The development and application of Information System for Water Management and Allocation (SIGA) to a negotiable water allocation process in Brazil.

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ABSTRACT

SIGA (Information System for Water Management and Allocation) is a generalized water resources system developed to help the planning and operation of water resources systems. Based on a node-link water resource network, SIGA has simulation, optimization, hydrologic and water quality models used to simulate the impacts of management and allocation rules in a water resources system. This paper presents the formulation and components of SIGA and its application to water allocation in the Upper Jaguaribe river basin, in the Ceara state of Brazil. The water allocation in Ceara is based on a negotiable process that relies on technical information (reservoir storages, water demand and availability scenarios) and participatory involvement of stakeholders. This paper presents the scenarios built in SIGA using two different methods of water system simulation showing possible improvements on the decisions by revealing the risks related to each allocation alternatives.

INTRODUCTION

Water resources management issues in Brazil have evolved rapidly since the National Water Resources Policy Act in 1997 known as 9.433 Law. The framework for the democratization and decentralization of the water resources management is one of the innovations of this law, which created the water basin committees and their roles, particularly in the water allocation process. Members of these committees are water users (farmers, sanitary companies, industries), governmental institutions (state and municipalities), universities, NGOs and even church organizations.

The state of Ceara has been recognized as a pioneer in involving the water users (organized in basin committees) in the water allocation process. Sited in the northeastern region of the country (one of the most populated semi-arid region in the world), the Ceara state is a fairly highly populated region, with poor social and economic indicators. The capital of the state concentrates around 42% of the state population and most of the jobs divided among the industrial and service activities. In the countryside, low levels of income have been related to environmental, climatic and socioeconomic conditions characterized by low and fairly distributed rainfall, droughts, poor soils, feel job opportunities (mostly related to agricultural activities) poverty and low levels of education. These environmental, social and economic scenarios compose the background of the water allocation process in the state of Ceara.

Despite of being frequently cited as a successful example of democratization (user participation and public debate) in integrated water management, the water allocation process in Ceara has been questioned in many ways, but mostly due to the lack of empowerment of local members resulting in actual concentration of power on state government. For more details of the water allocation process in Ceara state, readers are referred to Taddei (2010).

The State Water Agency (COGERH) is responsible for the organization of nine (out of the eleven river basins) water basin committee meetings that decide about water allocation in the state. Due to spatial and temporal variability of precipitation, most of the water in the state comes from a network of reservoirs that form the water resources system based on some water basin transfers. The water basin committee meetings happen at the end of the rainy season (Jan – May) when the reservoirs are at the maximum levels in the year. At the beginning of the meeting, water users attending the meetings receives from COGERH some technical information (tables and graphs related to reservoir levels, evaporation, water released in the past and proposed rates of water release to be voted, etc) to base the discussion and decisions. The quality of these information and the way it is presented to the members of the committee are important issues to be considered when one wants to communicate properly with the variety of water users and improve the water allocation process.

The planning and management of water resources systems involves the consideration of different objectives, interests and responsibilities the usually requires collaboration among conflicting interests. Because of these reasons, watershed management has been increasingly reliant on information technology. Recent advances in computer technology have enabled and accelerated the use and integration of mathematical models in the scope of watershed information systems. Most of these systems incorporate features that are useful for the complex task of water resources planning and management, such as: user-friendly interfaces (for both input and output information), fast computational ability, geographic representation of watershed features and scenarios, versatile output platform, and modules to guide consensus and discussion among stakeholders.T he development and use of information system to support decision in water management has been illustrated largely in the literature (Loucks et al. 1995; Loucks, 2000; Dai & Labadie, 2001).

