XVII[th] World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR)

Hosted by the Canadian Society for Bioengineering (CSBE/SCGAB)
Québec City, Canada June 13-17, 2010

SAD-RH: A GENERIC DECISION SUPPORT SYSTEM FOR WATER RESOURCE MANAGEMENT

M.DE A.G.M. DA HORA[1], E. MARQUES[1], A.F. DA HORA[1]

[1] M.deA.G.M. DA HORA, Universidade Federal Fluminense, Rua Passo da Pátria, 156, bloco D, sala 133, São Domingos, Niterói, RJ, BRAZIL, CEP 24.210-240, dahora@rionet.com.br.
[1] E. MARQUES, emarques@ic.uff.br.
[1] A.F. DA HORA, dahora@vm.uff.br.

CSBE101529 – Presented at the 10th American Ecological Engineering Society Annual Meeting (AEES) Symposium

ABSTRACT The new Brazilian water resource policy brought an innovation in the management, organizing and planning of water use in river basins, especially the instruments provided for its implementation, as the water right. During the decision process, the water manager may select the best alternative for a use or effluent discharge, so he must access information related to water resources and environmental issues, which are usually scattered among the environmental public services. Gathering such knowledge becomes a complex task that often does not allow the access to complete data. Thus, it is important to design a computational tool that can aggregate all necessary information to the water manager during the decision process, such as the issue of authorization. This paper presents a generic decision support system for water resource management called SAD-RH, developed in Delphi programming language. The system has layers containing relevant factors, such as: hydrographs, vegetation, conservation units, geology, slope, hydrological stations, surface water and groundwater monitoring points and water withdrawal points. The basin selected for implementation of the system is the Guapi-Macacu and Caceribu-Macacu region, located in the eastern portion of Guanabara Bay in Rio de Janeiro state, Brazil. The selection of this region was motivated by the fact that the Petrochemical Complex of Rio de Janeiro - Comperj, greater individual enterprise in the history of Petrobras, will be installed there.

Keywords: Water resource policy, Decision support systems, Water uses.

INTRODUCTION The water right is an administrative and legal instrument certified by the government agencies to allow anyone to use a specific quantity of water, on a specific time schedule, at a specific place, and for a specific purpose. The characterization of the water availability and the determination of its relationship with the current and future demands are fundamental in the definition of rules for the water partition among several users. The balance between the availability and the demand for several uses indicates the situation of deficit or of abundance in a specific basin.

Then, to the water resource manager it is important to work with a computational tool that allows him, during the decision process, to select in a safe and faster way the best alternative for the water use. It is necessary the data acquisition, usually dispersed among the several environmental public entities. Gathering such knowledge becomes a complex task that often does not allow the completeness of the data. Thus, it is important to design a computational tool that can aggregate all necessary information to the water manager during the decision process, such as the issue of water use authorization.

In this context, as proposed by BRAGA, BARBOSA and NAKAYAMA (1998), the decision will be linked to an information processing that will result in the choice of an action. The decision support system integrates models, data and routines that process the information and display the results in an easy format of being interpreted.

Based in this direction, it was conceived the Generic Decision Support System for Water Resource Management - SAD-RH, [HORA & MARQUES, 2010]. It was developed under the software development environment Delphi. The system presents layers that contain elements for the management of water resources, as: hydrography; vegetation, conservation units, geology, slope, hydrological stations, surface water and groundwater monitoring points and water withdrawal points. Moreover, it was formatted to generate information of discharge in any point of a river reach.

MODULES STRUCTURE SAD-RH was divided in four modules: SisMap (Thematic Maps Visualization System), SisInfo (Climate, Hydrology and Water Quality Information System), SisGeU (Water Uses Registration System) and SisRes (Reservoirs Operation System). The tool structure is presented in Figure 1.

