	**BRAZIL**
Form / System of Government	Federalism
	Republic
	Executive
Water Resources Regions	Twelve National Hydrographic Regions: 1) Amazonian; 2) Tocantins-Araguaia; 3) Western Northeast Atlantic; 4) Parnaiba; 5) Eastern Northeast Atlantic; 6) Sao Francisco; 7) East Atlantic; 8) Southeastern Atlantic; 9) Parana; 10) Uruguay; 11) South Atlantic and 12) Paraguay. Brazil's territorial base, at the national level, was established by *Resolution #32* of the Water Resources National Council in 2003.
Purposes	Allows guidance for water resources planning and management at the National Water Resources Plan level. The federal government established national hydrographic regions, recognizing the importance of establishing regional policies for the country at the river basin level.
Criteria considered when delineating water resources regions	Mainly Hydrographic. The National Hydrographic Regions are defined based upon river basin limits or groups of river basins, including socioeconomic, cultural, environmental, institutional, political, and regional aspects. Prior subdivisions of Brazil's territory present three regional committees and eight Hydrographic Region Councils. These and additional aspects were considered in some studies developed prior to the establishment of the national hydrographic regions. In the first study, selected aspects include hydrographic, main urban centers, climatic conditions, ecosystems, hydrogeology potential, water quality and quantity, predominant uses, political-institutional and socioeconomic conditions. In the second study, selected aspects include hydro-environmental (scarcity, pollution, flooding, conflict and protection of natural ecosystems) and strategic factors (related sectors' policies, governmental programs, management institutionalization stage and sensitivity of the interested parts).
Other Established Regions	More than 400 Federal and State Water Resources Regions. In these regions, there are 161 River Basin Committees installed at the state level and seven River Basin Committees installed at the federal level. The National Water Resources Plan established 56 planning units. At São Francisco River Basin Plan, for instance, four subdivisions were also established. Furthermore, there are divisions established by important sectors, such as hydroelectricity and transportation.
Purposes	Planning and Management, in general, including, river basin committees, licensing abstraction, controlling, and monitoring. They vary among states.
Criteria	Mainly Hydrographic. However, the criteria used to define water resources regions vary among states, as demonstrated by some studies on the definition of territorial boundaries for water resources planning and management. In São Paulo, 22 territorial units were established in 1991, considering historical (i.e., 1972 DAEE subdivision into 18 units), physical (geomorphology, geology, regional hydrology, and hydrogeology), political (compatibility with neighbor's regions, up to 50 municipalities per unit), and socioeconomic aspects (size limits, road distances). In Minas Gerais, 34 territorial units were defined considering physical (climate, hydroelectricity potential, hydrogeology, pedology, and morphology), socioeconomic (IBGE mesoregions, up to 50 municipalities per unit, human occupation process, and existing social organization initiatives), and hydrographic aspects (river basin limits, water quality indicators). In Santa Catarina, the territory is divided into ten hydrographic regions in 1998, considering river basin limits as the basic units, reasonable level of homogeneity (physical and socioeconomic aspects) among these basic units, maximum of three river basins and 40 municipalities per region, existing inter-municipalities associations, and size limits.

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Committees	In Brazil, river basin organizations are instituted by law. State and National River Basin Committees have been created in several regions according to existing social demands or political interests. However, they do not represent a uniform concept and are not present in the entire country. Legislation limits the creation of committees to the third level of tributary river basins; however, no additional guidelines are provided in order to promote better coordination.
Public Participation	Yes. Participation of governmental representatives, water users, and civil society is legally enforced, including deliberative power into River Basin Commissions. The representatives approve the River Basin Plan and propose the value to be paid for water use.
Real Planning and/or Management at River Basin Level	Yes, but not for the entire country. The 12 National Hydrographic Regions do not promote real and effective integrated water resources planning and management at the river basin level. Federal and State Water Resources Regions promote planning and management at the river basin level, but coordination must be improved in order to have IWRM.
International River Basin Commissions	Multi-lateral Agreements at La Plata Basin (Tratado da Bacia do Prata, 1969) and at Amazonas River Basin (Tratado de Cooperação Amazônica, 1978). There are several specific bilateral agreements also, for instance at Quaraí (1991) and Lagoa Mirim (1977) River Basins, between Brazil and Uruguai.
