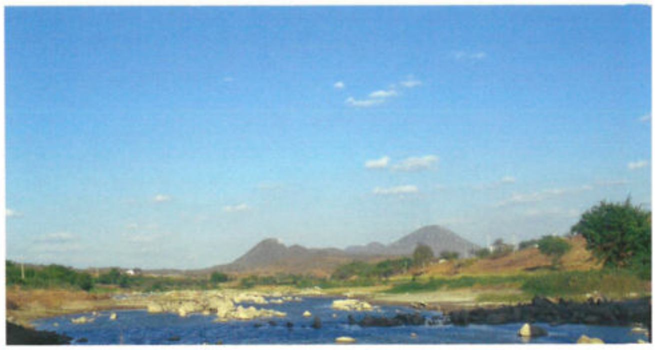

6

The BRAMAR Information and Decision Support System (Results from WP 7)

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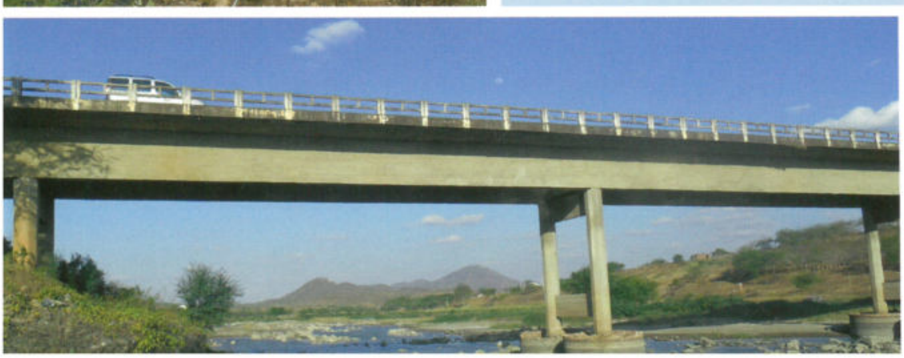


6.1 Decision Support towards IWRM Implementation

6.1.1 Need for Decision Support

The integrated management of all water resources is a complex and challenging task, especially in the case of regions affected by water scarcity, like in semiarid North-East Brazil. Indeed, there is a strong competition between the different water users under water scarcity conditions. This requires all stakeholders, water users and decision-makers to participate in the water-resources planning and decision-making process.

Due to the complexity of water resources systems, which commonly include man-made hydro-infrastructure, the system reaction to potential human interventions is difficult to analyze. Required are so-called Decision Support Systems (DSS) or Expert Systems, which offer special analysis and modeling tools in order to study the impact of human interventions in social, economic and environmental terms. Innumerous structural and non-structural measures may be implemented by water-resources planners to attend to the gap between decreasing water resources and increasing water demands due to climate change impact and uncertain socio-economic development, as in North-East Brazil. The chapter on WP 8 will provide an overview of potential IWRM measures, which also include innovative water technologies, e.g. related to wastewater reuse, as one of the focus areas of the BRAMAR research project. In a certain manner, all these measures compete with each other, each of them contributing to the sustainable development of water resources, but with different performance in social, environmental and economic terms. How well they can be implemented and transferred, how well they are accepted both politically and socially play an important role, too, when adequate IWRM measures are selected as response actions to specific water management challenges of a region. Innovative Decision Support Systems and planning procedures are required to support the water-resources planning process, taking all relevant aspects into account to select the most efficient response measures to guarantee sustainable development.

6.1.2 Main Challenges for System Development

A number of Information and Decision Support Systems (IDSS) have been developed in the past, attending to different water management challenges or objectives, such as water allocation, flood control or water quality management. They have proved to be powerful tools to support decisions with regards to different water-resources planning and management tasks. Thanks to DSS developments to support Water Resources Planning and Management (WRPM) tasks started in the mid-1970's, significant progress has been made in last decades. The following DSS may be mentioned: (a) Flood management: CWMS (FRITZ et al., 2002), SMS (EMRL, 2004), WMS (EMRL, 2004), (b) water allocation: AQUATOOL (ANDREU, 2004); DELFT TOOLS (DELFT HYDRAULICS, 2008); MIKE BASIN (DHI, 2008), (c) water quality: BASINS (USEPA, 2008), MODULUS (OXLEY et al., 2004), WISDOM (BMBF, 2010). (d) Managed Aquifer Recharge: GABARDINE DSS (RUSTEBERG et al., 2012). DSSWRP and MULINO are decision-support systems (EC, 2008) that specifically address the integrated management of water resources. The systems are mainly desktop solutions. Since most of the systems are directly linked or loosely coupled to hydrological models, the transferability of each DSS has to be carefully studied.

The main challenge for the development of an innovative Decision Support System within the BRAMAR project is to support water-resources planning and management decisions in a way that provides transparency in the decision-making process in order to guarantee political and social acceptance later. Thanks to automated processes, the user should be able to produce key information for water-resources planning – water-budget calculations for any partial river basin under study, budget forecasts based on different climate change and socio-economic development scenarios and identification of critical areas with regards to water scarcity. The information of the data base should be accessible to all persons and institutions involved in the decision-making process. This only can be achieved by a web-based, flexible, highly interactive and modular system structure, which guarantees that new tools and models can be easily integrated, and that different water-resources systems and boundary conditions flexibly applied. Therefore, a framework for a DSS has been developed in the present project. In order to support water-resources planning decisions and IWRM implementation, a generalized, participative and transparent approach had to be defined in the project and implemented in the DSS. Further information about this task is given under the following chapter.

Finally, when interdisciplinary demands and integration between project groups and stakeholders are considered, effective programming solutions are required in order to improve the allocation of time and to reduce the level of uncertainty in analysis, modeling and decision-making. Data organization and analysis were a key challenge of all BRAMAR research groups in order to contribute to efficient data-base management.

6.2 The BRAMAR-IDSS

6.2.1 Conceptual Structure, Data Base and Graphical User Interface

The BRAMAR Information and Decision Support System (IDSS) is a web-based modular system. **Figure 6.1** shows the Modular System Architecture. The BRAMAR IDSS is made up of four key components: Interfaces, data bases (internal/external), a tool base for analysis and a decision-support tool set for water-resources analysis and planning or comparison of technological options (SPRAGUE, 1989).

The user interface, which was developed for Internet browsers using the ArcGIS API for JavaScript (ESRI, 2017), ArcGIS for Server services (ESRI, 2015) and the DOJO/DIJIT/DOJOX JavaScript toolkit, along with other tools to enrich the user interface. The developed graphical user interface (GUI) uses an HTML site with JavaScript, which uses AJAX techniques; Ajax is a concept of asynchronous data transmission between a browser and the server (NIEDERAUER, 2013). This makes it possible to perform website requests, while the website is displayed, and allows a user to change the page without completely reloading it.

The GUI is very similar to most of the GIS platforms (BURROUGH and MCDONNELL, 1998). **Figure 6.2** presents an example of a GUI, using the Web Geographic Information System, to access water demand information, presenting the main system menu in the upper part of the screen. The main menu items are View, Water-Resources Planning, Geoprocessing, DS Tools, Analysis, Bookmarks, Water Permits and Help. Different water resources stakeholders with various knowledge levels (professionals, students, policymakers, etc.) can easily access the BRAMAR-IDSS.