However, decision makers and stakeholders are often excluded during the simulation modelling exercises, jeopardizing their acceptance and support of recommendations suggested as a result of the model application. Most of the time, the complexity of models, their large number of parameters and poor interfaces are obstacles for the effective application of models and appropriate interpretation of their results. Developing computational tools capable of overcoming these obstacles has been a challenge and a goal yet to be accomplished. These tools should be able to integrate different types of models and still be easy to apply

Since 2005, the Water Resources and Meteorology Research Foundation (FUCEME) has developed the Information System for Water Management and Allocation (SIGA). A watershed information system is defined as a computer tool designed to represent the elements comprising a watershed and their interactions. Since the simulations from watershed information systems will support watershed management decisions, confidence in them is extremely important. Developing or selecting appropriate watershed information systems is therefore essential for the credibility of management decisions and for the bases of public participation and debate. For the past three years, COGERH and FUNCEME have invested on efforts to improve and expand some functions of the SIGA in order to use its simulation models as the basis for the implementation of water management decisions in the state. This paper presents the use of SIGA to build shared vision scenarios of water allocation in the Jaguaribe basin. A discussion of the allocation process in the Jaguaribe basin follows the presentation of the SIGA components. Finally, the results of the simulation models are presented and discussed.

THE INFORMATION SYSTEM FOR WATER MANAGEMENT AND ALLOCATION (SIGA)

Some innovative methods of software engineering have been applied to the development of watershed information systems. Object-oriented methods are moving to the mainstream of these efforts and are providing a promising philosophy of systems development. In the last few years, several research papers have discussed the use of object-oriented approaches to the development of watershed information systems (Wilson & Droste, 2000). The application of object-oriented analysis and design methods permits software modularity and re-use. The C++ was chosen for the development of the watershed information system discussed in the present paper.

The mathematical models included in SIGA are organized in components integrated through graphical user interfaces (GUIs) that provide the connection among the models and permit interaction between models and users and model inputs and output data. In this paper, the Water System Operation component is presented in detail. The other components of the system are: network design; hydrology simulation and calibration; reservoir water quality; nonpoint source pollution; results presentation. Figure 1 depicts the interface of SIGA for the Water System Operation interface.