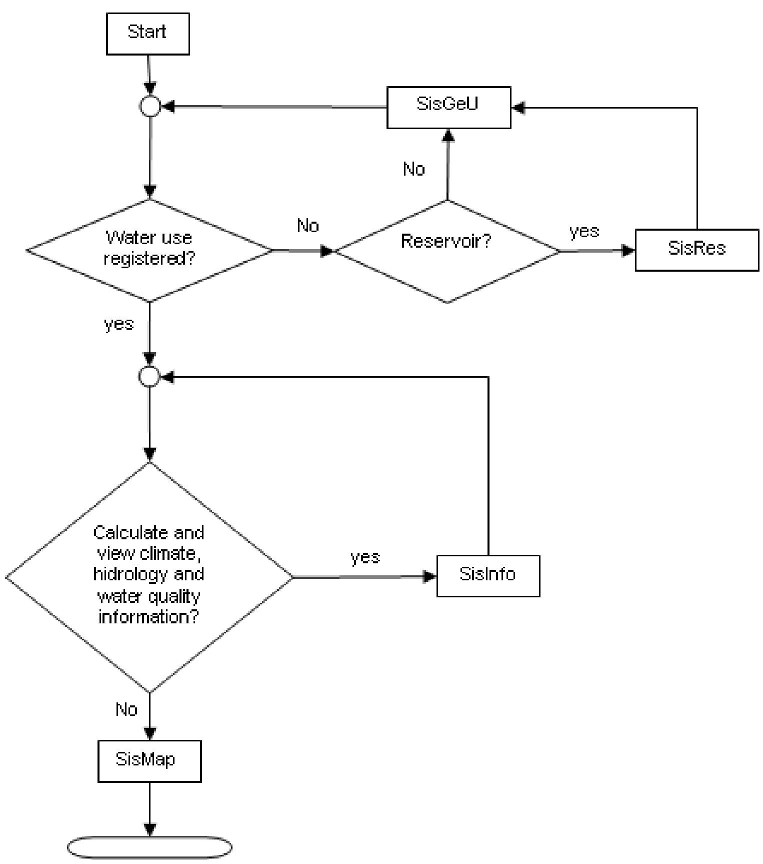


Figure 1. SAD-RH: Relationship diagram

METHODOLOGY SAD-RH was developed to be applied in any basin of the Brazilian territory. However, to certify its applicability and validation, available information about Macacu and Caceribu rivers, located in Rio de Janeiro State, were inserted. The study of this watershed was proposed by the Universidade Federal Fluminense with Petrobras Environmental Program support. The study received the denomination of "Strategic Planning of Guapi-Macacu Hydrographic Region".

Climate Calculation To evaluate the climatic variables, it was considered those involved in the reservoir water balance. Liquid evaporation and real evapotranspiration were calculated by CRLE - Complementary Relationship Lake Evaporation and CRAE - Complementary Relationship Areal Evapotranspiration Models, [MORTON,1983a] and [MORTON,1983b]. These models are adopted by the hydroelectric sector for the estimation of the liquid evaporation on reservoirs of the Brazilian Electric System, [ONS, 2004].

Hydrological Calculation To evaluate the hydrologic variables, it was considered those regarding the maximum, minimum and average discharges. The module has a functionality that estimates the discharges in any point of a river reach, with watershed between 25 to 597 km^2, as proposed by CPRM (2002).

The regionalized equations are potential type, $Q = a.A^b$, where Q is the discharge, in m^3/s, and A the drainage basin, in km^2. From the estimated equations, the constants “a” and “b” where recorded in the data base system.

Reservoir Routing To estimate the flood control, Godrich´s reservoir routing method was adopted, as proposed in SCHULZ (1989). The routing can be expressed as:

$$\frac{2 \cdot S_{t+\Delta t}}{\Delta t} + Q_{t+\Delta t} = I_t + I_{t+\Delta t} - \frac{2 \cdot S_t}{\Delta t} - Q_t \qquad (1)$$

If the initial storage state of the reservoir is known (or assumed) and if the hydrograph is given, then all the terms on the right side of the equation (1) are known.