General Comments and Questions	Water legislation in Brazil was initiated with the institution of the Water Code in 1934. The political context at that time lead to the prioritization of the hydroelectric sector as the main user of water resources and the existence of water resources regions reflects hydroelectricity interests exclusively. On January 8, 1997, *Federal Law #9.433—Water Law*, established the National Water Resources Management System and introduced the National Water Resources Policy. On July 17, 2000, the Brazilian Water National Agency was charged by *Federal Law #9.984*, with the responsibility for the implementation of the *Water Law*. The *Water Law* defined river basin limits as the territorial unit for implementation of the policy and performance of the National System of Water Resources Management. However, this law did not expressly define *river basin* or *main course of the basin*. Considering the huge territorial extension of the country and its diverse drainage net, specific regulation regarding the most adequate scale and level of river basins for IWRM is necessary. For instance, river basins may include one to ten states, varying from small coastal watersheds (~50 km^2) to the Amazon River Basin (4 million km^2). In addition, article 20 of the *Brazil Federative Republic's Constitution*, from 1988, established the dual jurisdiction of Brazilian rivers, defining as the federal goods: lakes, rivers and other water flows in its lands of domain, or which flow through more than one state, are the boundaries with other countries, or flow to or come from foreign land, as well as marginal lands and river beaches. The advancement of the national policy is, therefore, dependent on agreements between federal and state governments, which should be based upon standard, widely accepted, and harmonized geographic regions that are not regulated yet. The legislation provides flexibility in the institutional solutions, foreseeing that the models would be negotiated between federal and state governments. True IWRM at the river basin level, instead of the river level, is the real challenge. Considering their legal authority, states also have their own water resources legislation, some prior to the federal government's legislation. Without the necessary guidelines from the central state, there are many existing obstacles to effective IWRM. For instance, the 12 National Hydrographic regions do not have appropriate scale for promoting water resources planning and management. There are several overlapping and disarticulated water resources regions and a high risk of extreme proliferation of river basin committees. For instance, 31 requests for the creation of Federal River Basin Committees (in river basins that

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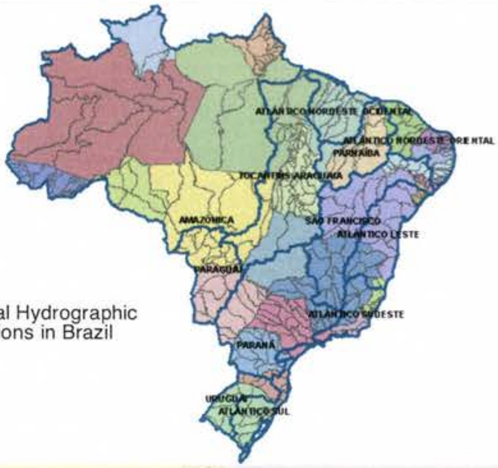
General Comments and Questions (cont.)	contain federal domain rivers) and only at Rio de Janeiro State, there are 25 federal domain rivers, with varied national and local relevance. The question of subsidiarity versus centralization is also important, given the dimension of Brazil's territory, regional differences, and the centralist tradition. For instance, a restricted analysis considering rivers as indivisible units should result mostly in water resources regions under the federal government domain. On the other hand, the extreme proliferation or water resources regions at very local levels, and respective river basin committees, may result in high financial costs for the system and lack of coordination. It is evidently the necessity of defining adequate criteria and appropriate levels for water resources planning and management regions, as well as the appropriate coordination among these levels. One step to address this issue was taken on April 13, 2010, when the National Water Resources Council approved *Resolution #109* that establishes the National Water Resources Management Regions at the federal domain rivers. It is expected that it provides better guidance on this process.
Map of the Water Resources Regions	 National Hydrographic Regions in Brazil  National Water Resources Management Regions
References	Barth, 2002; Kettekhut, 2000; DAEE, 1992; IGAM, 1999; Costa, 2003; Costa, 2000; Guimaraes and Magrini, 2008; Gontijo and Reis, 2008; Tortajada, 2001; Vasconcelos, 2006; Porto and Porto, 2008; Coelho et al., 2003; Sollero, 2003; Garrido and Freitas Jr, 2002; Braga, 2009; Lotufo, 2009; Flecha, 2009, Gontijo, 2009, Gondim, 2009; Costa, 2009; Braga and Lotufo, 2008; Silva, 2009.