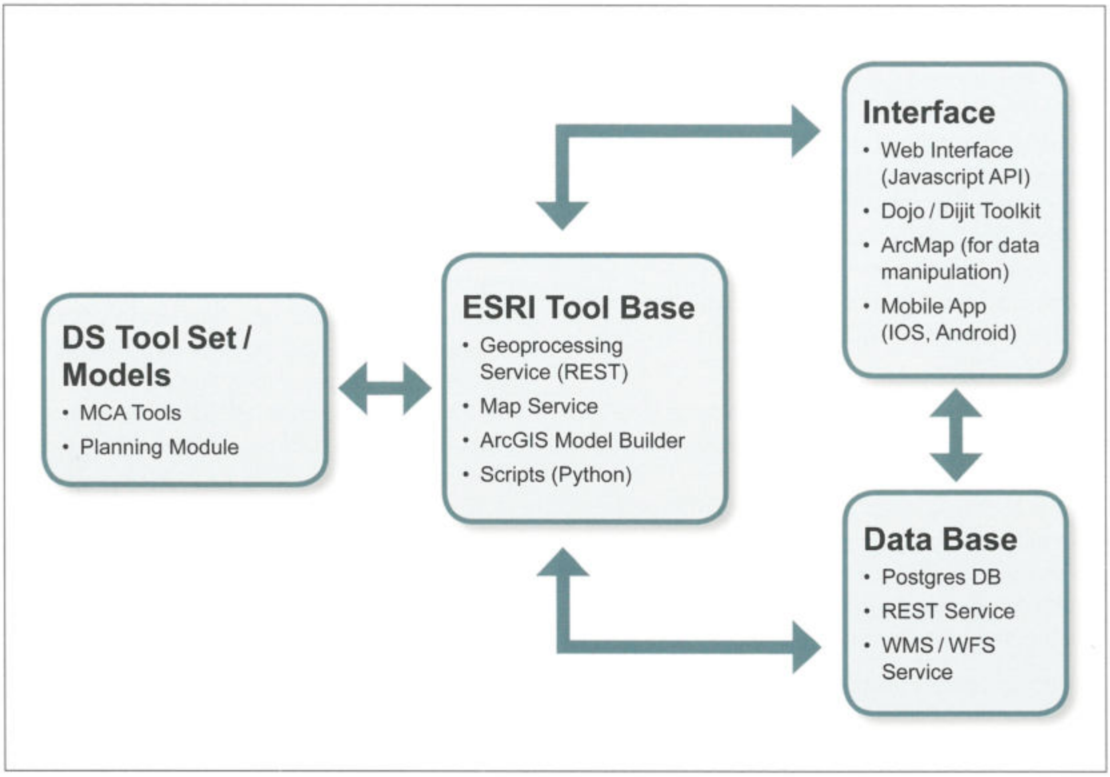


Figure 6.1: Conceptual/modular system architecture of the IDSS

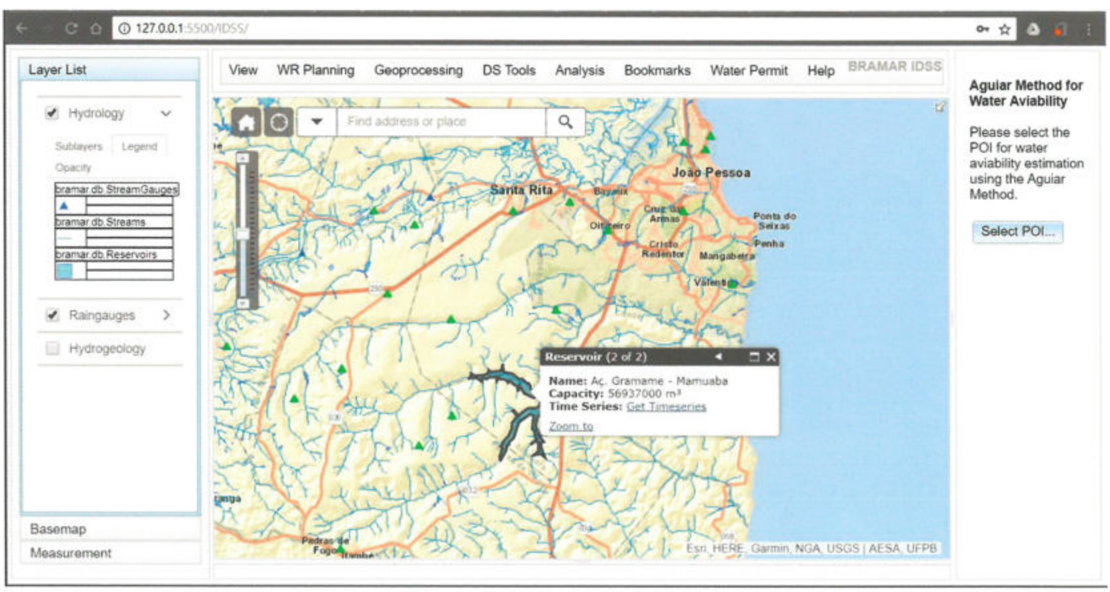


Figure 6.2: Graphical user interface BRAMAR IDSS (Esri, HERE, Garmin, NGA, USGS AESA, UFPB, edited by: G.N. Souza da Silva)

The adopted solution allows maps and geographical information to be accessed anywhere, anytime, on any device, including web browsers, smartphones and desktop applications. The target users are water-resources stakeholders (end users and/or policy makers), academic users and researchers. The IDSS provides them with access to the information in a collaborative way; users can provide some information to the system, too. **Figure 6.3** presents different system users, from different levels of knowledge and different roles in the system.

Three components are connected to the user interface: a database where every single kind of information is stored, from temporal data to spatial data; a tool base that provides general tools for data processing; and a model base where different procedures and environmental models can be linked. A hydrological regionalization model may be accessed from the model base.

Proper support for water-management decisions requires a well-modeled database. In the BRAMAR-IDSS the geo- and water-resources database is a core module, allowing spatial and temporal data management. The IDSS connects to the data base and supports the visualization of relevant water-resources management information as well as the access to source data as basis for mathematical modelling. **Figure 6.4** shows the conceptual layout - spatial data (features) and temporal data (time series) of the BRAMAR database.