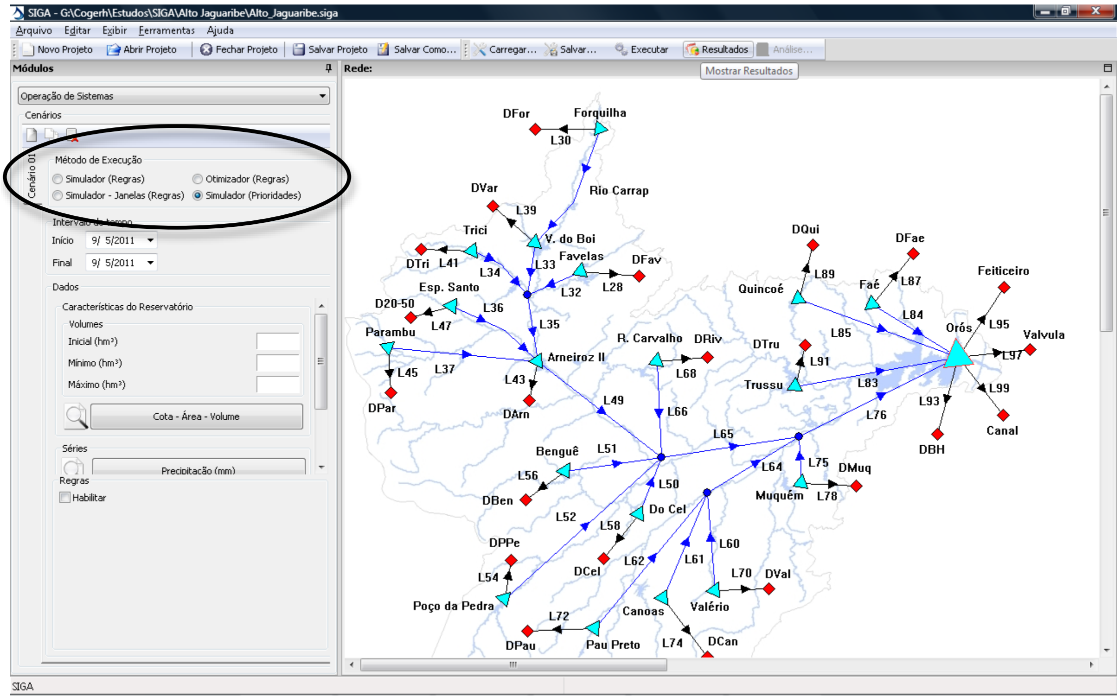

Figure 1: SIGA interface showing the Upper Jaguaribe basin system.

SIGA APPLICATION IN UPPER JAGUARIBE BASIN - CASE STUDY

The Upper Jaguaribe basin is part of the Jaguaribe river watershed. Twelve out of the 19 major reservoirs in the basin have capacity greater than 10 hm^3. These 12 reservoirs are responsible to meet the demands on the basin during the whole year. The water accumulated in the other 7 reservoirs (capacity lesser than 10 hm^3) is released during the dry season (June through December) to the water system and is used in rural demands during the year around. The Oros reservoir is the greatest one (1,940 hm^3) accumulating almost 70% of the total water in the basin. However, due to its location (lower end of the basin), this reservoir is also very important for the downstream basin demands (Medium and Lower Jaguaribe basin). Table 1 presents the monthly demand and capacity of the reservoirs in the Upper Jaguaribe basin.

Data from FUNCEME and the Thiessen Method were used to calculate the mean precipitation series in the basin. Mean precipitation in the basin varies from 532 mm/year to 1,127 mm/year. Discharge data from COGERH and National Water Agency (ANA) HidroWeb data base (www.hidroweb.ana.gov.br) were used to calibrate the hydrological model. This work calculated the incremental flow for the reservoir basins using the monthly SMAP (Soil Moisture Accounting Procedure) model available in the hydrological component of SIGA. SMAP is a conceptual lumped model that accounts the storage and flow of water in the soil using sequential linear reservoirs representing the hydrological processes. The detailed formulation of SMAP is available in Lopes et al. (1981).

Tabel 1: Reservoir capacities and monthly water demands in Upper Jaguaribe basin.

					Water System Demands in Upper Jaguaribe basin(m^3/s)								
Reservoirs	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	K (hm^3)
Forquilha	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	3.4
V. do Boi	0.034	0.034	0.034	0.034	0.034	0.034	0.232	0.232	0.232	0.199	0.199	0.199	51.9
Favelas	0.011	0.011	0.011	0.011	0.011	0.011	0.218	0.264	0.263	0.174	0.174	0.153	30.1
Trissi	0.076	0.076	0.076	0.076	0.076	0.076	0.166	0.186	0.123	0.131	0.101	0.076	16.5
Parambu	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	8.5
E. Santo	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	3.39
Arneiroz	0.058	0.058	0.058	0.058	0.058	0.058	0.76	1.058	0.855	1.258	1.075	0.688	197.1
R. Carvalho	0.042	0.042	0.042	0.042	0.042	0.042	0.127	0.042	0.438	0.042	0.042	0.042	19.5
Do Coronel	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	1.8
P. de Pedra	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	52
Bengue	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.121	0.351	0.021	19.6
Trussu	0.532	0.821	0.542	0.542	0.542	0.542	0.771	1.442	1.442	1.365	1.273	1.047	301
Quincoe	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	7.1
Muquem	0.096	0.087	0.029	0.029	0.029	0.099	0.342	0.361	0.503	0.771	0.479	0.229	47.6
Valerio	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	2
Pau preto	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	1.8
Canoas	0.15	0.08	0.08	0.08	0.08	0.1	0.15	0.17	0.2	0.25	0.3	0.25	69.3
Fae	0.002	0.002	0.002	0.002	0.002	0.002	0.1	0.1	0.1	0.1	0.1	0.1	23.4
Oros 1	0.269	0.351	0.18	0.18	0.18	0.06	0.455	0.5	0.5	0.723	0.6	0.535	
Oros 2	1.4	1.8	0.95	0.95	0.95	0.35	2.33	2.55	2.55	3.66	3.05	2.73	
Oros 2	1.967	1.201	0.685	0.54	0.54	0.54	0.766	2.04	2.04	2.379	2.923	3.395	
Oros 4	0.449	0.449	0.449	0.449	0.449	0.449	0.449	0.449	0.449	0.449	0.449	0.449	1,940

