DOI: 10.5327/Z2176-947820151001

BALANCING ECOSYSTEM SERVICES AND SOCIETAL DEMANDS IN A HIGHLY MANAGED WATERSHED: SETUP AND PROGRESS OF A COMPREHENSIVE RESEARCH PROJECT

EQUILIBRANDO OS SERVIÇOS ECOSSISTÊMICOS E DEMANDAS SOCIAIS NUMA BACIA HIDROGRÁFICA ALTAMENTE MANEJADA: ORGANIZAÇÃO E PROGRESSO DE UM PROJETO CIENTÍFICO ABRANGENTE

Marianna Siegmund-Schultze

Senior scientist at the Environmental Assessment and Planning Research Group, Technische Universität Berlin (Berlin Institute of Technology) – Germany.

Johann Köppel

Full professor and head of the Environmental Assessment and Planning Research Group, Technische Universität Berlin (Berlin Institute of Technology) – Germany.

Maria do Carmo Sobral

Full professor in Civil Engineering, Universidade Federal de Pernambuco – Recife (PE), Brazil.

Corresponding address:
Marianna Siegmund-Schultze
Technische Universität Berlin –
Secr. EB 5 – Straße des 17.
Juni 145 – 10623 Berlin – Germany –
E-mail:
m.siegmund-schultze@tu-berlin.de

ABSTRACT

The INNOVATE project, a comprehensive Brazilian-German research collaboration, addresses sustainable land management in the São Francisco watershed and its Itaparica reservoir. The project studies management options, which promote sustainable ecosystem services and economic viability in climate change conditions. At basin scale, questions of water quantity and quality prevail, including resource allocation and governance. Local and regional studies investigate natural land processes and water resources in addition to their management post dam construction. Consortium researchers are confronted with a multitude of expectations, ranging from knowledge production to interacting with stakeholders and scientists of different disciplines and cultures. As an overview, we predicted potential changes of studied ecosystem services under different conditions within possible scenarios. Further integration of results is ongoing, as is the conversion of scientific results into guidance for stakeholders.

Keywords: inter- and transdisciplinary research; sustainable land management; São Francisco watershed; Itaparica reservoir; follow-up stakeholder analysis; ecosystem services; scenarios.

RESUMO

O projeto científico INNOVATE, uma cooperação teuto-brasileira, investiga o uso sustentável de recursos naturais nas escalas da bacia hidrográfica do Rio São Francisco e ao redor do seu reservatório de Itaparica. O projeto estuda opções de manejo que sustentam tanto os serviços ecossistêmicos como o bem-estar da população num cenário de mudanças climáticas. Na escala da bacia estudam-se assuntos de vazão e qualidade de água, inclusive questões de alocação e governança da água. Na escala local, anos depois da construção da barragem, pesquisamos processos naturais da água e terra e sua gestão. Os pesquisadores enfrentam uma série de expectativas – gerar conhecimento, interagir com interessados e cientistas de outras disciplinas e culturas. Como uma síntese exemplar, são apresentadas as mudanças de serviços ecossistêmicos estudados sob diferentes condições de cenários possíveis. A integração dos resultados está atualmente em andamento, bem como a conversão de resultados em diretrizes úteis nas diferentes escalas.

Palavras-chave: pesquisa inter e transdisciplinar; gestão sustentável; bacia hidrográfica do Rio São Francisco; reservatório de Itaparica; análise de atores; serviços ecossistêmicos; cenários.