ArcGIS for Server has been identified as most appropriate solution with an underlying PostgreSQL database management system (RAMAKRISHNAN and GEHRKE, 2000) for the development of the BRAMAR data base and the IDSS. The system offers a wide spectrum of capabilities, which can be easily customized for geographical and hydrological analyses within the BRAMAR project. Database/GIS features are accessible through a rich web interface including data and group management and facilitates the use of a complex database for Non-GIS professionals. The web interface makes it simple to integrate, store, share and publish data (RUBALCAVA, 2015). Advanced users can use ArcGIS for Desktop or any other API/Query interface for DB/GIS access. Furthermore, the obtained data and developed tools can be accessed

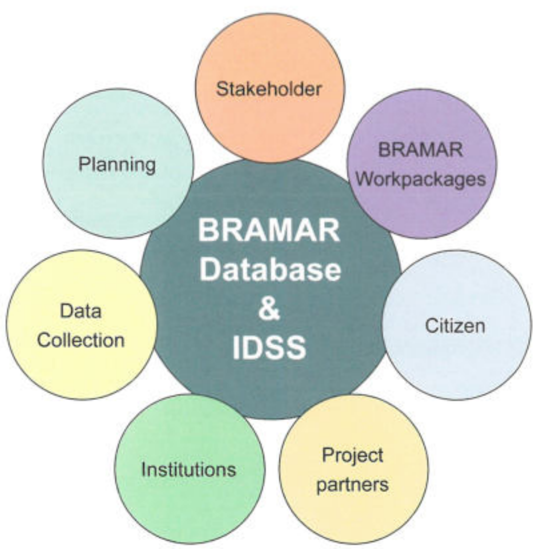


Figure 6.3: BRAMAR database and integrated concept of the system

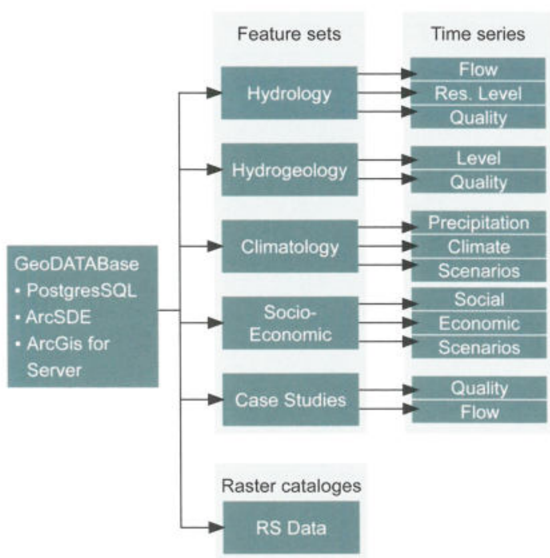


Figure 6.4: Conceptual layout - spatial data (features) and temporal data (time series)

with common web and desktop applications, like Google Earth, ArcGIS Online, SNIRH (ANA) and open source platforms. There are several Brazilian government institutions that use the same platforms to share data, such as the National Water Agency (ANA) for the National Water Resource Information System (SNIRH) , CPRM and IBGE .

The IDSS allows, for example, the editing of BRAMAR borehole data and monitoring data and provides, therefore, support to the joint monitoring and conjunctive management of surface and groundwater resources, which is one of the major challenges of the National Water Agency ANA and all state water agencies. **Figure 6.5** shows the borehole selection table and information window.

Time series can be edited by using different interfaces (beyond the IDSS), using the ArcGIS REST services connected to the BRAMAR database.

Based on aquifer characteristics, groundwater monitoring data and hydrogeological models, several groundwater related maps and information may be generated, such as on aquifer thickness, depth to groundwater, residence time in case of controlled groundwater recharge or location of pollution sources and impact.

6.2.2 BRAMAR Decision Support Tools

Introduction

The Decision Support (DS) tool base consists of Operations Research methods, especially based on Multi-Criteria-Analysis methods. They can be used for identification, rating and selection of decision alternatives, exemplification of the decision-making process, and allow the comparison of alternatives by means of performance matrices.

Water Permits

To provide support for the analysis of water demand, tools for water-permit management and technical analysis were integrated into the BRAMAR-IDSS. The system aims to provide support for the technical analysis of requested water rights and decision support and even permits to plan field visits in order to check water-permit data in

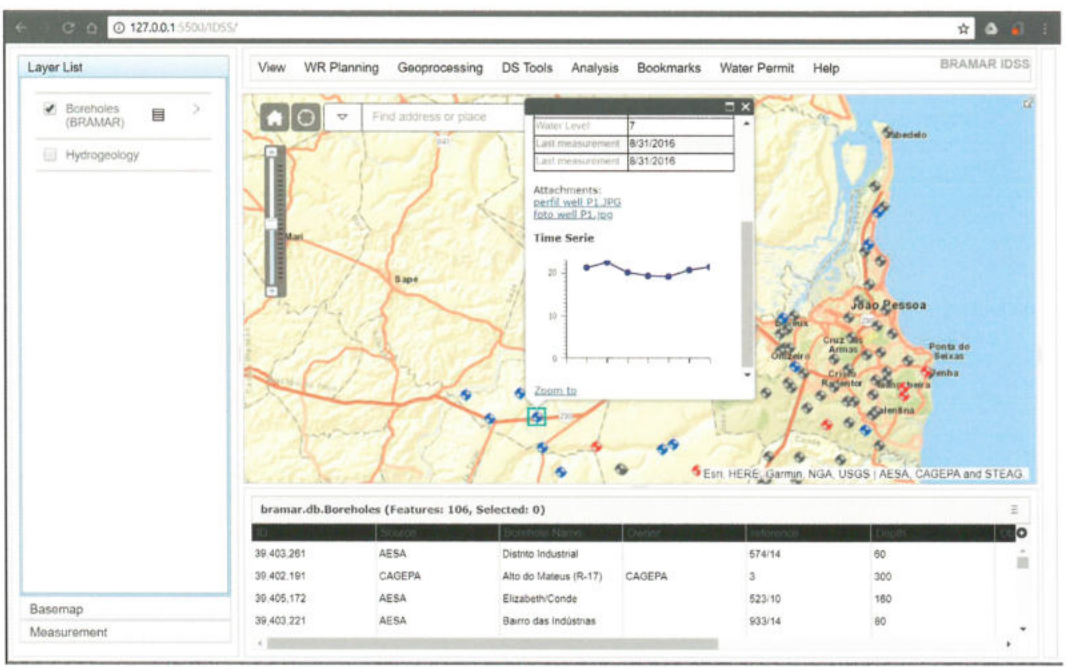


Figure 6.5: BRAMAR borehole data in the IDSS interface (Esri, HERE, Garmin, NGA, USGS, AESA, CAGEPA and STEAG, edited by: G.N. Souza da Silva)

loco. Granting water permits is a very important task, since permitting additional water use in areas with previously existing or expected water deficits may result in serious water conflicts. **Figure 6.6** shows the simplified process of the water-permit process.

The water permit support tools were integrated in the IDSS interface. **Figure 6.7** shows the interface with added SNIRH data (national water-permit web service).

Innovative tools for the filtering of water-permit data have been introduced into the BRAMAR-IDSS in order to support the work of the Environmental State Agency AESA, by making the access to the existing water permits easier and enable specific water demand assessments.