Table 2: Evapotranspiration data in Upper Jaguaribe basin. Source: INMET (2009)

	Mean Evaporation (mm)												
Gage					Potential evapotranspiration (mm) - Hargreaves								
(Lat/Long)	Jan	Fev	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
C. Sales	175	119	102	103	154	183	235	302	313	282	276	249	2494
7°0'/40°38'	162	118	115	106	107	108	120	151	173	195	192	190	1737
Iguatu	161	114	89.5	86.4	101	147	188	218	219	237	215	213	1988
6°37'/39°30'	204	160	146	127	128	130	152	170	185	206	203	209	2020
M. Nova	208	150	87.7	90.1	112	129	180	244	247	279	260	250	2235
5°2'/38°38'	189	150	135	126	120	117	142	172	183	201	196	202	1933
Tauá	220	161	119	129	132	166	226	248	274	308	290	276	2548
5°77'/40°42'	197	151	147	135	123	120	141	160	175	186	195	199	1929

The parameters in SMAP model for the Ceara state were defined using a parametric regionalization based on physiographic characteristics of the reservoir drainage areas and of the streamflow gages (Nascimento et al., 2009). The hydrological calibration component in SIGA was developed using the evolutionary algorithm Multi-Objective Particle Swarm Optimization-MOPSO (Alvarez et al., 2005; Alves, et al. 2006; Barros, et al. 2010). Table 2 presents the evaporation data from the National Institute of Meteorology (INMET) used to in the hydrological modeling of this work.

The first step in SIGA modeling is the drawing of the network that represents the water resources system one wants to simulate. Figure 1 presents the SIGA interface for the Water System Operation component. It shows the four possibilities of system modeling highlighted in the black circle of Figure 1: 1) rule simulator; 2) rule optimization; 3) rule window simulator; 4) priority simulator. The user should define the simulation period, reservoir data (initial, minimum and maximum capacity) and stage-area-volume curves for all reservoirs of the system and.

The simulation presented here used the methods 3 and 4 mentioned in the above paragraph. Both methods use a network flow model based on previously defined priorities for reservoirs and demands. The model searches for solutions that meet the demands considering the storage water available in the reservoirs upstream of the demands.

The method 4 (the priority simulator) represents the simulation of the water resources system (based on demand and reservoir priorities) considering there will be no inflow in the following months after the rainy season. This is the usual scenario used during the water user committee meetings for the allocation process. The method 3 (rule window simulator) is actually an alternative available in SIGA to be used during the water committee meeting for allocation process. It simulates the water available in the system for the next year considering historical data of the reservoir inflows. SIGA simulates the water system behaviors using many "windows of simulation" for the available inflow historical data. In this method, SIGA presents monthly percentiles of reservoir storage and stages. The authors consider this method more valuable for the allocation process because it gives a statistical analysis of the simulation and an evaluation of the risks related to each decision (allocation).

RESULTS DISCUSSION

This paper presents the results of the simulation of the water resources system in the Upper Jaguaribe basin using the method 3 (rule window simulator) and 4 (priority simulator) of the Water System Operation component of SIGA. The authors present here the results for the period of July - 2009 through January - 2010. Figure 2 shows the storage results in Oros reservoir based on releases decided during the water committee meetings for the allocation process. The volume of 1,274.9 hm^3 is the result for the Oros reservoir in January 2010. However, SIGA gives no information about the volume of the Oros reservoir during the rainy season because the method 4 has no tools (data) to simulate this information.

