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IWRM Implementation in North-East Brazil (Results from WP 8)

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7.1 Integrated Water Resources Management

7.1.1 The BRAMAR Project Initiative

The present research and cooperation project between Germany and Brazil in the water sector faced the challenge of improving Integrated Water Resources Management (IWRM) implementation in the semiarid and coastal areas of North-East Brazil, a water-scarce region that frequently suffers from drought events. Both research teams, involving a total of 22 institutions (private companies, universities, research centers and governmental agencies on the federal and state level), worked jointly together on a number of case study areas which were identified as representative for the regional conditions. The project focused, on the one hand, on analyzing structural IWRM measures and innovative water technologies as part of an integrated water resources planning process. On the other hand, new approaches, methods and tools were developed in order to support the integrated planning and management of water resources towards the sustainable development of the region. In the following subchapters, we discuss the suggested water resources planning approach as well as structural and non-structural IWRM key measures as a response to the existing water related challenges. We draw conclusions on how they can be implemented under the conditions of North-East Brazil as part of the IWRM concept as well as how well they can be transferred to similar regions.

7.1.2 Challenges

Among the challenges faced in the next century are an increasing population, unsustainable agricultural and industrial development and water quality degradation. The stress on water resources in many regions of the world is potentially great enough to spark conflict. Without mitigation, conflicts and environmental degradation may be inevitable. Minimizing water scarcity is, thus, the best mitigation and prevention strategy for possible future water conflicts that, while they may seem to be unavoidable, can be hindered with innovative water resources management response measures and technologies. These measures, as well as water and environmental technologies need to be integrated for IWRM implementation. At the core of the IWRM concept is the integrated management of all available water resources on river-basin level within a participative planning and decision-making process (RUSTEBERG et al., 2012). IWRM considers all water resources, especially in case of water scarcity mitigation, being the latter one of the main challenges in North-East Brazil. Water deficits, as a result of non-sustainable water resources development, are the main reason for water-related conflicts in water scarcity-affected regions, especially due to strong competition between the different water users. Non-conventional water resources, such as treated wastewater, brackish or imported water, need to be part of an integrated strategy for IWRM implementation.

Integration also refers to the need to take all relevant social, environmental and economic aspects into account. Acceptance from all stakeholders and public is needed, which requires transparency of the planning process and a close cooperation between state and federal water and environmental agencies. Another challenge relates to the uncertainties with regards to future climate change impact and socio-economic development, both of which need to be properly addressed. In North-East Brazil, regulations for sustainable water resources development are still lacking, e.g. in the area of wastewater reuse and the conjunctive use of surface and groundwater resources. The required participative decision-making process, involving the public, especially the so-called basin water committees, needs to be fully implemented. Also, water management instruments as stated in the Brazilian national and state legislation, such as water permits, water charge and water resources quality improvement are not fully implemented yet.

Last but not least, the poor sanitary situation in North-East Brazil requires special attention in the planning process to improve water resources and health protection.

7.1.3 Water Resources Planning and Management

Water resources management refers to both, the management of the natural water resources system as well as of the man-made hydro-infrastructure; new hydro-infrastructure is being implemented for different reasons, but mainly to make water resources available for different water users, e.vg. by means of wells, surface water reservoirs, pipelines etc. Water resources planning refers, on the one hand, to the upgrade of the water resources system by means of hydro-infrastructure, e.g. to attend to increasing water demands. On the other hand, it means to prepare for the future water related challenges to avoid water related conflicts, taking uncertainties of future conditions into account. Both the impact assessment of water resources planning decisions as well as the assessment of the external conditions, e.g. related to future climate change impacts, require the application of advanced mathematical analysis and modeling tools. Sustainable water resources planning requires actions on both "sides" of the water budget equation. Water supply has to be strengthened to increase the amount of the available water resources, on the one hand. On the other, water demand management measures are required to decrease the existing or foreseen water demand to a minimum. Each drop of water that can be spared on the demand side or in terms of water losses during water transfer and allocation does not need to be produced on the water supply side. Water resources protection may be considered a key task of the planning process to ensure sustainability. Furthermore, polluted water resources may require cost-intensive treatment before being used in the different water sectors. Another key task of water resources planning is to improve water resources system resilience and robustness against high hydrological variability or extreme events. Innovative water technologies, such as Managed Aquifer Recharge (MAR), enable the conjunctive use of water resources, minimizing surface water losses, providing additional water storage and, therefore, improving the system resilience during dry periods.

7.1.4 Decision Support

Due to the importance and need for efficient decision support to the water resources planning process, an innovative Information and Decision Support System, the BRAMAR-IDSS, has been developed in the present project and is presented in chapter on WP7.

Although the need for decision support to water resources planning and management task and related challenges has been extensively discussed in the previous chapter, some aspects should be highlighted in the context of IWRM implementation.

During the entire project, a very close cooperation between the works on "Decision Support" and "IWRM Implementation and Water Resources Planning" took place, due to their strong interaction. Specific procedures and approaches were defined under WP8 and implemented under WP7 in the BRAMAR-IDSS.

Since the BRAMAR project focused on water technologies, the BRAMAR-IDSS gives special attention to structural IWRM measures as response to the water resources challenges of the study region within the overall context of IWRM implementation. North-East Brazil needs to cope with increasing water scarcity due to climate change impact, still aggravated by drought events, and uncertain socio-economic development. Therefore, the water resources planning approach, developed under WP8 and integrated in the BRAMAR-IDSS under WP7, gives adequate importance to scenario definition, water budget assessment for any partial river basin and those IWRM response measures which are able to combat water scarcity and related water deficits.

The BRAMAR-IDSS is already being applied by the water agency AESA of the Federal State of Paraiba, but requires, in spite of all efforts during the last three years, considerable further development in order to provide full-scale support to the water resources planning process.

7.2 BRAMAR Water Resources Planning Approach

7.2.1 Methodological Procedure

The strictly participative water resources planning approach towards IWRM implementation consists of the seven-step procedure listed below. The procedure starts with the definition of the main water development goals in the river basin. These goals depend on the stakeholder and decision-makers' vision for the desired development of the river basin under study and the major water-related problems to be solved with set of water resources (IWRM) measures as a response to those challenges. Typical water development goals may refer to increasing the irrigated agricultural land to a certain extent or to strengthening the irrigation of specific crops, such as sugar cane or to collecting and treating some percentage of the total wastewater produced in the river basin. Frequently, the planning horizon is limited to 20 years, due to increasing uncertainties over time, and takes into consideration that any Water Master Plan on river basin level should be frequently updated, depending on the governing regulations on national and state level. The so-called Millennium Development Goals should be taken into consideration to guarantee sustainability.

The following sub-chapters will present and discuss each step of this water resources planning procedure, giving special attention to the structural IWRM measures as potential response to the water scarcity challenge as well as their evaluation and comparison by means of the BRAMAR-IDSS. All structural IWRM measures studied in the context of the BRAMAR project due to their competitive nature have been evaluated by the responsible research groups, who used a set of indicators, taking social, economic, environmental, health, technical or even administrative aspects into account. The results have been incorporated into the BRAMAR-IDSS. The integration of non-structural measures may be considered as obligatory for IWRM implementation. Further information on the methodological procedure is provided in the following sub-chapters.