The option opens a new window which allows users to select the search field and define a value for a similarity search. The tools permit them to aggregate and analyze water permits for any partial

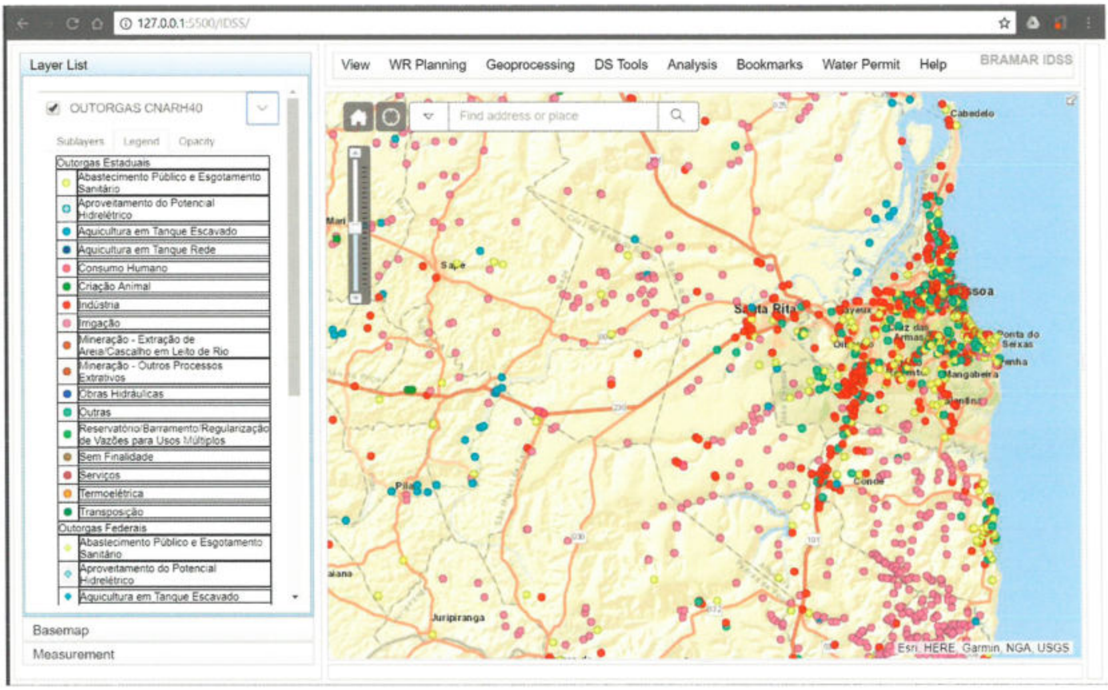


Figure 6.7: Water-permit analysis (Esri, HERE, Garmin, NGA, USGS, AESA, ANA, edited by: G.N. Souza da Silva)

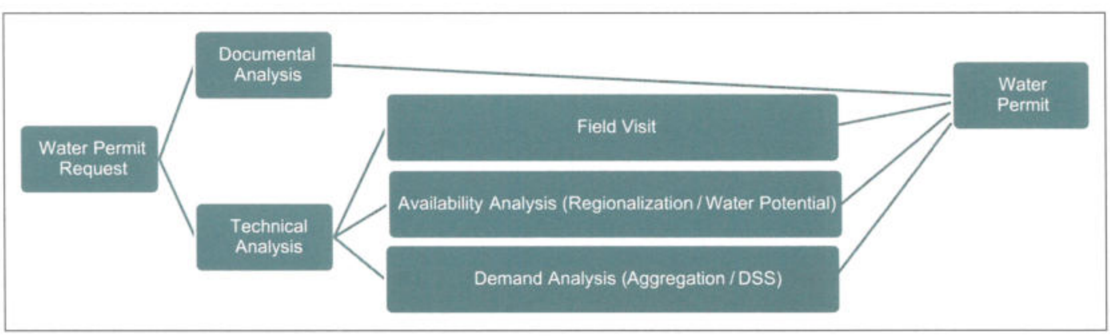


Figure 6.6: Water-permit process

area, designed by the user, or any partial watershed, which is being generated by the BRAMAR-IDSS in an automated process. **Figure 6.8** shows how selected water-permit data is being listed and how to access the filter, which permits data filtering, e.g. according to process number, type of water use, source of water, name of river, requesting party or state of licensing process.

Multi-Criteria Analysis

The BRAMAR-IDSS contains Multi-Criteria-Analysis (MCA) tools to support water-resources planning decisions. In this section, a short example is given how the system supports the selection of locations for groundwater recharge facilities in the context of Managed Aquifer Recharge (MAR) implementation. More detailed information about BRAMAR research on MAR is given in the chapter on WP 3. The planning procedure follows the approach presented by Rusteberg et al. (2012). The main steps of this procedure refer to so-called constraint and suitability mapping. First of all, the relevant decision criteria (indicators) are selected from those for constraint mapping and suitability mapping. For the selected criteria, criteria maps were developed for the project region, which represent their spatial distribution. For example, the land-use map was reclassified for the MCA site selection using eight classes. **Figure 6.9** shows the reclassified land-use map for the Gramame and Lower Paraíba region.

The interfaces for constraint and suitability mapping were developed using range sliders. Horizontal range sliders are used to define upper and lower threshold values for suitability mapping. This has the advantage that false user input is eliminated, because minimum and maximum values of the data are already defined by the sliders. Selected values are also visualized. Furthermore, a mapping window for feasible land use selection is generated.

Furthermore, all processed criteria can be reviewed to detect which ones do not meet the selected thresholds. The suitability analysis has more parameters and is more complex than the constraint mapping; therefore, a Python Script was created which calculates the suitability map-

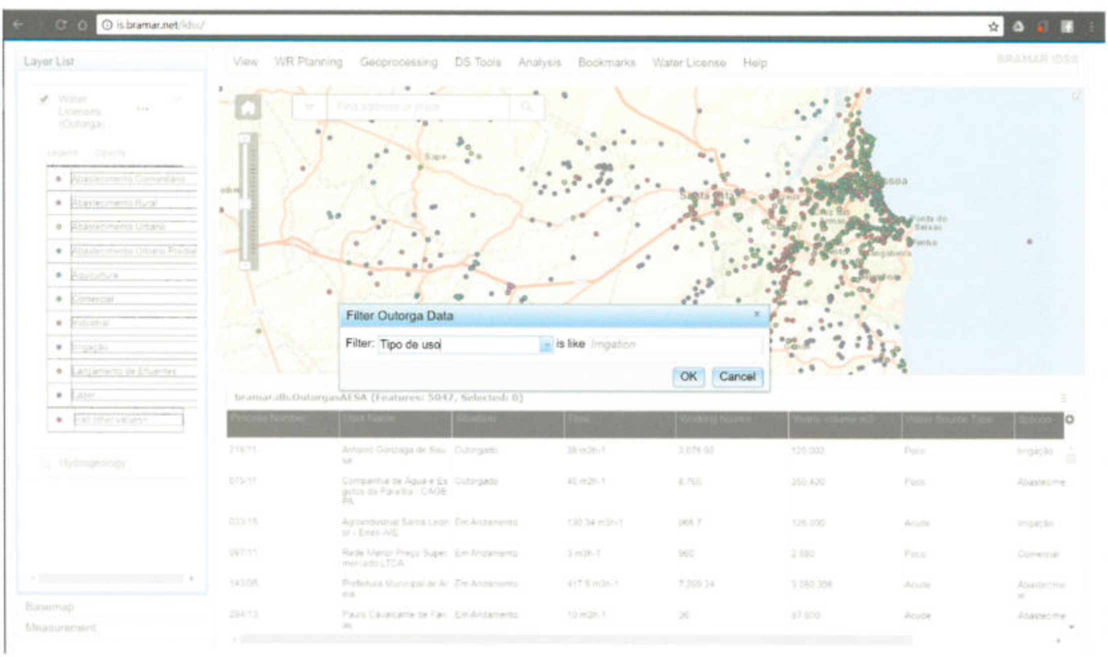


Figure 6.8: Analysis of Water-Permit Data (Esri, HERE, Garmin, NGA, USGS, AESA, edited by: G.N. Souza da Silva)

ping with the provided parameters including standardization, weighting and raster summation. **Figure 6.10** shows the user input form for Suitability Mapping. The different weighting is selected, and lower/upper bounds are chosen by the user.