<u>Spillway Capacity</u> It was considered in the reservoir routing, a free overfall spillway with vertical-faced ogee crest shape. The discharge capacity can be written as:

$$Q_{VERT} = C \cdot L \cdot (Hd)^{1,5} \qquad (2)$$

where:
Q_{VERT} spillway discharge, in m^3/s.
C discharge coefficient for vertical-faced ogee crest, in $m^{1/2}/s$, and equal to 2,08.
L crest length, in m.
Hd total head on the crest, in m.

<u>Submerged Orifice</u> In order to maintain a regular outflow, a circular submerged orifice was provided in the system. The outflow is found as follows:

$$Q_{DESC} = \mu \cdot A \cdot \sqrt{2 \cdot g \cdot H} \qquad (3)$$

where:

Q_{DESC} submerged orifice outflow, in m^3/s.
μ coefficient of discharge for submerged orifice and equal to 0,6.
A submerged orifice area, in m^2.
g standard gravity and equal to 9,81 m/s^2.
H total head, in m.

Discharge Regularization To simulate the reservoir operation, two conditions were considered due to the water level:

- **Water level between minimum and maximum stage:** the reservoir is in a filling or emptiness period, so the outflow is equal to the regularized discharge.
- **Water level between maximum and maximum maximorum stage:** the reservoir is fulfilled, so the outflow represents the spillway discharge and the regularized discharge sum.

The regularized discharge was defined as the constant outflow, calculated during the simulated period. As suggested by HORA (2008), it is calculated by an iterative process, equating both sides of equation (4):

$$\sum_{t}^{t_1}(Qaflu - Qreg) = \Delta V_{máx} + |\Delta V_{mín}| \quad (4)$$

$$\Delta V_{máx} + |\Delta V_{mín}| = Vutil \quad (5)$$

where:

Qaflu inflow, in m^3/s.
Qreg regularized discharge, in m^3/s.
$\Delta V_{máx}$ maximum accumulated difference between inflow and regularized discharge, in m^3.
$|\Delta V_{mín}|$ minimum accumulated difference between inflow and regularized discharge, in m^3.
Vutil reservoir useful volume, in m^3.

The orifice discharge is given by equation (6):

$$Q_{DESC} = Qreg \quad (6)$$

The useful volume of a reservoir can be expressed as:

$$Vutil_t = Vutil_{t-1} + (Qaflu_t \cdot ns) - (Q_{DESC\,t} \cdot ns) - Vevap_t \quad (7)$$

$$Vevap_t = EL_t \cdot A \cdot 1000 \quad (8)$$

$$EL = Ew - ETR \quad (9)$$

where:

$Vutil_t$ reservoir useful volume in month t, in m^3.
$Vutil_{t-1}$ reservoir useful volume in month t-1, in m^3.
$Qaflu_t$ inflow in month t, in m^3/s.

Q_{DESC_t}	orifice outflow in month t, in m^3/s.
$Vevap_t$	volume of evaporation from reservoir in month t, in m^3.
A	liquid surface area, in km^2.
EL_t	liquid evaporation in month t, in mm.
ETR	real evapotranspiration, in mm. Estimated by Morton's CRAE model.
Ew	lake evaporation, in mm. Estimated by Morton's CRLE model.

MODULES OPERATION In order to make efficient the manipulation, SAD-RH was build incorporating designs patterns, as the maps manipulation, GIS patterns.

Map Manipulation The basin map will be loaded when initiating the system and the user can access the navigation bar tabs, as shown in Figure 2:

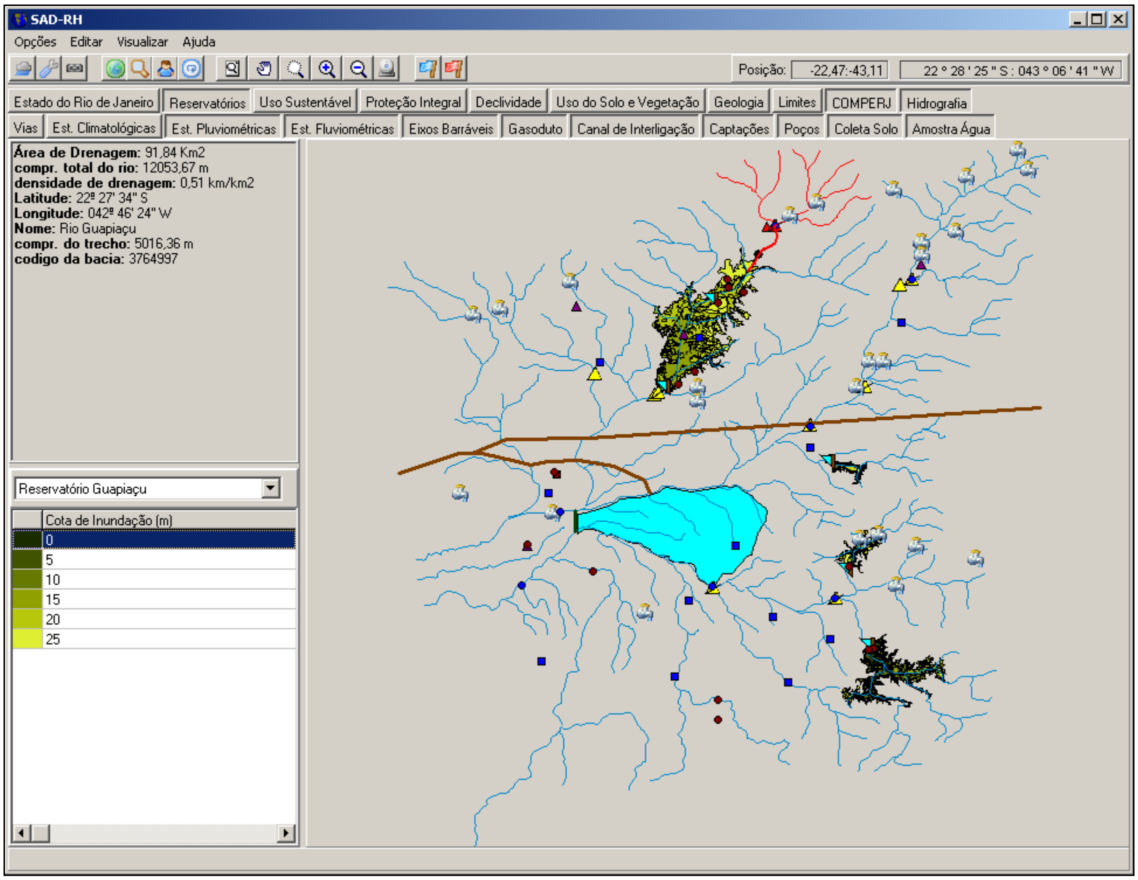


Figure 2. SAD-RH: Initial screen

The available physical characteristics information is:

- **Drainage area**
- **Total length of the river**
- **Drainage density**
- **Latitude and longitude**
- **Name of the river**
- **Length of the river reach**

Identification and localization of the drainage basin to a point defined by the user SisMap module allows the user to visualize the drainage area, as well as identify and locate the existing stations and reservoirs in any river reach. The user will be able to access the calculated area and the maximum, minimum and average discharges in the selected point, as illustrated on Figure 3.

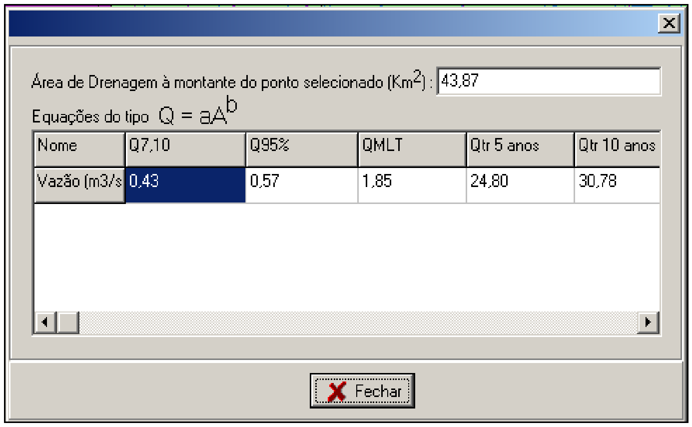


Figure 3. Maximum, minimum and average discharges of a selected point

Climate Variables To estimate the climate variables in any point, the user must select the initial and final period and click the 