Table 7.1: Steps of water resources planning approach

1	Water Development Goals and Scenario Definition
2	System Analysis
3	Present and Future Water Budgets
4	Structural IWRM Response Measures
5	Indicator Assessment
6	Measures Comparison
7	Integration of Non-structural Response Measures

7.2.2 Scenarios and Water Budgets

In order to cope with the considerable uncertainties related to climate change impact and socio-economic development of the river basin under study, a set of different scenarios are being defined as important step of the water resources planning procedure. Since scenario definition and the assessment of present and future water budgets are intimately linked, both are being treated together in the present sub-chapter.

Both climate change and socio-economic development have an impact on the water budget in different ways. While climate change tends to decrease precipitation rates and, therefore, surface water availability, socio-economic development increases water demand over time. Under the water scarcity and drought conditions in North-East Brazil, both driving forces together tend to increase the water deficit over time. Additionally, as climate change causes temperature to rise, evapotranspiration increases as does, therefore, irrigation water demand. In the BRAMAR project, three scenarios (water for all, water for some, and water for few) were considered, based on the National Water Resources Plan (MINISTÉRIO DO MEIO AMBIENTE, 2006). Population and socio-economic growth projections, based on water agencies' reports and plans, were included, incorporating the impact of climate change on irrigation as a function of increase in temperature for the climate change scenarios RCP 4.5 and 8.5. Detailed information about the climate change studies is presented in the chapter on WP1. Forecasts of precipitation and temperature data can be accessed and mapped by the Decision Support System. Accessing the water resources planning tool of the BRAMAR-IDSS, the system user selects the relevant scenarios and corresponding planning horizon to analyze their impact future water budgets. The integration of rainfall-runoff models to estimate future water availability for any partial watershed in an automated process is still under development.

7.2.3 System Analysis

The second step of the suggested water resources planning procedure refers to the analysis of the relevant subsystems, their interaction and their environment. **Figure 7.1** presents the subsystems and relationships in a simplified schematic way (LOUCKS et al., 2005). The total system consists of the following subsystems:

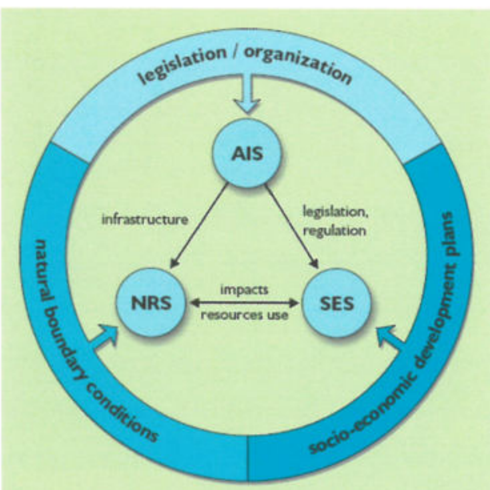

Figure 7.1: Interactions among subsystems and between them and their environment (LOUCKS et al., 2005)

a) Natural Water Resources System (NRS), where all hydrological (physical, chemical and biological) processes take place;

b) Socio-economic Subsystem (SES), which considers related human activities; and

c) Administrative and Institutional Subsystem (AIS), where the decision processes related to water resources planning and management take place, where legal constraints and regulations are be defined.

Water resources planning and management measures may impact and improve the interaction of these three subsystems. Lacking attention to one of the sub-systems can compromise any work done to improve the performance of the others.

Within the BRAMAR project, a series of studies were developed in the project region in order to study these subsystems and their interaction with different approaches. The present sub-chapter provides a short overview about these studies and procedures which may be applied to improve the system understanding and to identify potential conflicts and upcoming challenges. The latter, in turn may require specific IWRM response measures which will be later treated in this chapter.

A range of methods and theories have been studied in the context of the BRAMAR research project in the study region in order to provide decision support for a structured system analysis towards a better understanding of the system: from causal models to water justice and political ecology, urban metabolism, actor-network analysis, institutional analysis, Ostrom's institutional design principles, integrated policy analysis, social media analysis, conflict analysis, risk and crises management and negotiation theory. Public participation in the basin committees was also analyzed to provide support to IWRM implementation. Below, some key studies are listed:

The Epitácio Pessoa multi-purpose surface water reservoir is the second largest water reserve in the State of Paraíba, suffering from two major drought events during the last 15 years. The Causal Chain Analysis (ACC) has been applied, taking technical, political-managerial and socio-economic-cultural causes into consideration. It became obvious that water management strategies capable of optimizing surface reservoir operation had not been defined because the entities unfortunately did not exercise their functions in a coordinated, articulated and integrated way (SILVA, 2015).

Amorim et al. (2016) applied the Integrated Policy Analysis to the Federal Piranhas-Açu river basin, which is located in the States of Paraíba and Rio Grande do Norte. The Regulatory Framework during its ten years of existence (2004 to 2014) was analyzed, verifying aspects which led to its creation and contribution in resolving and mitigating conflicts. The study concluded that the Regulatory Framework allowed participants to discuss the challenges, but that the lack of sufficient monitoring and water uses control actions made it difficult to solve conflicts during water shortage periods. Integrated Policy Analysis has been applied by Ribeiro (2017), Guedes & Ribeiro (2017) and Brito (2017), too.

Silva et al. (2017) applied the Institutional analysis to evaluate how a combination between climate variability and water governance might affect water scarcity and increase the impact of extreme events. For this evaluation, Ostrom's framework for analyzing social-ecological systems (SES) was applied. Ostrom's framework is useful for understanding interactions between the different subsystems. The study proved that deficiencies in water management intensify droughts' impact on the water users and that the reasons are more related to water management and governance problems than to drought event magnitude or climate change.

Ribeiro et al. (2016b) studied the evolution of public participation in the committee of the river basins in the northern coastal area of Paraíba and the importance of capacity-building measures. In the context of the study, many members of basin committees and other experts in water resources have been trained to effectively implement the Water Resources Integrated Management and have had a very positive impact on the performance of the river basin committee. Further studies on public participation and performance in the study region have been done by Ribeiro et al. (2014, 2016a) and Ribeiro (2016).

Moraes and Galvão (2016) apply the method of Urban Metabolism in order to support the integrated planning and management of water resources of urban environments, here of the City of Campina Grande, which is one of the BRAMAR Case Study Areas (CSA). The method is based on the assessment of the water budget within and outside the city, including all fluxes of water into the city as well as leaving the city. The method proved to have great potential for an optimized water management. In the case study, a considerable potential for rainwater harvesting and water reuse could be identified and quantified.

Last but not least, the so-called Driver-Pressure-State-Impact-Response (DPSIR) method should be mentioned in this context, capable of identifying upcoming conflicts and main water resources related challenges. The method has been applied in the context of the BRAMAR WP1. Detailed information about the method and its application will be found in the corresponding chapter.

Figure 7.2 shows how system analysis is being accessed in the BRAMAR-IDSS. The user can select the type of analysis and retrieve more information on the specific studies, applied methods, conclusions and recommendations. In the same way, non-structural (complementary) measures are integrated the IWRM.