Lower and upper threshold are used to linearly transform the function values to a specified evaluation scale. For suitability mapping all criteria values are transformed in a value range from 0 to 1. **Figure 6.10** provides an example of how suitability mapping results are presented. Results are classified in four ranges: 0 to 0.25, 0.25 to 0.5, 0.5 to 0.75 and 0.75 to 1. This mapping classification provides information for the best locations with regards to the implementation of groundwater recharge facilities.

Water budget

Any partial watershed can be analyzed using the tools provided in the IDSS, which are based on a point of interest and the watershed delineation of this point. Based on this delineated watershed, water demand and availability are analyzed using provided data from work packages. The water budget is key information in any water-resources planning process. Detected water deficits in the present or near future are main causes of water-related conflicts.

The calculation of the water budget for partial watersheds as automated procedure in the scope of BRAMAR-IDSS follows a step-wise approach, as presented in the below **Figure 6.11**.

The regionalization tool is especially helpful in regions with scarce river runoff data to transfer available river runoff time series to any nearby river cross section in the watershed.

The tool uses the web interface to select the point for which the regionalization will be executed (outlet of partial watershed) and nearest or most appropriate point with available runoff time series. The BRAMAR-IDSS provides a discharge duration curve based on river runoff data and the regionalization data in order to derive characteristic parameters for

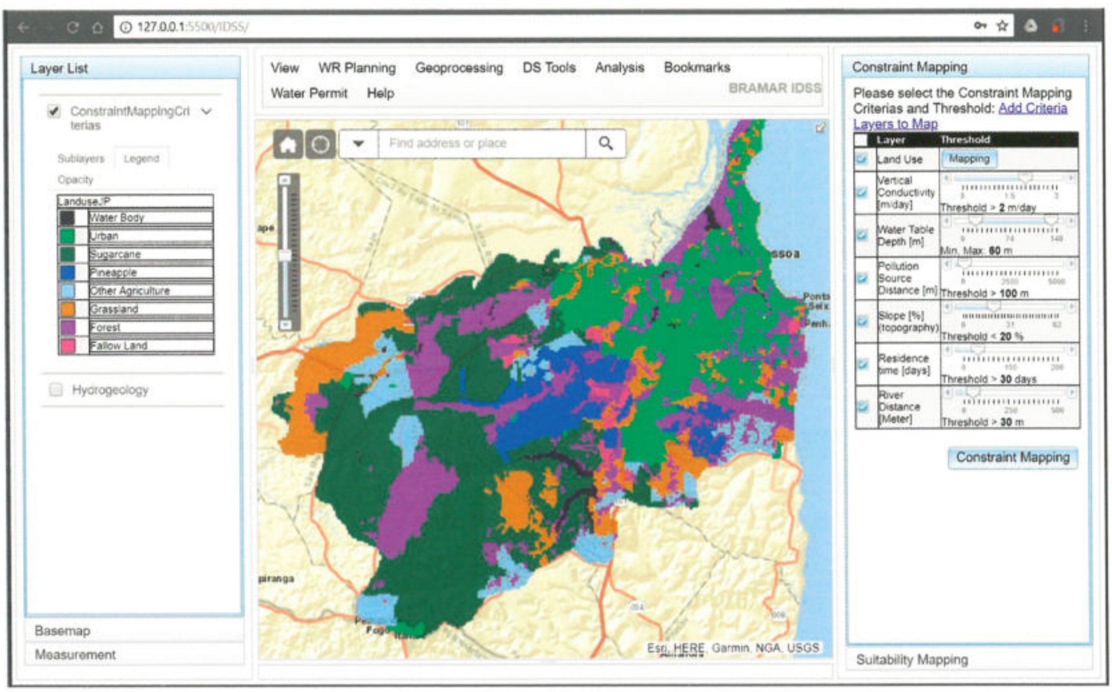


Figure 6.9: Land-use map for MCA site selection (Esri, HERE, Garmin, NGA, USGS, UFPB, edited by: G.N. Souza da Silva)

the assessment of the surface water availability at the outlet of the partial river basin (**Figure 6.12**).

Climate change data was provided in BRAMAR work package 1. Three models were used in WP1 with scenarios for RCP4.5 and RCP8.5. This data (precipitation and temperature) can be accessed for visualization in the IDSS. Rainfall runoff models are used to estimate water availability, using the rainfall distribution and temperatures. The integration of climate change scenarios uses runoff data and the developed regionalization for partial watershed availability estimation. Detailed information about the climate change studies is presented in the chapter on WP 1.

For the water budget forecast, first of all, water demand and water availability must be calculated by the BRAMAR-IDSS. The obtained data is automatically used in a water budget sub-module, which allows the comparison of the scenarios. For both, water demand as well as water availability assessment, the development and climate change scenario, respectively, must be selected. Furthermore, a time horizon for forecast calculation needs to be specified by the system user.

A key functionality of BRAMAR-IDSS is a comparison between the surface water availability of the partial watershed and the water demand, based on a water-permit data base. These are most valuable results for any water and environmental

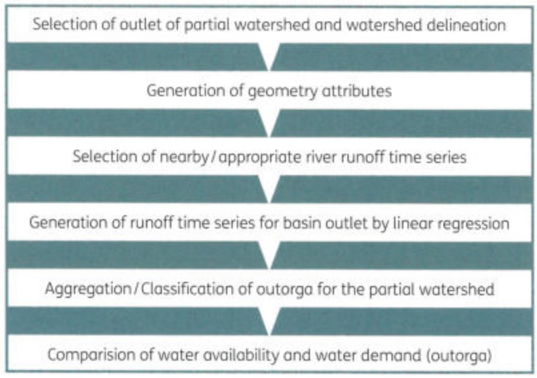


Figure 6.11: Calculation of water budgets for partial watersheds within BRAMAR-IDSS