INTRODUCTION

Access to enough water of adequate quality is crucial for productive resource use in semiarid regions. Climate change appears to make future water availability increasingly unpredictable. Managing land and water resources is often controversial: different users share the same or parts of the same environment and they make decisions that affect the options of other users. Ecosystems cannot campaign for themselves; they require conservation advocates. The concept of ecosystem services is bridging the gap by providing a framework for identifying, assessing, valuing, and analyzing usage rules of nature's life sustaining goods and services. These ecosystem services are now commonly sorted into three groups: habitat and regulatory services, provisioning services, and cultural services. The Sustainable Land Management (SLM) program, launched by the German Federal Ministry for Education and Research (BMBF) (EPPINK *et al.*, 2012) assesses interactions between land management, climate change, and ecosystem services to inform the decisions of local and global stakeholders on land management (in its broader definition including soil, water, vegetation, fauna, and people) and foster transformation towards more sustainable resource stewardship. INNOVATE is a large consortium of Brazilian and German researchers, organized within the SLM program, committed to inter and transdisciplinary research, including the implementation of selected results. The core period of the project is January 2012 to December 2016.

The overarching concept and title of the research project is "Interplay among multiple uses of water reservoirs via innovative coupling of aquatic and terrestrial ecosystems." Members study the current situation and model future scenarios. The underlying general question is "which existing management options are promising and conducive for sustainable land and water management in the study region?" The study is multi-scale — the entire São Francisco watershed, the area around one of its artificial reservoirs belonging to the Itaparica microregion including municipalities in the Pernambuco portion affected by the Itaparica (actually called Luiz Gonzaga) dam, down to single natural resource users and plots. The transformation drivers are primarily hydropower generation, water usage, demographics, technology use, and climate change. Indicators used in the studies include biodiversity patterns, nutrient balances, carbon dynamics, water use efficiency, trade-offs, water availability, minimal flow, economic efficiency, stakeholder endorsement, and institutional fit.

Interdisciplinary integration, inter-cultural openness, and understanding are fundamental to forming a large project with 7 sub-projects and a total of 21 research modules, each with Brazilian and German researchers. Part of this integration is structurally organized by mixing the research modules. Joint planning and learning in project workshops and smaller meetings is complemented by cooperation in research activities. Research is also transdisciplinary, connecting with stakeholders at different levels and from different sectors while facilitating exchange among these stakeholders in order to reach meaningful results for society. Environmental studies at the watershed scale typically require interdisciplinary and transdisciplinary collaboration as a range of knowledge and actors are at stake (REED *et al.*, 2014).

The transitional phase towards the uptake of innovations is challenging: drivers and barriers work against each other (MUTOKO *et al.*, 2014). The project aims to identify major drivers and barriers in order to increase transparency and system understanding, which enables informed decision-making. Main issues at watershed scale are the safeguarding and allocation of scarce water resources (Figure 1) in an integrated, participatory method, as outlined in the National Water Act (BRASIL, 1997). The São Francisco watershed is a large watershed. The Itaparica reservoir in the semi-arid Northeast region was selected as a nested case study. The central issues at the reservoir scale are unsolved interferences in land use and water ecology following dam construction (Figure 2). The management of the basin and the major reservoirs, which are roughly 25 to 50-years old, is regularly difficult. Despite frame conditions changing, reservoir ecology and management will remain topics of discussion since there are still more dams planned in Brazil (WESTIN *et al.*, 2014).

Our overall problem statement and approach can be summarized as a sectorial perspective on how a sole focus on short-term benefits threatens the natural resource basis - in this case, mainly water for diverse uses