7.2.4 Structural IWRM Response Measures

Introduction

According to the suggested BRAMAR planning approach for IWRM implementation, structural IRWM measures compete with each other and require a specific assessment in order to compare, select and combine them, while non-structural measures may be considered as mandatory for IWRM implementation. Numerous structural IWRM response measures have been studied under BRAMAR. In the following subchapters, these measures are classified, and main project activities and studies are presented for these groups of measures, taking aspects, such as level of today's implementation in North-East Brazil, viability and importance in the context of IWRM implementation into account.

Conjunctive use of surface and groundwater resources

Due to considerable water losses by evaporation from open water storage, the conjunctive use of surface and groundwater resources is gaining special importance. A key measure is Managed Aquifer Recharge (MAR), which permits the conjunctive use of these water resources and, therefore, is an important component of IWRM. Implementing a MAR system requires careful planning

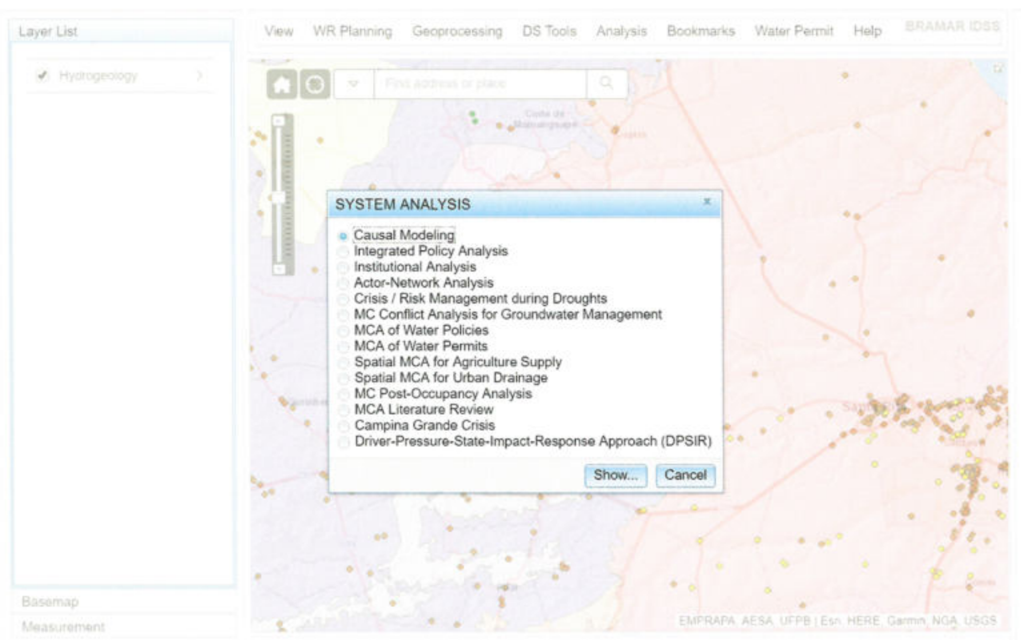

Figure 7.2: Accessing different methods for system analysis in the BRAMAR-IDSS (EMPRAPA, AESA, UFPB Esri, HERE, Garmin, NGA, USGS, edited by G. N. Souza da Silva)

in terms of achieving efficient integration into the water resources system and the overall water resources management objectives (RUSTEBERG et al., 2013). To recharge the water, different infiltration and injection technologies are available. The most common methods are infiltration basins (spreading basins), sink-pits and canals, induced recharge by bank filtration, and injection wells. Use of these methods depends upon basic planning parameters. The roles that MAR may play within the framework of a water resources system are short and long term storage for later recovery during dry seasons, recovery of groundwater level of over-exploited aquifers, provision of barriers to seawater intrusion in coastal areas, improvement of water quality, use of the aquifer as a water distribution system for individual users, and flood-prevention by deviating peak-flows (RUSTEBERG et al., 2012).

In the present book a separate chapter has been dedicated to the MAR studies undertaken in the context of the BRAMAR project. The studies at the representative case study areas of João Pessoa, Recife and Sumé show that the development of a comprehensive data base – leading to profound knowledge of the water resources system – is of crucial importance for the successful planning of MAR facilities. Clearly, implementing MAR concepts and technologies is of major importance to combat water scarcity in North-East Brazil. The studies show that its implementation is viable in general terms and highly beneficial for both the regions, the semiarid rural areas inland as well as the coastal region with its large aquifer systems. Nevertheless, further studies, including the installation of pilot plants, especially at the coastal areas, are required in order to achieve the required knowledge for the planning and operation of MAR facilities as part of IWRM implementation under the conditions found in North-East Brazil.

Wastewater Treatment and Reuse

Numerous studies have been developed within the scope of the BRAMAR project related to wastewater treatment and reuse. The chapter on WP4, 5 and 6 summarize all research work done within the collaborative BRAMAR project by the Brazilian and German Universities and technology firms in cooperation with governmental agencies in the field of wastewater treatment and water reuse. While the German partners focused on conventional and innovative, partially high-tech solutions and their transferability and implementability in North-East Brazil, including industrial water reuse, the Brazilian partners gave special attention to innovative low-cost solutions for wastewater reuse in irrigated agriculture, appropriate to local conditions.

The studies show that there is a need in the project region for further and continuous investments in basic sanitary infrastructure. In the Federal State of Paraíba just 44 % of the produced wastewater is being collected, while around 70 % of the collected wastewater is being treated. In the major urban centers, such as Campina Grande and João Pessoa, the situation is much better. For more detailed information please refer to the corresponding chapter. The responsible Brazilian Authorities on national, regional and state levels are aware of the situation. Approximately R$ 30 billion was invested in wastewater treatment from 2007 to 2015. The so-called National Sanitation Plan PLANSAB will provide approximately another R$ 180 billion for investments in sanitation infrastructure until 2033 (ANA, 2017).

The BRAMAR studies proved the general transferability of innovative wastewater treatment technologies to North-East Brazil, which includes efficient solutions mainly for non-potable reuse, including industrial wastewater reuse. Even measures for direct potable water reuse, along with the usage of desalinated water, may be of increasing interest for North-East Brazil, especially under drought conditions.

The inadequacy of wastewater systems and water shortages in semiarid North-East Brazil encourage the reuse of water in the production of agricultural crops. Costa et al. (2014) and Vasconcelos (2014) analyzed the effect of irrigation with treated domestic wastewater on the production of different crops. Especially for the rural areas, low-cost and low-tech solutions for wastewater treatment and reuse in irrigated are advantageous, taking, for example, solar radiation schemes into consideration. Cavalcante (2017) states that using solar radiation is inexpensive, easy to operate and does not need chemicals in wastewater disinfection for agricultural use. The BRAMAR researcher developed and validated a solar reactor for the disinfection of greywater from rural areas in the semiarid region, aiming at the reuse of the effluent.

As the practice promotes the improvement of effluent quality disposed in agricultural systems, it could also be feasible in this region to promote part of the wastewater treatment in small and medium cities with financial and operational difficulties to implement and maintain efficient conventional WWTPs.

The viability of low-cost water reuse solutions for agriculture, microbiological and hydraulic performance as well as fertilizing effects have been studied by several research groups in the context of the BRAMAR project; they show that there is a wide range of wastewater treatment and water reuse measures applicable in North-East Brazil (BATISTA et al., 2017; SILVA et al., 2016; COELHO et al., 2016).