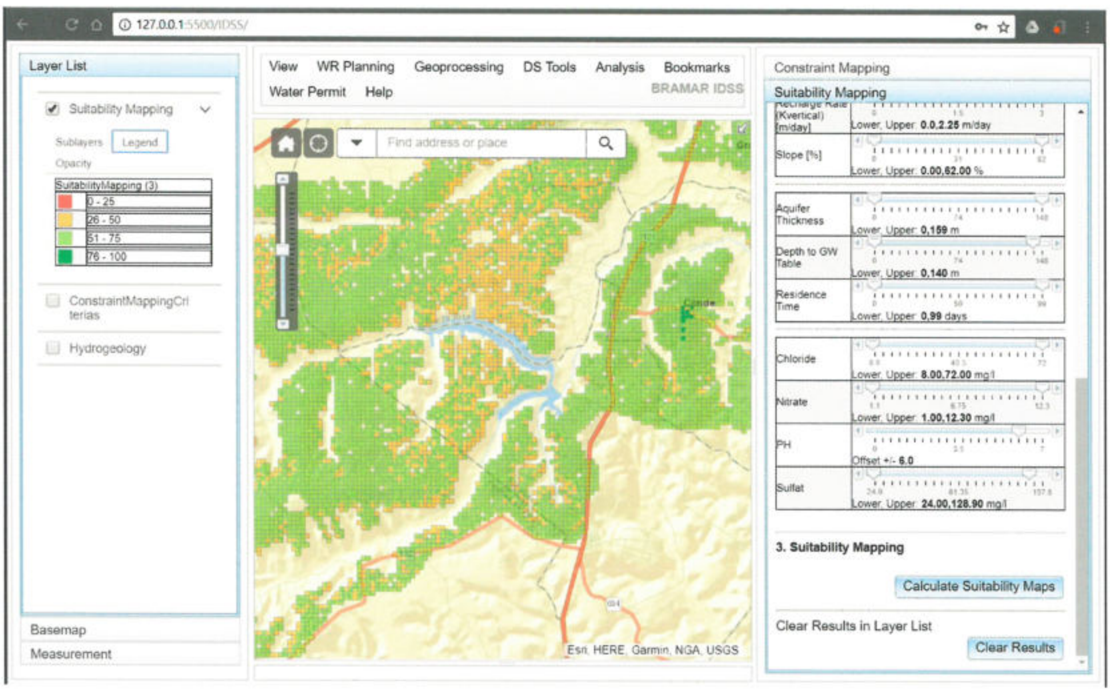


Figure 6.10: Suitability mapping result (Esri, HERE, Garmin, NGA, USGS, BRAMAR, edited by: G.N. Souza da Silva)

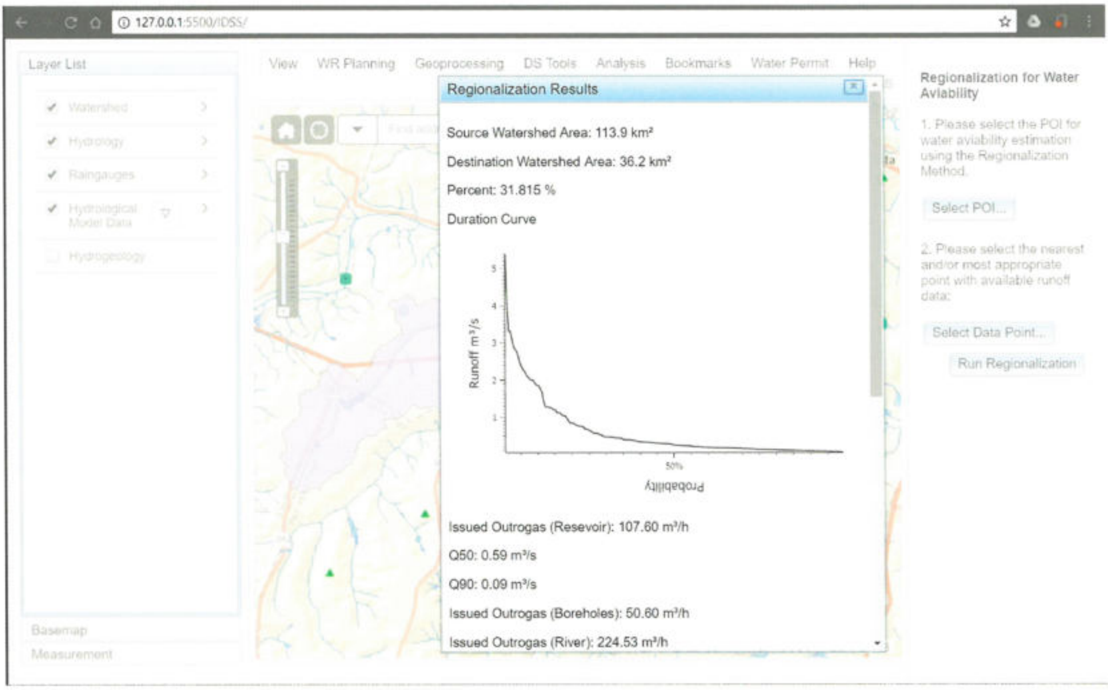


Figure 6.12: Regionalization report - duration curve and regionalization data (Esri, HERE, Garmin, NGA, USGS, AESA, UFPB, edited by: Souza da Silva, G.N.)

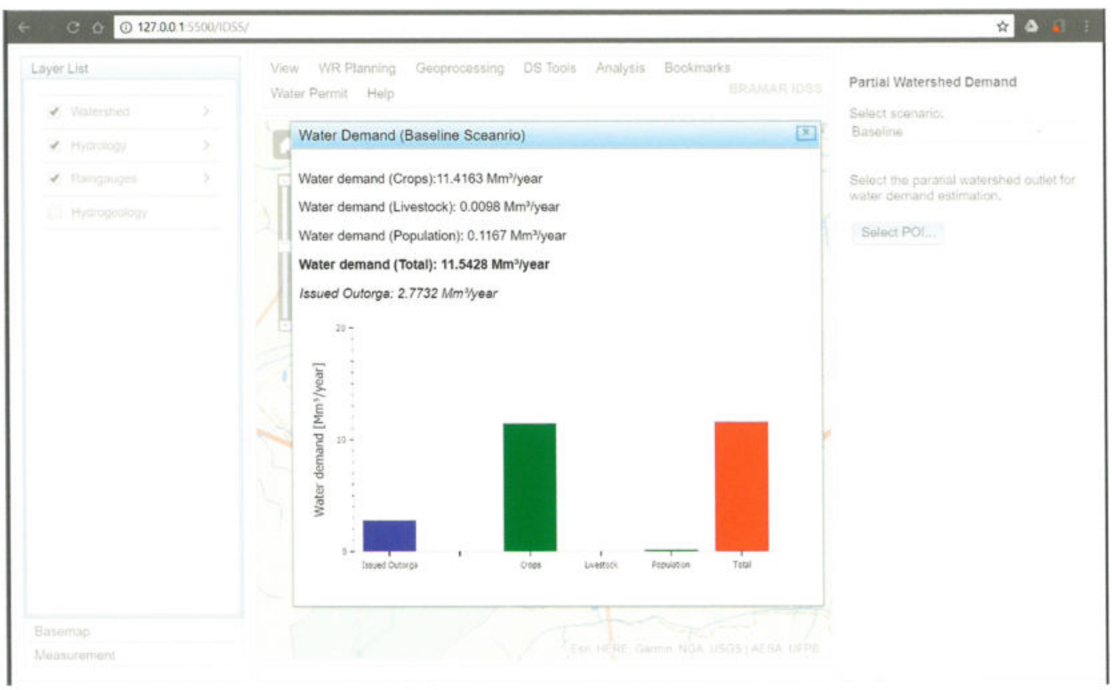


Figure 6.13: Example for water-demand assessment for partial watershed with Census data from IBGE 2010 (Mm³/year) and outorga data (Esri, HERE, Garmin, NGA, USGS, AESA, UFPB, IBGE, edited by: G.N. Souza da Silva)

agency, especially with regards to assessing water permits. **Figure 6.13** shows water demand and previously issued water permits in the partial watershed. The example shows that the actual water demand (IBGE, 2010) of the partial basin under study is much higher than the annual volume of water, related to the given water permits.