button. The system will fill the table with the calculated values of lake evaporation (Ew), real evapotranspiration (ETR) and liquid evaporation (EL), as presented in Figure 4.

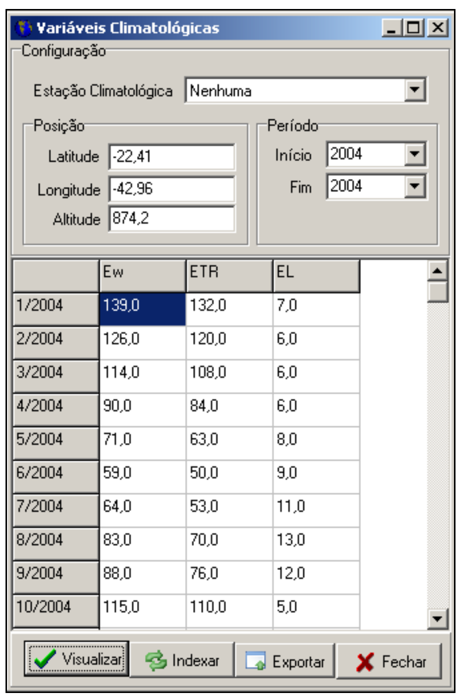
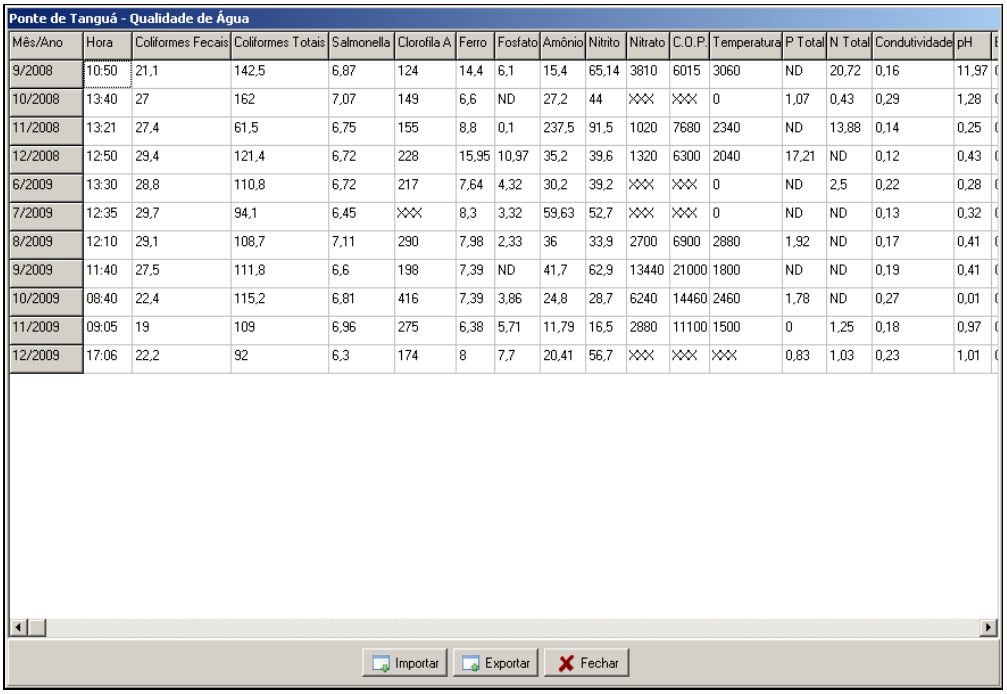


Figure 4. Climate Variables screen

Water Quality Data Base The user can access the water quality information. It is possible to import and export the data base, as shown on Figure 5.