All wastewater treatment and reuse measures studied under BRAMAR were evaluated by the responsible research groups based on a set of indicators, taking social, economic, environmental, health, technical or even administrative aspects, e.g. with regards to their implementability, into account. The results may be reviewed by accessing the BRAMAR-IDSS.

Rainwater Harvesting

Since 1999, the ASA (Brazilian Semiarid Articulation – Articulação Semiárido Brasileiro) has been adapting and implementing rainwater harvesting programs in the semiarid region of North-East Brazil. The main program is called P1MC – One Million Cisterns for the Semiarid Program – (Programa Um Milhão de Cisternas para o Semiárido). Thanks to an agreement with the Brazilian Ministry of the Environment (MMA), financing was secured to prepare the project and construct water catch tanks (cisterns) to supply water for 500 families in the year 2000. A second agreement signed in 2001 with the Brazilian Water Agency (ANA) financed the construction of water catch tanks for 12,400 families. By March 2018, the Program had achieved the following results: 614,442 cisterns of 16 thousand liters for capturing and storing rainwater for human consumption and 6,228 cisterns for rural schools. With the aim of increasing the water supply for families, rural communities and traditional populations to account for agricultural and animals' needs, ASA created a new, very successful action called One Land and Two Waters Program, P1 + 2 (Programa Uma Terra e Duas Águas, o P1+2) in 2007.

These so-called rainwater harvesting systems (SCAC), however, have been affected mainly by variable precipitation patterns. For this reason, it is important to evaluate them in different climatic scenarios. Within the scope of the BRAMAR project, Dantas et al. (2015) carried out simulations on the vulnerability of SCAC for three localities of Paraíba. The results showed that even under current weather vulnerabilities rainwater harvesting systems are an important IWRM measure. In spite of relevant climate change impact, adaptation measures, such as increasing rainwater harvesting area, are able to mitigate these effects.

Andrade et al. (2015) reported that in the Brazilian semiarid region, rainwater harvesting has proven to be a successful measure to mitigate the effect of the dry seasons in rural communities. Conflicts may arise when cisterns are used to store water from water tank trucks. BRAMAR researchers confirm that the cisterns are both effective tools for risk and crisis management and, therefore, an important IWRM measure.

Pereira et al. (2014), still within the scope of the BRAMAR project, analyzed a device for hydraulic tests in rainwater harvesting systems and Nóbrega et al. (2014) performed a sensitivity analysis of water balance parameters of cisterns in the semiarid region. Batista (2017) recommended guidelines for rainwater harvesting systems in open public spaces (POSs) of the CSA Campina Grande. These guidelines aim to combine the factor of the improvement of the rainwater management with the planning of public places located in the urban mesh of the city. Additionally, Souza (2015) confirmed the considerable potential for water savings from the conventional water supply system by adopting rainwater harvesting in the urban area of the municipality.

Water Allocation and Reallocation

According to Lopes & Freitas (2007) and Freitas (2009), water allocation in Brazil, historically, is characterized by a strong intervention of the public sector. Nevertheless, national and state water resources authorities implemented alternative models for water allocation based on participative processes. The analysis of different procedures shows that the water allocation process should be adapted to the specific conditions of each region, with regards to conceptual and methodological aspects as well as with regards to the definition of multiple strategic objectives.

Water allocation can be understood as an IWRM measure that aims to provide water to current and future users of the water resources system, matching water supply and demand, even meeting environmental demands and being in line with strategic management objectives. In this sense, there are several mechanisms of water allocation, which operate according to public authority guidelines, based on negotiation processes among water users or technical concepts, such as the limits of the use of water bodies, or economic ones, such as charging for water use. The evaluation of the advantages and disadvantages of each mechanism, from the point of view of objective criteria, allows a use to choose the most appropriate to each region and each situation, with a view to the sustainable use of water resources (LOPES and FREITAS, 2007).

For the so-called Negotiated Water Allocation a methodology is described in Freitas, (2003); ANA/GEF/PNUMA/OEA (2004); Freitas, (2010) and improved by Freitas (2013), Martins et al., (2013). This methodology was largely internalized in the administrative procedures of the National Water Agency, through Technical Note No. 10/2015/COMAR/SRE (ANA, 2015) and has been applied throughout the semiarid region of North-East Brazil.

For the semiarid North-East Brazil, which regularly suffers from extreme water scarcity and even droughts, water allocation may be also understood as a measure for drought management. The so-called Drought Management System (SIGES) has been validated in the context of the BRAMAR project (**Figure 7.3**). In the North-East region, 1,409 or 78.5% of the 1,794 municipalities declared an emergency or state of calamity due to the droughts between 2003 and 2017.

To optimize water allocation from surface reservoir networks, several modeling tools are available. The Information System for Water Allocation Management, or SIGA, is one of those (FUNCEME,

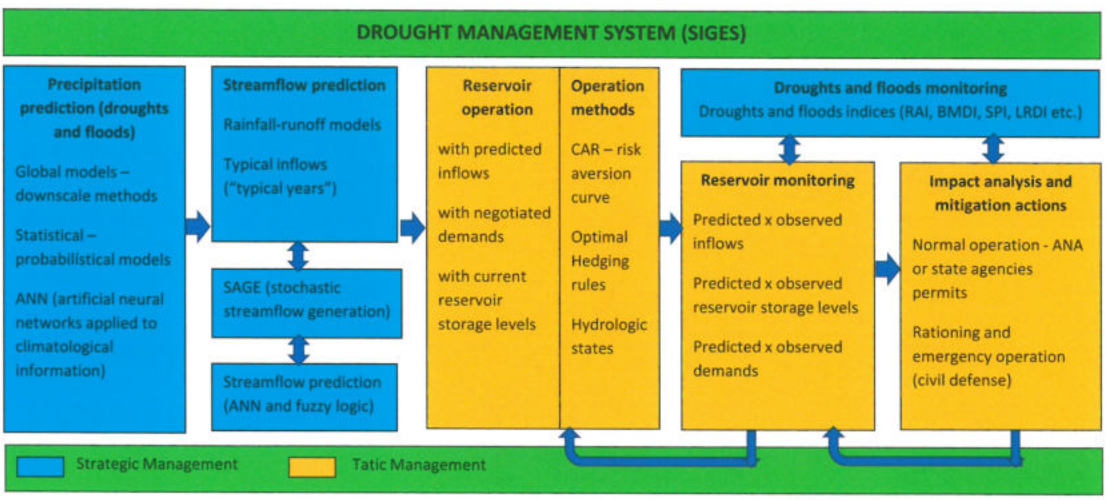

Figure 7.3: Drought Management System – SIGES (FREITAS, 2013)

2018). The water allocation software Acquanet was applied to study potential trade-offs by changing the water allocation through the adaptation of the water distribution network as well as the impact on the water budget situation (FREITAS, 2016).

The BRAMAR CSA Campina Grande suffered a serious water scarcity crisis during the project execution, which was analyzed in real-time by the project team, which also intensively participated in the crisis' discussion on potential solutions. The main reservoir storage volume was consumed by 2016, and the collapse of the water supply was barely avoided through the construction of an extra pumping system to extract water from the dead storage. Rêgo et al. (2016) studied the operation of the Epitácio Pessoa/Boqueirão reservoir during the water crisis as an opportunity to analyze the water allocation scheme and defined emergency measures, including the reallocation of water to the different users. The study shows the importance of studying and improving water allocation in order to avoid conflicts between water users and of adapting to extreme water scarcity conditions, even if hydro-infrastructural interventions are required to reallocate the water.