Water-Resources Planning

The IWRM planning sub-module is integrated in the BRAMAR IDSS platform and operated in an interactive manner. It guides the system user through the planning and analysis process which has been developed within the BRAMAR project. The eight-step planning procedure will be presented in the following chapter which describes the work in BRAMAR WP 8. In the system, the procedure is presented by means of a planning flow chart. **Figure 6.14** shows how to access the water-resources planning menu item in the BRAMAR-IDSS. Clicking the specific sub-items leads to the different stages of the water-resources planning procedure.

Due to the technological focus of the BRAMAR project, special attention is given to the so-called structural IWRM measures which require the implementation of hydro-infrastructure. Different structural IWRM measures, discussed in detail in chapter on WP8, have been evaluated by means of indicator sheets by the BRAMAR research groups, providing explanations with regards to the evaluation of each of the indicators. While using the BRAMAR-IDSS, researchers may add new IWRM measures and evaluate them at any time. For initial system analysis, the user may access relevant studies to numerous different methods in order to select the relevant procedures and provide a better understanding of the natural water resources, socio-economic and administrative subsystems and their interactions. Further information, together with the relevant screen of the BRAMAR-IDSS, is provided in the chapter on W P8.

Using filter, stakeholders, water-resources planners and decision makers can access this information in the BRAMAR-IDSS in order to access the

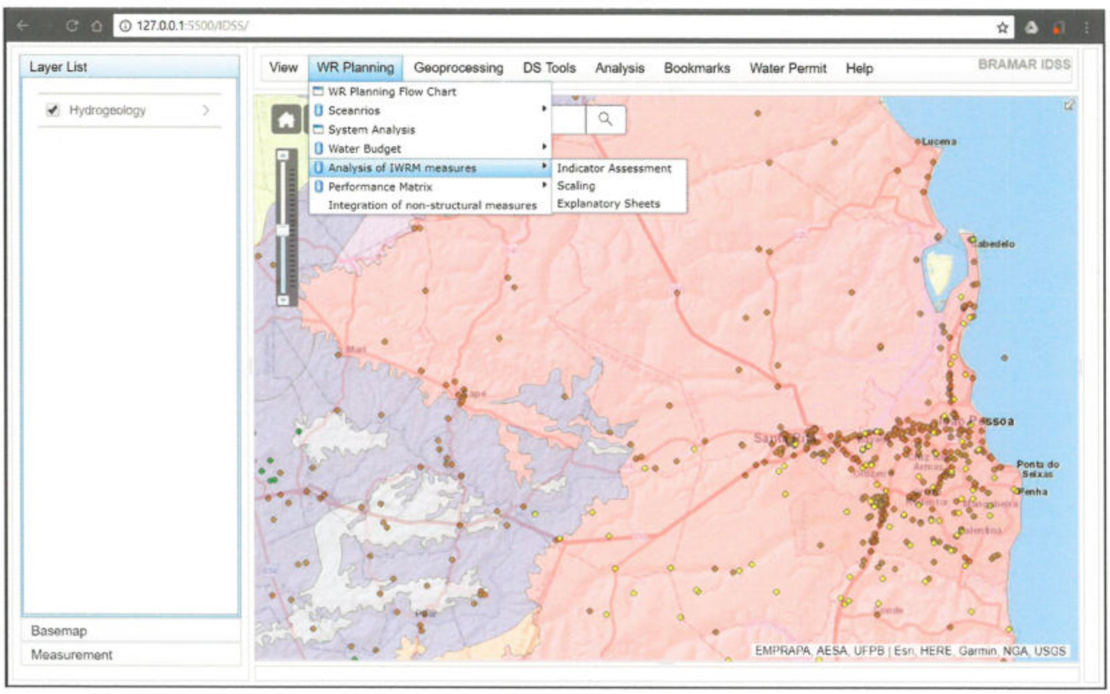


Figure 6.14: Water resources planning menu items (EMPRAPA, AESA, UFPB, Esri, HERE, Garmin, NGA, USGS, edited by: G.N. Souza da Silva)

results in a very structures objective oriented manner. **Figure 6.15** shows the analysis of structural IWRM measures, where the user can select measures, the region where the measure will be applied and minimum values for the indicators using horizontal sliders and the scale values from 0 to 10. The list of indicators is presented in more detail in the following chapter about the works of WP 8.

Based on the application of these filters, a performance matrix is created by the system which takes selected measures and minimum values for the indicators into account (**Figure 6.1**).

In order to provide an integrated approach to water-resources planning and management, the BRAMAR-IDSS offers access to a comprehensive list of non-structural IWRM measures, such as water pricing, demand management, water licensing and system operation with comprehensive studies, publications and recommendations, related to the region in North-East Brazil. All of these measures have been undertaken within the Brazilian-German BRAMAR research and development project and should be taken into consideration for IWRM implementation.

6.3 System Usage and Technology Transfer

The BRAMAR-IDSS is already being applied by the Water Agency of the State of Paraíba (AESA) and will be made fully available for decision-makers and technicians of the relevant water and environmental agencies of Paraíba, Pernambuco and Rio Grande do Norte. Version 1.0 of the BRAMAR-IDSS requires further development in a number of aspects. The need for further system validation and

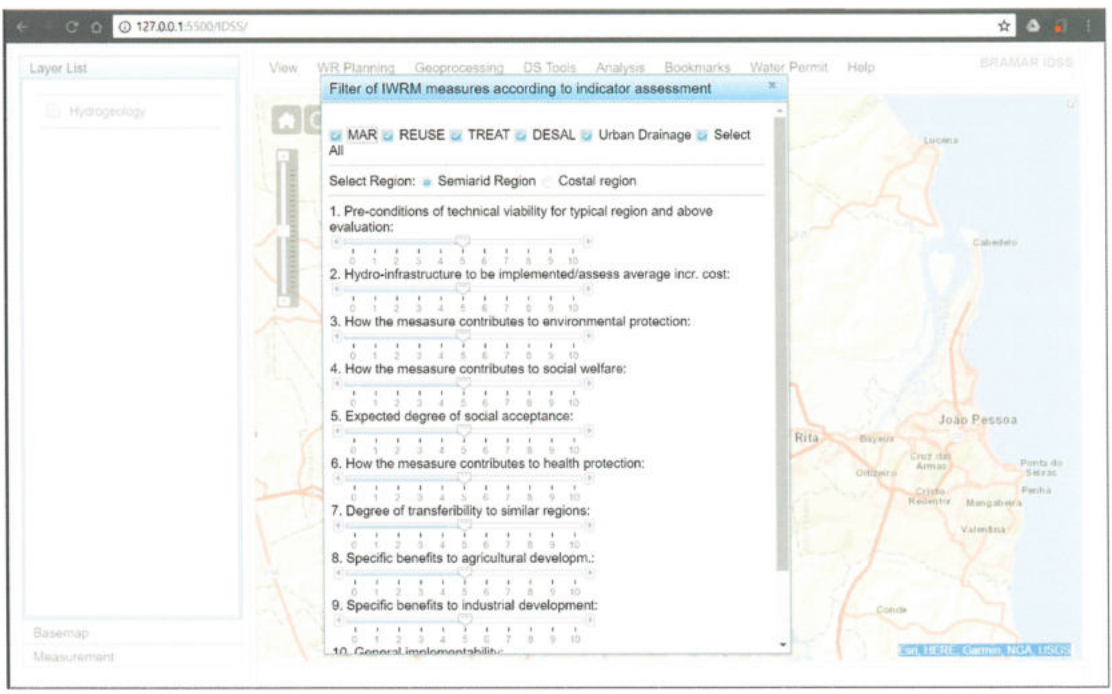


Figure 6.15: Filter/analysis of structural IWRM measures (Esri, HERE, Garmin, NGA, USGS, edited by: G.N. Souza da Silva)