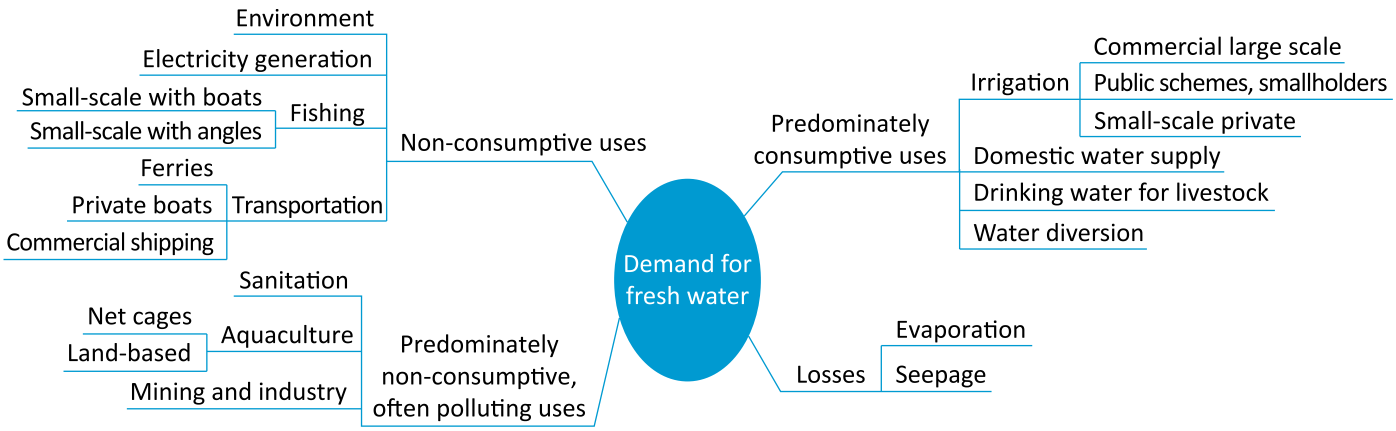

Figure 1 – The different, partly mutually exclusive water demands from the São Francisco River.

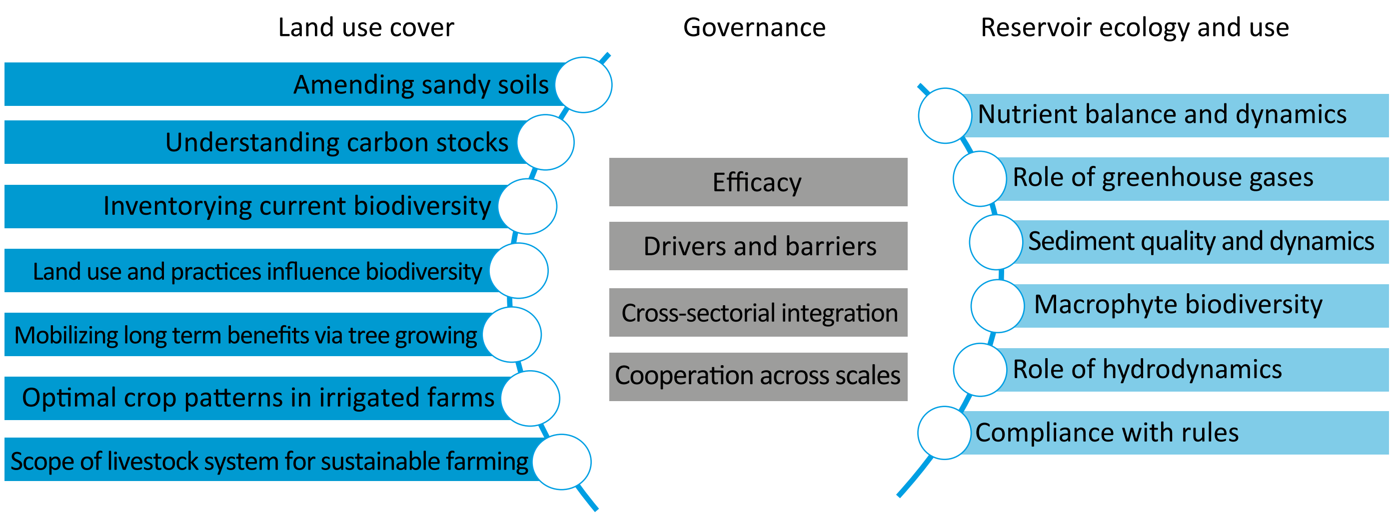

Figure 2 – Topics of large dam follow-up (INNOVATE project): The case of the Itaparica reservoir in the Brazilian Northeast.

and land suitable for farming. Addressing the concept of ecosystem services in an interdisciplinary consortium reveals interlinkages and provides insights and prerequisites for sustainable resource management. Recommendations for action will be tailored for and with different stakeholder groups in an iterative process. The following sections present snapshots of the scientific work and its integration.