Water Transfer

In cases where the present or future water deficit in a river basin cannot be covered by the local water resources and local measures, as described above, external water resources, those outside the river basin may be identified, activated and transferred to the river basin under study. Then, the transfer of water from neighboring basins or even from more distant basins may be taken as additional structural IWRM measure into consideration. This is the case in the largest part of the BRAMAR project study area. In order to mitigate the water deficits of this region, the PISF project (San Francisco Inter Basin Water Transfer Project) was developed and is now in its final stage of implementation (**Figure 7.4**). According to the ANA Resolution 029/2005, a water permit has been established for a water delivery of 26.4 m^3/s at any time from the Rio São Francisco; and up to 114.3 m^3/s (daily average) and 127 m^3/s (peak), depending on water availability in the Sobradinho reservoir. The maximum water carrying capacity

Figure 7.4: Transposition Project Rio São Francisco – North and east axis for water import (MI, 2004)

on the axes is about 28 m^3/s along the so-called "East axis" and limited to 99 m^3/s along the "North axis".

To guarantee institutional sustainability of the PISF project, a specific institutional arrangement has been developed, according to the ANA Resolution 412/2005, which is presented in **Figure 7.5**. The regulation framework of the PISF Project includes a water permit, a water sustainability certificate, a commitment agreement and the Decree n. 5995, which creates the management council, the content of PGA (Annual Management Plan), and designates CODEVASF (Companhia de Desenvolvimento dos Vales do São Francisco e do Parnaíba) as the federal operator. Additionally, a contract between federal and state operators is under discussion.

Rêgo et al. (2017) analyzed the water transfer from Rio São Francisco to the BRAMAR CSA of Campina Grande. They argued that the adoption of appropriate and permanent water management measures would minimize the effects of prolonged droughts. The authors stated that the inter-basin water transfer is just a "hydraulic solution" and cannot be considered as a full-scale IWRM solution for the region. Radical change in the patterns of water and effluent use (and reuse) from multiple sources must occur in order to improve the resilience of the water resources systems and water supply sustainability of the semi-arid zone. Grande et al. (2016) analyzed the perception of water users about the impact of water rationing on their household routines for the Campina Grande case study area. In the context of the BRAMAR project, the performance of managers, water users, public power, press and population in the face of the water supply crisis in Campina Grande has been analyzed by Rêgo et al. (2017), too. The BRAMAR studies show that the water transfer from - even distant - neighboring basins to water-scarcity affected areas in the project region is a viable solution if all local water resources have been already efficiently exploited in the context of IWRM implementation. The water transfer is just an additional measure to activate external water resources and as such does not substitute the implementation of the IWRM concept.

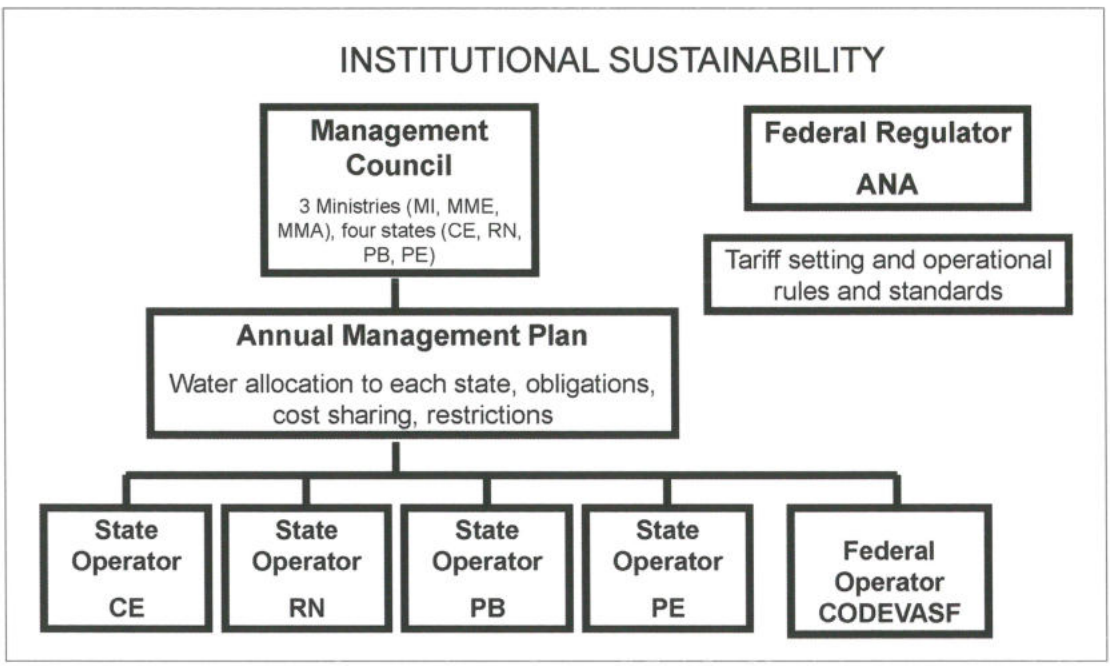

Figure 7.5: Institutional sustainability - PISF project (FREITAS, 2017)

7.2.5 Non-structural Response Measures

Introduction

Non-structural response measures are measures which do not focus or even need the implementation of hydro-infrastructure. They may consist of regulative or legal measures, like water permits or charges in order to promote the rational use of the scarce water resources, demand management measures, measures to improve the efficient operation of hydro-infrastructure, such as surface water reservoirs or pipelines, measures to improve the quality of water resources planning and management decisions, including public and stakeholder participation. These measures are essential for IWRM implementation, mitigation and even prevention of adverse impact related hydrological extreme events. A series of non-structural measures was analyzed in the context of the BRAMAR research project, which will be described in more detail below. They have to be understood as non-competitive, obligatory measures that are complementary to the structural measures in the context of IWRM implementation.

Surface Reservoir Operation

Various studies on the expected benefits of water import by means of the PISF project with regards to water availability have been developed. Initially, due to the water crisis during the long drought period between 2012 and 2017 and, finally, with the start of the operation of the PISF project, ANA had to modify the operation of the reservoirs of the receiving basins of the Eastern Axis, especially the reservoirs Epitácio Pessoa and Acauã. Several ANA resolutions were implemented and a new operation scheme for the Epitácio Pessoa reservoir had to be developed (FREITAS, 2017 / **Figure 7.6**).

BRAMAR researchers Nunes et al. (2016), using surface reservoir operation and optimization studies, developed a rule curve for reservoir operation, which permits excess water to be used in periods of large inflows without compromising water supply during dry periods. The efficient operation of the water resources system is an obligatory measure to minimize water losses and mitigate conflicts between different water users.