Figure 3 depicts the minimum, maximum and the 50th percentile volumes the Oros reservoir using the method 3 of the System Operation component in SIGA. This method uses historical inflow data to build the reservoir storage scenarios. The results presented in Figure 2 and 3 show that the storage values in Oros reservoir from July until December are the same, 1,274 hm^3. This confirms the hypothesis of zero inflow during the dry season of the year, July through December, stated in method 4 previous' simulation. But, the results from the method 3 stated in Figure 3 gives more information to the allocation process, once they simulate storage values for the rainy season too and evaluates upon statistical measures (percentiles) the risks related to the allocation (releases) defined for the simulation.

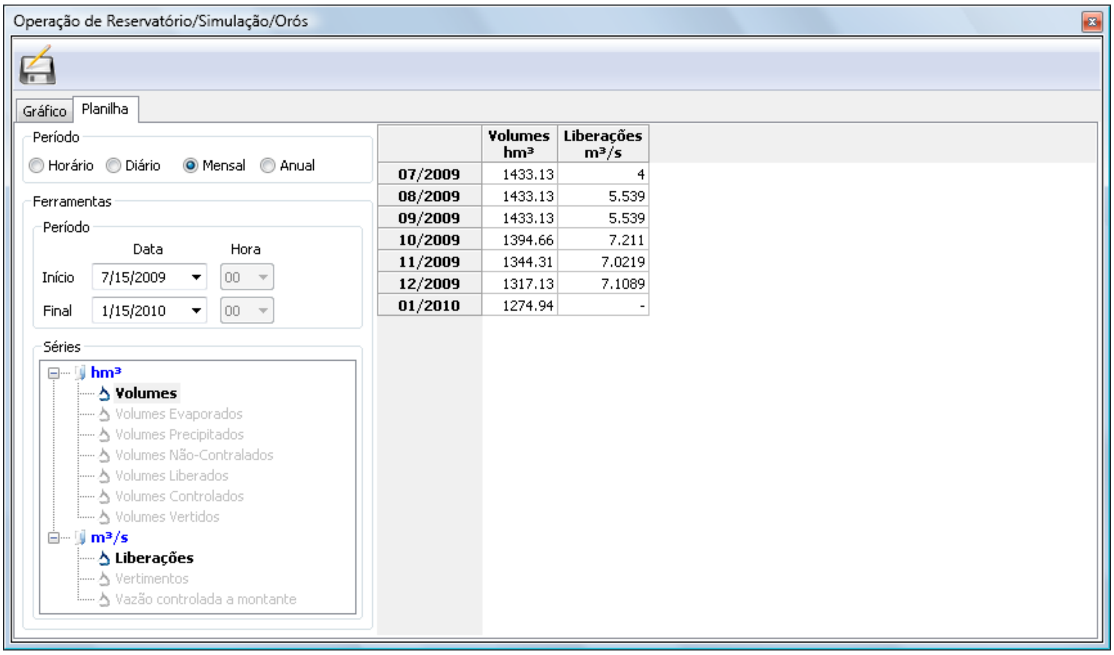

Figure 2: Storage and release results for the Oros reservoir using the priority simulator in SIGA and inflow zero after the rainy season.