Ponte de Tanguá - Qualidade de Água

Mês/Ano	Hora	Coliformes Fecais	Coliformes Totais	Salmonella	Clorofila A	Ferro	Fosfato	Amônio	Nitrito	Nitrato	C.O.P.	Temperatura	P Total	N Total	Condutividade	pH
9/2008	10:50	21,1	142,5	6,87	124	14,4	6,1	15,4	65,14	3810	6015	3060	ND	20,72	0,16	11,97
10/2008	13:40	27	162	7,07	149	6,6	ND	27,2	44	XXX	XXX	0	1,07	0,43	0,29	1,28
11/2008	13:21	27,4	61,5	6,75	155	8,8	0,1	237,5	91,5	1020	7680	2340	ND	13,88	0,14	0,25
12/2008	12:50	29,4	121,4	6,72	228	15,95	10,97	35,2	39,6	1320	6300	2040	17,21	ND	0,12	0,43
6/2009	13:30	28,8	110,8	6,72	217	7,64	4,32	30,2	39,2	XXX	XXX	0	ND	2,5	0,22	0,28
7/2009	12:35	29,7	94,1	6,45	XXX	8,3	3,32	59,63	52,7	XXX	XXX	0	ND	ND	0,13	0,32
8/2009	12:10	29,1	108,7	7,11	290	7,98	2,33	36	33,9	2700	6900	2880	1,92	ND	0,17	0,41
9/2009	11:40	27,5	111,8	6,6	198	7,39	ND	41,7	62,9	13440	21000	1800	ND	ND	0,19	0,41
10/2009	08:40	22,4	115,2	6,81	416	7,39	3,86	24,8	28,7	6240	14460	2460	1,78	ND	0,27	0,01
11/2009	09:05	19	109	6,96	275	6,38	5,71	11,79	16,5	2880	11100	1500	0	1,25	0,18	0,97
12/2009	17:06	22,2	92	6,3	174	8	7,7	20,41	56,7	XXX	XXX	XXX	0,83	1,03	0,23	1,01

Figure 5. Water quality information

Water Use Registration SisGeU module was divided in responsible user, reservoirs and water withdrawal. Besides these, there is a spatial visualization with the location of all registered uses. Figure 6 illustrates a water well registered use and Figure 7 the spatial visualization map.