SITE DESCRIPTION AND PROJECT LOCATION

A number of large-scale studies analyzed the conditions of the São Francisco watershed, including the comprehensive 10-year water resources management plan (ANA *et al.*, 2004), and the ecologic-economic macro-zoning (MMA, 2011). Both emphasize technical aspects and illustrate selected socioeconomic conditions. In summary, critical structural causes determine water scarcity. Economic water scarcity can be rooted in a lack of infrastructure and exclusion in social criteria and political processes (MOLLE *et al.*, 2007). Therefore, conflict mediation for water allocation is needed. Water management is an increasingly political process (MOLLE, 2009). In the example of the São Francisco watershed, the regional development agency (CODEVASF; current name since 1974, an early predecessor was created by a law in 1949) follows the watershed development discourse, while the more recent discourse, introduced in Brazil by the Water Act 9433/97 (BRASIL, 1997), requires decentralized and participatory management, steered by a watershed committee. The committee for the São Francisco watershed (CBHSF) was created in 2001 (AGB PEIXE VIVO & CBHSF, 2011). To our knowledge, no comprehensive cooperation protocol has been established between the committee and CODEVASF. CODEVASF's suggestion and current construction of water transfer channels diverting water out of the original watershed have made this complex coexistence evident (AGB PEIXE VIVO and CBHSF, 2011). The majority of committee members were against the water diversion project. However, the installation of new irrigation schemes, an option after water diversion, is often welcomed by the local population or farmers moving in from other regions.

The São Francisco watershed roughly measures 630,000 km^2 (MANETA *et al.*, 2009). Specifications on the length of the river vary between 2,700 km (BRAGA *et al.*, 2012) and 3,200 km (CHESF, n.y.). The main river contains nine large hydropower plants (BRAGA *et al.*, 2012). There are three major artificial reservoirs: Três Marias (since 1961), Sobradinho (1979) and Itaparica (1988); total storage capacities are 19, 34, and 10 billion m^3, respectively (ANA *et al.*, 2004), and maximum surface area is 1,142, 4,214 (MANETA *et al.*, 2009), and 834 km^2 (AGAM TECNOLOGIA LTDA & CHESF, 2003), respectively. The watershed has been divided into four administrative sub-regions. The currently used division and the four sub-regions themselves are described in Siegmund-Schultze *et al.*(2015).

The construction of the Itaparica dam expelled 40,000 inhabitants (CERNEA, 1991). Resettlement was costly and to some extent inefficient. Additionally, installing compensation infrastructure in the form of irrigation schemes for farmers was slow (WORLD BANK, 1998). Compensation payments lasted at least until 2011, when a further irrigation scheme had been established (RODORFF *et al.*, 2013). The livelihoods of the local people widely rely on natural resources, such as land for agriculture and water for fishing. These resources were highly affected by the artificial lake construction. People's practices are not yet satisfactorily adapted and natural processes not sufficiently understood.

INNOVATE researchers from different disciplines investigate related problems. Studies at the basin scale address the current debate on water quantity and quality from technical, economic, and governance viewpoints. While technical and economic studies at the basin level mainly draw on existing datasets, the other researcher groups predominantly collect primary data via surveys, key person interviews, and experiments. On the local level, six municipalities in Pernambuco located north of the Itaparica reservoir have been selected: Belém do São Francisco, Itacuruba, Floresta, Petrolândia, Jatobá, and Tacaratu, with one activity taking place in Delmiro Gouveia in Alagoas state. Figure 3 depicts the basin and presents it by municipality where interviewing, surveying, and sampling is taking or took place, and where the experiments are located. The local scale study region is, on the one hand, characterized by major changes in land use and population dynamics in the last decades and, on the other hand, by the typical inter-annual variation of rainfall and high potential evaporation rates due to the semiarid environment. The predominant biome, Caatinga (covering also roughly half of the basin), is a dry forest with a distinct and regionally varying flora and fauna. Roughly half of the local study area has arenosols (*areias quartzosas*, south of Icó-Mandantes creek), while the other half alfisols, partly hydromorph (*bruno não cálcico*, *planossolo*) (EMBRAPA-SOLOS, 2000).