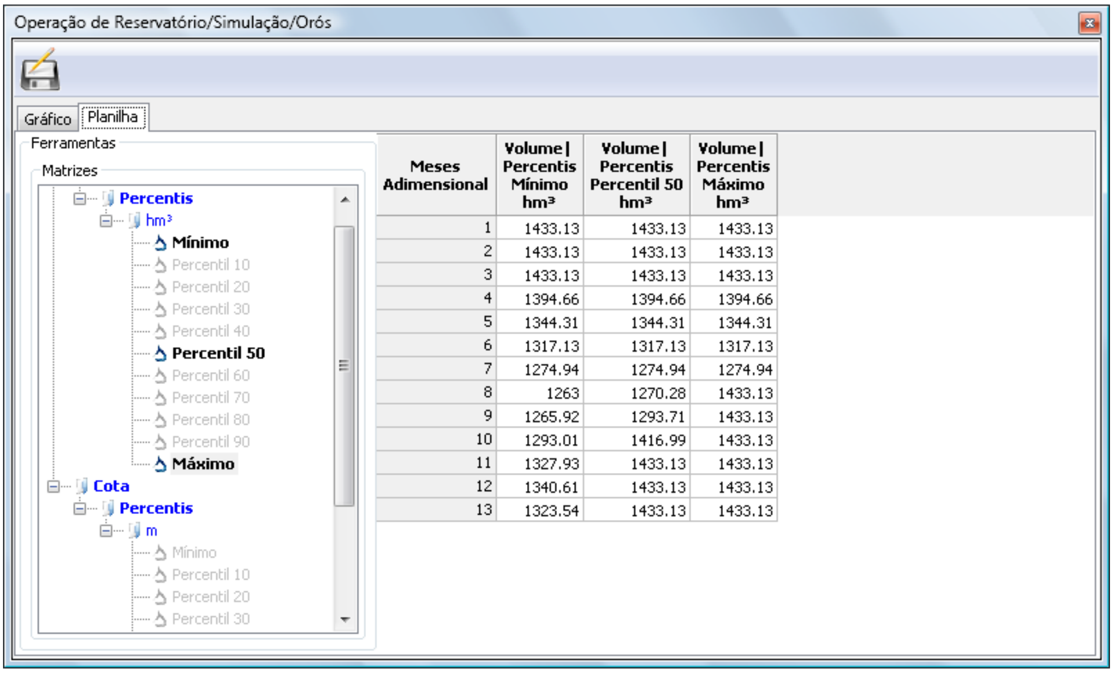

Figure 3: Storage and release results for the Oros reservoir using the window priority simulator in SIGA and historical inflow data for the following rainy season.

The success of the allocation process in the state of Ceara depends strongly on the clear understanding by the water committee members of the impact of their decisions on the reliability of the water system, on the economic development of the region and more broadly on the empowerment of water management stakeholders. Revealing the risks associated to each scenario based on the releases defined by the allocation process opens room for debates and negotiation among the members. Having more information available allow for more understanding about the water system behavior and about the consequences of each decision. And this is clearly one of the greatest roles of water information systems, to build information for the decision process and make them clear and understandable for the decision makers and stakeholders.

Comparison between methods 3 and 4 presented in this work favors the first method, the window priority simulator, because it gives more information for the decision process. However, the meaning of this information is most of the time hidden to the great majority of the stakeholders because they can't really understand the concepts behind the simulations and the probability results. In order to overcome this obstacle, it is very important to communicate properly and use as much as one can the available features in the water information system for the visualization of the results (graphs, maps, worksheets, etc). The way the simulation results are communicated to the public may have great impact on the results of the negotiation and on the effectiveness of the democratization itself.

CONCLUSIONS

SIGA is a water information system developed for the main purpose of supporting the water allocation process expanding the access to clear and understandable information. In that sense, it is a suitable tool to be used during the committee meetings. After more than a decade of water negotiations, the water committees are getting more and more technical leaving important sectors of the society out of the representation in the water committees.

Part of the critics about the allocation process in the state of Ceara comes from the lack of representativeness of some stakeholders such as small farmers, local social movements, local religious groups and even leaders of irrigation projects. On the other hand, researches have showed that most of the committee members believe that different levels of technical knowledge among participants is actually the main reason for inequality within the committee (even considering economic and political disparities). This announces the urge to invest in tools that could facilitate the communication among members of the committees and at the same time could improve the decision process by using knowledge based information and making them clear to all stakeholders. The SIGA has been developed upon this argument.

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