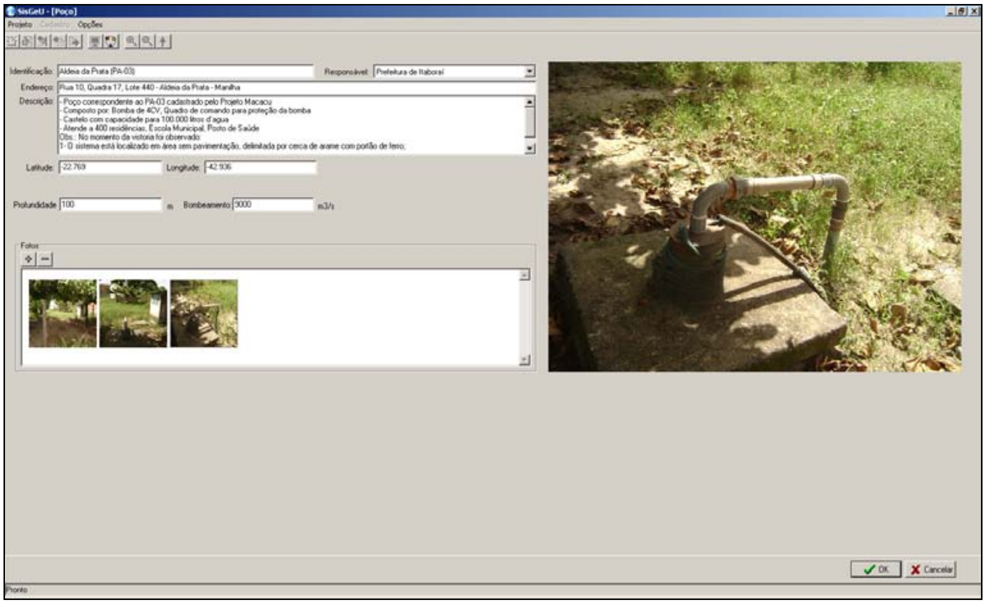


Figure 6. Water well registration screen

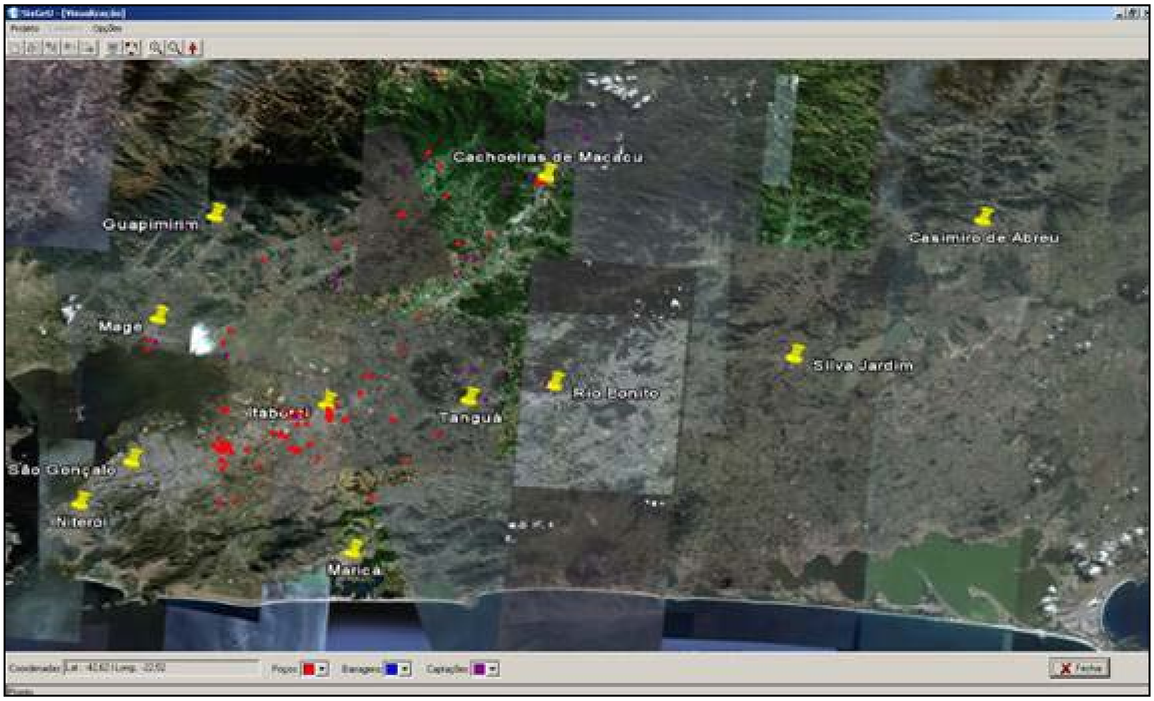


Figure 7. Registered users map

Reservoir Operation The SisRes module has two functionalities: Propag (reservoir routing) and Reg (regularized discharge). Both to aid in the knowledge of the flood control and regularization effectiveness caused by reservoir or hydroelectric power plants on rivers, more specifically in the definition of the outflow available to the downstream reach.

SYSTEM APPLICABILITY SAD-RH was developed to help the water resource manager needs and it is expected that it will be a useful and productive tool. The system assists the needs and requirements that motivated its construction. The evaluation of the accuracy was made by comparison among the drainage areas calculated by SAD-RH and those informed by the Brazilian National Water Agency - ANA for the hydrological stations. The results were very close, as illustrated on Table 1, percentage differences under 5%, allowing to infer that the system presents consistent answers. Applications showed also acceptable results that validate the use of the regionalized relationships.