ECOSYSTEM SERVICES

The Millennium Ecosystem Assessment (MA, 2005) created an influential conceptual framework, which connects ecosystem services and biodiversity with human well-being. The original four service categories (provisioning, supporting, cultural, and regulating) are framed by direct and indirect drivers at different scales and under different time horizons. Inherent to the systemic ecosystem services concept is analyzing the impact of or

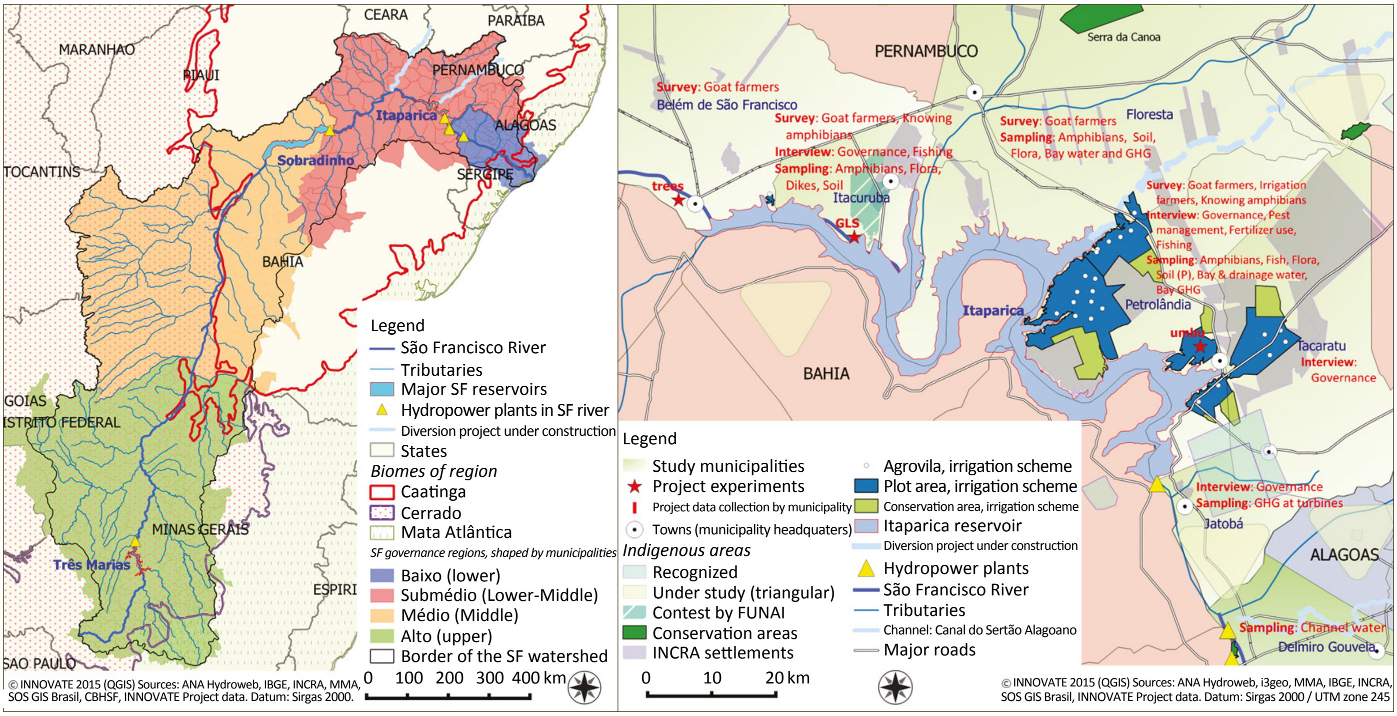

Figure 3 – Location and characteristics of the São Francisco watershed (left) and experimental sites of the INNOVATE project (right).