Demand Management

Seventeen resolutions and other normative acts were issued from 2013 to 2016 restricting or suspending water use within Brazil. Actions to control regulative or demand management measures were intensified in the semiarid region, especially in the Piancó-Piranhas-Açu River basin, due to the small volume of the reservoirs, which caused risks to the public water supply of numerous municipalities in the states of Paraíba and Rio Grande do Norte. By means of forecasting and monitoring

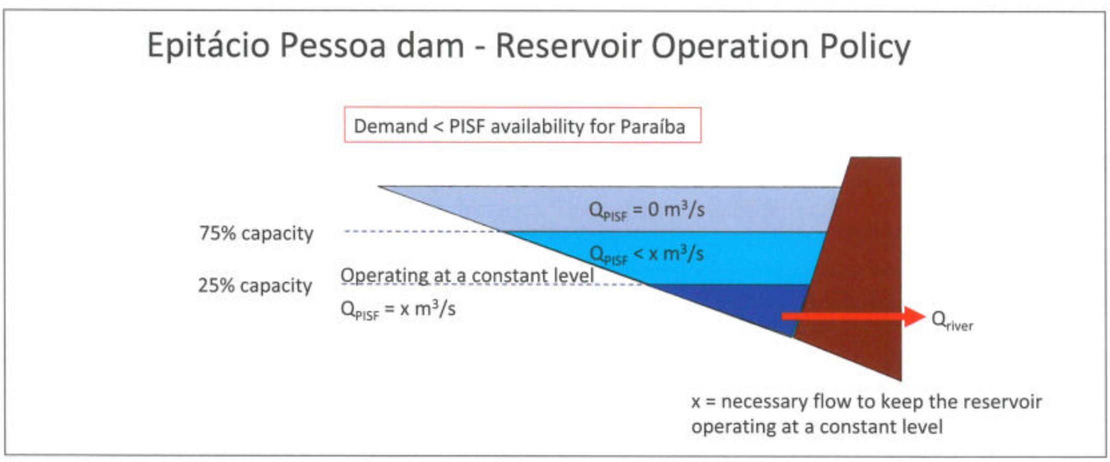

Figure 7.6: Reservoir operation policy using reservoir storage zones for Epitácio Pessoa Dam in the context of the PISF project (FREITAS, 2017)

measures during critical periods, water losses could be reduced and, therefore, water shortages mitigated.

Barros et al. (2016) evaluated the use of water saving equipment in vertical buildings, in order to minimize the increase in water demand over several years for the case study area Campina Grande. According to the study, the installation of water-saving devices in buildings considerably decreased water consumption and, therefore, is a demand management measure of first choice. The reduction of the water use caused by water savers in residential buildings was monitored and parameters for the new buildings have been established. Guedes et al. (2014) analyzed alternatives of water demand management in a city scale for the BRAMAR case study area of Campina Grande. Araujo et al. (2015) developed a new method for improved urban water management for Campina Grande. The integration of demand management measures is obligatory in the context of IWRM implementation in order to minimize investments in structural water supply measures.

Water Permits and Charges

Ribeiro et al. (2014) presented a study in the context of the BRAMAR project that considers the priority of surface water use as a criterion for the concession of water permits. The study focused on the Coastal Sedimentary basin of the Lower Course of the Paraíba River and the Gramame River basin, both in the state of Paraíba. The potentialities and availability of surface water were monitored in order to assist the responsible agencies in the concession of water permits. According to the applied criteria, the use of surface water is considered a priority, while groundwater should be considered as strategic resource and only be used if water supply from surface water resources is not viable.

In the state of Paraíba, the groundwater is abstracted in accordance with the regulation established by Decree N°19.260/1997 (AESA, 2018), which defines the well yield and the aquifer recharge capacity as criteria. BRAMAR researchers Braga et al. (2015) used numerical modelling techniques to estimate groundwater resources availability in a region of the Coastal Sedimentary Basin of the Paraíba River Basin. An over-exploitation of groundwater could be detected. It became obvious that the criteria adopted by local regulations for the concession of water rights need to be improved in order to avoid over-exploitation. The authors suggest that groundwater monitoring should be improved and present a method for defining additional criteria based on the modulated concession of water permits. Furthermore, Braga et al. (2017) presented an assessment of the water permits criteria proposed in a previous study. Among the eight criteria assessed, the criteria of aquifer vulnerability and implementation of demand management measures were identified as the most relevant.

According to Assis (2016), the raw water charge in Brazil was introduced by Law N°. 9.433 of January 8, 1997, as an economic instrument for the management of Brazilian water resources. The author presents an analysis of the raw water charge system, identifying the aspects which could be improved. The results show that it is necessary to review the values currently used in the raw water charge system. Different aspects – quantitative, qualitative and protection for emergency situations – are not sufficient to ensure water sustainability of the river basin, since environmental problems and water crises persist. Assis et al. (2018) presented a proposal for improvements to the system for raw water charges.

Hydro(geo)logical and Climatic Monitoring

The National Monitoring Network (RHN) included in 2016 more than 20 thousand monitoring stations under the responsibility of several entities. ANA directly manages 4,663 stations: 2,722 rain gauges and 1,941 fluviometric stations. There are 1,646 fluviometric stations that measure water flow (river discharge), 1,652 stations that measure water quality and 480 stations that monitor sediments in suspension (solid discharge).

According to ANA (2017), despite the availability of huge amounts of hydrological data on national level, there are still large gaps with regards to hydrological monitoring data due to the size of the country. To solve these problems, a number of actions have been undertaken, such as the National Water Quality Assessment Program (PNQA), the

National Water Quality Monitoring Network (RNQA) and the Program to Encourage Quality Data Dissemination Water (Qualiágua).

The BRAMAR project had to face an small hydrological database in the case study areas, too. Numerous groundwater, fluviometric, precipitation and climatic monitoring stations had to be installed and are now being operated by the local partner institutions in order to characterize the water resources systems and to calibrate the hydro(geo)logical models required to study the behavior of those systems.

Water quality monitoring allows the characterization and analysis of trends in river basins. There are several ways to assess the water quality of a water body. Physico-chemical and biological parameters of water samples collected from rivers and reservoirs are widely used as indicators of water quality. In Brazil, the levels and concentrations of several indicators in water are used as reference for the classification of water bodies according to water quality classes. ANA and the Federal State Units (UF), including Paraíba, Rio Grande do Norte e Pernambuco, maintain monitoring networks based on these indicators.

The classification of water bodies according to water quality classes is one of the instruments established in the Law of Water (Law No. 9.433 of 1997) (Presidência da República, 2018) to ensure water resources protection and to reduce the cost to combat water pollution through permanent preventive actions.

ANA´s so-called "Situation Room" monitors and analyzes the evolution of rains, levels and flow of the main rivers, reservoirs and river basins. All information is shared through bulletins and monitoring systems, supporting the decision of the authorities responsible for the management of critical hydrological events in the country. The National Water Agency supported the implementation of situation rooms in all federal states and currently monitors and improves their operation.

The BRAMAR Information and Decision Support Platform, presented in the chapter on WP7, has been designed to integrate all hydro(geo)logical monitoring data, including data from the National Institute for the Semi-Arid Region (INSA) about the status of hundreds of reservoirs in that region.

The Drought Monitor Action refers to regular and periodic monitoring of the drought situation in North-East Brazil. The consolidated results are disseminated by means of the so-called Drought Monitor Map. Monthly information on the drought situation is available up to the previous month, with indicators that reflect the short term (last 3, 4 and 6 months) and the long term (last 12, 18 and 24 months), providing information about the evolution of droughts in the region.