Table 1. Comparison of Drainage Areas Values.

Station Code	Station Name	Drainage Area* (km^2)	Drainage Area** (km^2)	River´s Name
59235000	Cachoeira de Macacu	148,0	151,2	Macacu
59240000	Parque Ribeira	287,0	296,0	Macacu
59242000	Duas Barras	82,0	84,3	Guapi-Açu
59245000	Quizanga	352,0	355,2	Guapi-Açu
59500014	Reta Nova	374,4	395,0	Caceribu

* informed by National Water Agency - ANA.
** calculated by SAD-RH.

CONCLUSIONS The system can be considered as an aid tool in the water resources management, giving support to the manager in the decision process, as a water use authorization.

Starting from the visualization of the basin and the spatial distribution of the several uses in a point of interest, the manager can consult the available layers (vegetation, hydrography, conservation units, geology, etc.) and generate information of discharge in any point of a river reach to calculate the water availability. The comparison among the availability (estimated by SisInfo module) and the demand for multiple uses (registered in SisGeU module), indicates the water situation in terms of deficit or abundance in the area drained to the point of interest. The SisRes module can also support the water manager; it allows the knowledge of reservoir routing (Propag functionality) and the regulated downstream discharges (Reg functionality).

As future studies, it is recommended the application of SAD-RH in other Brazilian hydrographic regions.

Acknowledgements. This article has been realized with the financial support of the Petrobras Environmental Program that provided the development of the paper.

REFERENCES

BRAGA, B.; BARBOSA, P. S. F.; NAKAYAMA, P. T. Sistemas de Suporte à Decisão em Recursos Hídricos. **RBRH - Revista Brasileira de Recursos Hídricos**, Porto Alegre, volume 3, nº 3, p.73-95, jul./set. 1998.

BRASIL. Serviço Geológico do Brasil. **Relatório-síntese do trabalho de Regionalização de Vazões da Sub-bacia 59**. São Paulo, SP: CPRM, Novembro de 2002. 32p. Disponível em: www.cprm.gov.br/rehi/regionalizacao/sint_reg59.pdf. Accessed in May 2008.

HORA, M. A. G. M. **Metodologia para a Compatibilização da Geração de Energia em Aproveitamentos Hidrelétricos com os demais Usos dos Recursos Hídricos. Estudo de Caso: Bacia Hidrográfica do Rio Tocantins**. 2008. 143f. Dissertação (Doutorado em Engenharia Civil), Coordenação dos Programas de Pós-Graduação de Engenharia, Universidade Federal do Rio de Janeiro, Rio de Janeiro, 2008.

HORA, M. A. G. M.; MARQUES, E. **SAD-RH - Sistema Generalizado de Apoio à Decisão na Gestão de Recursos Hídricos**. 88p. Niterói, RJ; UFF/FEC. ISBN 978-85-910333-1-7. January 2010.

MORTON, F. I. Operational estimates of lake evaporation. **Journal of Hydrology**, Oct. 1983a, v.66, n.114, p.77-100.

MORTON, F. I. Operational estimates of areal evapotranspiration and their significance to the science and practice of hydrology. **Journal of Hydrology**, Oct. 1983b, v.66, n.114, p.1-76.

Operador Nacional do Sistema Elétrico. **Evaporações Líquidas nas Usinas Hidrelétricas - ONS-RE-3/214/2004**. Relatório. Rio de Janeiro: ONS, 2004. 61p. Disponível em: www.ons.org.br/download/operacao/hidrologia/rel_evapora%C3%A7%C3%A3o_08_02_2006.pdf. Accessed in June 2009.

SCHULZ, E. F. **Problems in Applied Hydrology**. Water Resources Publications. ISBN 0-918334-07-1. 501p. 1989. Colorado, USA.