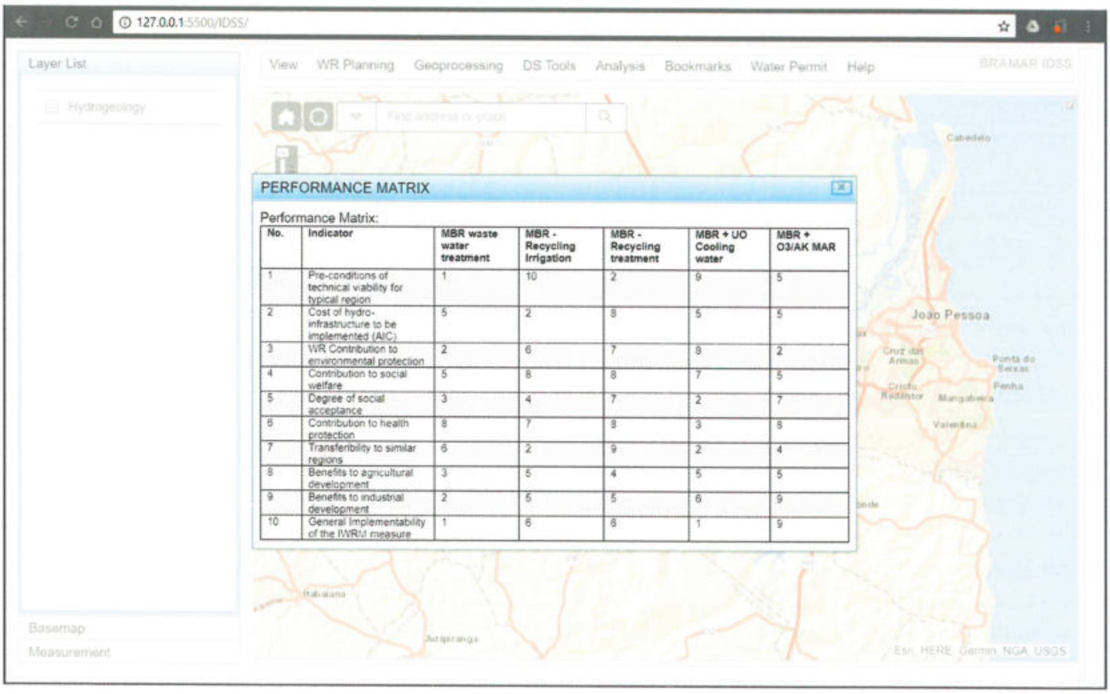
development is specified in the subsequent subchapter. It has been planned by the Brazilian IT firm I3Systems Ltda. in close cooperation with the German company Rusteberg Water Consulting to further develop the Decision Support System to attend to the demand of the state water agencies in the first place.The usage of the web-based BRAMAR-IDSS by the local water and environmental agencies in North-East Brazil will contribute to a continuous improvement of the water-resources and hydro(geo)logical data base of the system. We expect that there will be a continuously rising demand with regards to the further development of the system to include more functions and DS tools in the system. Some of the needs for further development are stated below.

6.4 Conclusions

6.4.1 Lessons Learned

The developed BRAMAR IDSS has proved to be versatile, allowing the easy integration of data and tools required for water-resources planning and management. Furthermore, the ArcGIS Rest interface allows users to integrate data and tools depending on future demands for information and decision support. However, the integration depends on how willing the different groups' are to contribute and publish available research data to the web-based BRAMAR-IDSS. Since they often use private working platforms or desktop software, they often do not share this data, thus hindering rather than helping the overall process.

As the system is developed with the ability to integrate data (services) from the SNIRH on water-resources management, compatibility with national



No.	Indicator	MBR waste water treatment	MBR - Recycling Irrigation	MBR - Recycling treatment	MBR + UO Cooling water	MBR + O3/AK MAR
1	Pre-conditions of technical viability for typical region	1	10	2	9	5
2	Cost of hydro-infrastructure to be implemented (AIC)	5	2	8	5	5
3	WR Contribution to environmental protection	2	6	7	8	2
4	Contribution to social welfare	5	8	8	7	5
5	Degree of social acceptance	3	4	7	2	7
6	Contribution to health protection	8	7	8	3	8
7	Transferibility to similar regions	6	2	9	2	4
8	Benefits to agricultural development	3	5	4	5	5
9	Benefits to industrial development	2	5	5	6	9
10	General Implementability of the IWRM measure	1	6	8	1	9

Figure 6.16: Performance matrix (Esri, HERE, Garmin, NGA, USGS, edited by: G.N. Souza da Silva)

data is guaranteed. This fact actually contributes to a high degree of acceptance and interest of the local water and environmental agencies to work with the system.

The implemented water-resources planning approach requires users to continuously add further conventional and innovative IWRM measures to the system and to evaluate them based on the indicator sheets in order to improve the data base on potential IWRM measures as part of an IWRM action plan. In this way, it can form the basis for decision-making for water-resources planners on state or national level.

6.4.2 Needs for Further System Development

The BRAMAR-IDSS, even after three years of development, may be considered as still under development. In the following, some needs for further system development are stated:

- The integration with regional or locally used systems (e.g. state water agencies) should be promoted and requires further development;
- Direct coupling of precipitation-runoff models and BRAMAR-IDSS for the direct quantification of present and future surface water availability at any partial river basin is recommended, taking the results of climate change models into consideration;
- Providing access to the IDSS and BRAMAR data base by means of mobile phones, especially during field visits, focusing on the control of water permits data, monitoring facilities and hydro-infrastructure;
- Providing full control of the water licensing process for improved decision support with regards to the concession of water rights;
- Surface water quality models may be linked to the system, too, in order to simulate the impact of pollution sources and wastewater treatment measures on the surface water quality.
- Direct coupling with groundwater simulation models would be advantageous in order to promote environmental impact assessment for groundwater resources, estimates of sustainable groundwater abstraction rates as well as the conjunctive use of surface and ground water resources, e.g. by means of Managed Aquifer Recharge;
- Integration of further Multi-Criteria-Analysis tools for option comparison and ranking, e.g. with regards to wastewater treatment and reuse;
- Integration of existing and planned hydro-infrastructure in the BRAMAR data base, including the facilities of the São Francisco water transfer project, in order to improve the assessment of present and future water budgets for partial water watersheds;
- Providing decision support with regards to the combination of different types of IWRM measures towards the definition of integrated strategies;
- Last but not least, the user management of the BRAMAR-IDSS needs to be further improved in order to permit the access of different user groups (universities, single researchers, state water and environmental agencies, secretaries of water resources, the National Water Agency) to the system and to have control on the level of access to the data base and entire system.

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