Hydro(geo)logical and climatic monitoring of the water resources system under study is an obligatory, per se, non-structural IWRM measure required for system characterization, hydr(geo)logical modeling, impact assessment and is the basis for decision-making towards the sustainable development of water resources and IWRM implementation.

Institutional Development

As discussed in the context of system analysis (Subchapter 7.2.3), the administrative and Institutional Subsystem (AIS) is where the decision processes related to water resources planning and management take place and where legal constraints and regulations are defined. Sustainable water resources management and IWRM implementation, therefore, require adequate measures for institutional development and capacity building.

In December 2011, ANA and leaders of the state bodies responsible for water resources signed the so-called National Pact for Water Management, a commitment to strengthen the State Water Resources Management Systems (SEGREHs) (ANA, 2016).

As a practical tool for the implementation of the Pact, in 2013 ANA launched the Program PROGESTAO for the Consolidation of the National Pact for Water Management, which provides for up to five annual installments in a total of 750,000 Brazilian Real for each unit of the federation when they fulfill pre-established institutional development goals. These financial resources should be applied exclusively to actions which benefit the sustainable management of water resources.

By the end of 2014, all Brazilian states, besides the Federal District, had joined the program. Paraíba was the first state to join. It is foreseen to extend the program to the year of 2019. The goals of the PROGESTAO were divided into federal cooperation goals defined by ANA and based on legal regulations on the one hand, or information sharing and water resources management goals at the state level on the other, approved by the respective State Water Resources Councils – CERHs.

7.2.6 Analysis and Comparison of IWRM Measures

Indicator Assessment

According to the suggested BRAMAR planning approach for IWRM implementation presented and explained at the beginning of the present chapter, structural IRWM measures compete with each other and require an assessment by indicators so that they can be compared, selected and combined, while non-structural measures may be considered as mandatory for IWRM implementation.

The planning approach has been implemented in the BRAMAR-IDSS. All structural measures need to be evaluated with the following list of qualitative indicators, taking social, environmental, economic and some other basic indicators into account.

1. Pre-conditions of technical viability for typical region
2. Cost of hydro-infrastructure to be implemented
3. Contribution to environmental protection
4. Contribution to social welfare
5. Degree of social acceptance
6. Contribution to health protection
7. Transferability to similar regions
8. Benefits to agricultural development
9. Benefits to industrial development
10. Benefits to drinking water supply
11. General implementability of the IWRM measure

This planning step requires the active contribution of the system user (researcher) to include the results on conventional or innovative structural IWRM measures and water technologies into the BRAMAR-IDSS. The evaluation of each measure by the above set of indicators is done separately for the semiarid and coastal region. After definition of a short synonym for the IWRM measure according to the system standard, the system user is requested to provide a short description of the IWRM measure under study and to select the study region.

The indicators are evaluated by providing a value between 0 and 10 to each of them, while the value of "0" refers to the minimum performance, the value of "10" refers to the maximum performance of the specific IWRM measure with regards to the given criteria. In terms of how viable a measure may be implemented, two indicators have been considered: the technical viability, taking the typical conditions in the semiarid and coastal region into account as well as the general implementability of the measure, analyzing additional aspects like political and social willingness as well as administrative or legal constraints. For the time being, one key economic indicator has been considered: accessing the implementation, operation and maintenance cost of hydro-infrastructure of the structural IWRM measure to be implemented. This indicator is the so-called "Average Incremental Cost," which is the present value in US dollars per m^3 of water produced or activated by the measure, including, beyond the implementation of hydro-infrastructure, all operation and maintenance costs during the planning horizon. In spite of the fact that this indicator is assessed in quantitative terms, the scientist, nevertheless, may provide a qualitative value according to a given scale; in this case, the value "10" refers to the most economic (least cost intensive) IWRM measures.

One generalized indicator to access benefits with regards to environmental protection and two indicators to access social aspects (welfare and acceptance) are being considered. A specific indicator focusing on health protection has been included, too. Finally, evaluation of benefits to water sector development is required and the general transferability of the IWRM measure to similar regions is judged by the responsible researchers of the study.

Figure 7.7 shows how the indicators are accessed by the BRAMAR-IDSS. After their qualitative assessment, it is required to insert a justification with regards to the selected indicator value by clicking on the corresponding button. A popup window opens in order to introduce the explanative text as background information for later decision support to water resources planners and decision makers.

Measures Comparison

The BRAMAR-IDSS permits the filtering and analysis of structural IWRM measures by water resources planners and decision-makers and their presentation in form of a performance matrix. The relevant screens have been presented in the chapter on WP7 chapter.

The system user, e.g. decision-maker or water resources planner, can select a type of structural measure, the region where the measure will be applied and a minimum value for each of the indicators, using horizontal sliders and the scale values from 0 to 10. Based on the application of these filters, a performance matrix is created by the system, which considers the selected measures, taking the minimum requirements of the water resources planners with regards to the performance of structural IWRM measures into consideration (Chapter on WP7: **Figures 7.15** and **7.16**).

The **Table 7.2** provides an example for a performance matrix, based on BRAMAR results for IWRM measures related to advanced wastewater treatment and water. The table shows that each of the filtered structural IWRM measures presents benefits and disadvantages with regards to the different indicators. The performance matrix, based on the set of indicators, provides basic decision support to water resources planners and decision-makers with regards to a preliminary selection of priority structural IWRM measures towards a better understanding of their performance in qualitative terms. By modifying the filters, taking new constraints and minimum requirements into account, the analysis adapts to different boundary conditions and development goals. After identification of a set of structural IWRM measures that attends to the minimum performance requirements, water resources planners are requested to

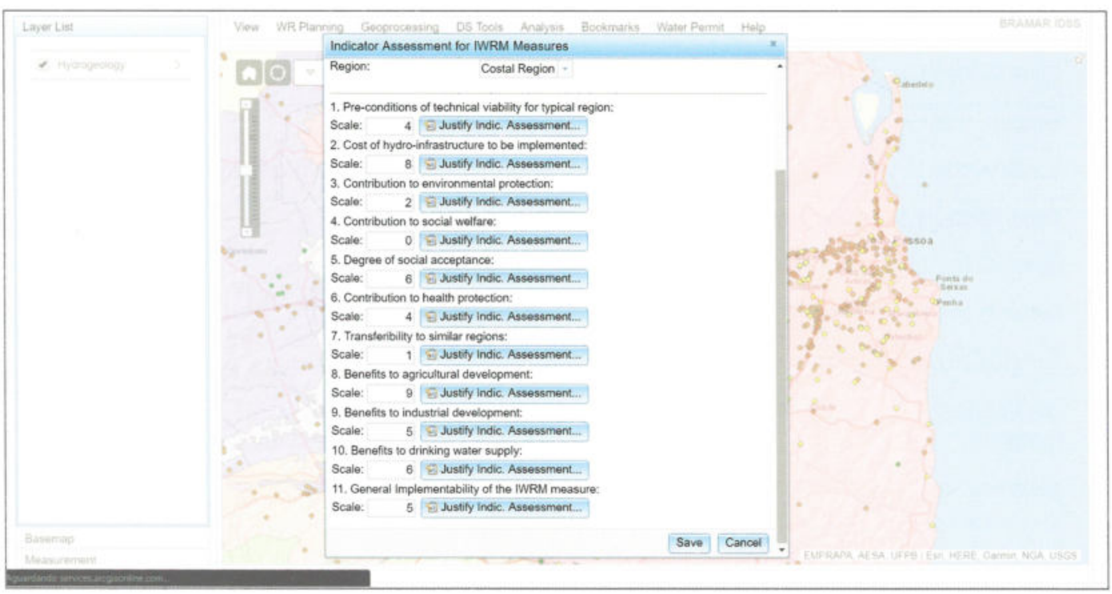

Figure 7.7: Assessment of indicators in the BRAMAR-IDSS (EMPRAPA, AESA, UFPB Esri, HERE, Garmin, NGA, USGS, edited by G. N. Souza da Silva)

rely on the corresponding in-depth research work and results for further decision support. At this stage of system development, the BRAMAR-IDSS only supports the pre-selection of structural IWRM measures according to the given set of indicators.

7.2.7 Integration of Non-structural Response Measures

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, system operation and institucional development. Moreover, it provides access to comprehensive studies, publications and recommendations related to the region in North-East Brazil, all of them undertaken in the context of the Brazilian-German BRAMAR research and development project. These studies and their most crucial results have been presented in this chapter and should be taken into consideration for IWRM implementation. The information is accessed in the BRAMAR-IDSS by selecting the non-structural measure out of a list in a pop-up window, similar to the selection of methods for system analysis, as presented in the chapter on WP7. As mentioned before, non-structural measures, in principal, do not compete with each other. Their integration may be considered as mandatory for IWRM implementation.

Table 7.2: Example of performance matrix for IWRM measures related to advanced wastewater treatment and recycling

No.	Indicator	MBR wastewater 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	Transferability 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	Benefits to drinking water supply*	–	–	–	–	–
11	General implementability of the IWRM measure	1	6	6	1	9

* just indirect influences on drinking water supply observed

7.3 IWRM Implementation and Transfer

7.3.1 Implementation

According to the Brazilian Water Law (1997), Law No. 9433 (Presidência da República, 2018), the implementation of an Integrated Water Resources Management (IWRM) relies on the following water resources instruments:

1. Water permits
2. Water charges
3. Framework of water bodies in classes
4. Water Resources Information System (SNIRH)
5. Water resources plans on national, state and basin level

The above-listed instruments refer to non-structural IWRM measures that have been discussed in the present chapter. Numerous programs and actions, partially initiated and coordinated by the Federal Water Agency ANA, as well as by state agencies, are being conducted in order to improve the implementation of the IWRM concept. Numerous studies have been undertaken within the BRAMAR project to contribute to the process and to improve the efficiency of these non-structural measures and their implementation by means of continued programs and actions on national and regional as well as on state and basin levels.

We expect that the BRAMAR-IDSS, which is being continuously developed, may support this process since the system is fully compatible with the National Water Resources Information System (SNIRH). Furthermore, it should encourage water resources planners and decision-makers of the water and environmental agencies in North-East Brazil to apply the innovative system to support decisions in water resources planning and management. The close cooperation with the National Water Agency ANA will certainly contribute to improving the existing legislation and to implement new regulations, directives, laws in new water resources policies, based on BRAMAR results and products.

7.3.2 Knowledge and Technology Transfer

All information and knowledge about innovative water technologies, e.g. related to water reuse, methods or DS Tools acquired in the context of the bilateral research and development project BRAMAR are being properly disseminated in and outside Brazil in the context of the national and international conferences and water related events. Therefore, the present book is being published in Portuguese and English.

The project focused on characteristic case study areas of the semiarid and coastal region of the Federal States of Paraíba, Rio Grande do Norte and Pernambuco. It is foreseen to test and validate the methods and approaches developed in the project in similar regions of other states in North-East Brazil. The Brazilian team is planning to continue the work until the end of 2018. Since the selected case study areas are representative for many others, it is expected that there is a great potential for the transfer of technologies, IWRM measures and methods to neighboring states in the region which face similar conditions and challenges with regards to the sustainable development of water resources. Capacity-building measures are part of the BRAMAR research program and play an important role in the context of technology transfer. Special training activities in order to enable students, researchers, water resources planners and decision-makers to work with the BRAMAR Information and Decision Support System have been already conducted during the course of the project and will be continued.

7.4 Conclusions

7.4.1 Lessons Learned

The bilateral research project BRAMAR produced innumerous results that, certainly, will benefit not just the study region with regards to an integrated and sustainable planning and management of water resources.

In North-East Brazil, there is still a lack of regulations for sustainable water resources development, e.g. in the area of wastewater reuse and the conjunctive use of surface and groundwater resources. The required participative decision-making process, involving the public, especially the so-called basin water committees, needs to be fully implemented. Also, water management instruments as stated in the national and state Brazilian legislation, such as water permits, water charge and water resources quality improvement have not yet been fully implemented.

The poor sanitary situation in North-East Brazil requires special attention in the planning process and integrated approaches with regards to water resources development. Major efforts are required to improve the basic sanitary infrastructure for wastewater collection and treatment, before focusing on the technically, legally and organizationally more advanced water reuse. The BRAMAR studies show that "water reuse" is a most important IWRM measure and should be better integrated in the water resources plans developed by the responsible federal and state agencies.

In Brazil, the legal attribution of groundwater management belongs to the states and not to the federal government (National Water Agency - ANA). In spite of huge efforts of the National Water Agency ANA to improve the monitoring of water resources, there is still a major lack with regards to hydro(geo)logical monitoring in North-East Brazil. Although the groundwater level of the large coastal aquifer systems is continuously decreasing, causing increased seawater intrusion and groundwater pollution in many states of the region, very few monitoring data of the important coastal aquifer systems are available.

Efficient groundwater monitoring together with a reformulation of criteria and procedures for the concession of water rights is required to avoid over-exploitation, especially of the most important coastal groundwater resources in the region. New technologies, such as MAR, studied in detail in the present project, are required to improve the conjunctive and sustainable management of surface and groundwater resources, contributing to the reduction of water losses and water resources protection.

Last but not least, the Brazilian-German collaborative research and development project BRAMAR has proved that multi-disciplinary research groups, governmental experts, professionals from the private sector and the civil society are able to work successfully together, providing mutual benefits for all entities involved.

7.4.2 Further Research Needs

The following needs for continued research on the line of the BRAMAR project have been identified:

- Validation of the suggested "Water Resources Planning Approach" in North-East Brazil within a participative process together with national and state stakeholders and decision makers;
- Extension of the existing network for hydro(geo)logical monitoring in Paraíba, Pernambuco and Rio Grande do Norte in order to improve water resources planning;
- Permanent improvement of the database of the BRAMAR-IDSS, related to indicator assessment for structural IWRM measures, giving special attention to the quantitative economic assessment and based on the so-called average incremental cost in USD/m³;
- Monitoring of the short and long-term impact of structural and non-structural IWRM measures
- Continuous further development of the BRAMAR-IDSS in close cooperation with the state agencies responsible for water resources planning and environmental protection, according to their demand;
- Extension and consolidation of the suggested basic indicator list by the Brazilian research groups, taking specific aspects of sustainable development and water sector/user interests into account;
- Further decision support to the development of integrated IWRM strategies as a combination of structural and non-structural priority measures.

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