on ecosystem services groups, not simply individual services (FOLEY *et al.*, 2005). Developing "the cascade" to distinguish between processes, functions, service potential, final services, benefits, and values was a milestone in the discourse connecting ecosystem services, biodiversity, and well-being (HAINES-YOUNG & POTSCHIN, 2010). The same authors suggested focusing on direct benefits, excluding the supporting services, to avoid a potential double counting of benefits. The final intention of the ecosystem service concept is to advocate for natural, non-marketed services and goods by strengthening their case in decision-making. Daily *et al.* (2009) have proposed a simple framework for integrating ecosystem services into decision-making. First, ecosystem services need to be specified, then valued differently, and, finally, the governing institutions and the incentives necessary for decisions should be outlined to show which human actions will affect ecosystems. Current management practices either sustain or threaten the availability of and access to the benefits. Deriving multiple benefits from one user is common, as is the more complicated situation of sustaining and threatening one or several services at the same time.

Stakeholder analysis, in general, is executed in three steps – identifying stakeholders, categorizing them, and exploring their relationships (REED *et al.*, 2009). Rodorff *et al.* (this issue) focus on the third step. Using constellation analysis, it goes beyond stakeholder analysis since the analysis of actors is complemented by the people's major frame conditions and stakes of action and concern – elements of the natural and technical environment and the institutions and rules in place. Table 1 presents a selection of stakeholders (beneficiaries and offenders) at different scales and belonging to different societal groups. The selection and classification changed slightly over the course of the project. Some stakeholders are highly time-specific and, therefore, transitory. The international consultancy plays a role in the renewal of the catchment's management plan; the World Bank enters occasionally, depending on implemented development projects.

The INNOVATE project mainly focuses on regulating ecosystem services, biological pest control, provision of fresh water, and reduction of greenhouse gas (GHG) emissions (carbon stocks, methane emissions). The related benefits to people are: more

Table 1 – Overview of selected stakeholders, classified by societal type and administrative level.

	Micro Local, unicipality	Meso Reservoir, regional	Macro Watershed, national	International
Private	Farmers, Fishers, Residents, Bloggers	Agricultural extension service[1], Operation & maitenance[1], Traders	AGB Peixe Vivo, CEMIG	Consultancy
Mixed	Associations[2], Irrigation district administration, Cooperatives[2], STR, CPP, Recognized indigenous, Recognized *quilombola*[3]	CHESF[4], CCR Submédio, FETAPE, Pólo Sindical, ASA, Território[2], IRPAA, Priest (Church)	CBHSF[2], CHESF, MST, MAB OXFAM5, WOCAT	
Public	Secretaries, Mayors, ADAGRO[5], IPA[5], IFPE[5], Schools, BNB[5], BB[5], BNDES[5]	CODEVASF[5], Secretaries, CPRH, INCRA, COMPESA, EMBRAPA, ITEP, APAC, UNIVASF, UNEB, UFPE, UFRPE, UFMG, UFAL, UFBA, IFPE	CODEVASF, ANA, ONS, ANEEL, IBAMA, INCRA, IBGE, FUNAI, MMA, MI, MME, MDA, MAPA, MPLOG, M transport, Senate, MCTI	World Bank, UNCCD, FAO, World Commission on Dams

[1]By CODEVASF contracted companies; [2]with civil society; [3]*quilombola* is a common designation given to refugee slaves into *quilombos* or descendants of African slaves whose ancestors escaped from sugar cane farms and other properties during the period of slavery and formed little villages named *quilombos*; [4]local/regional offices or branches; [5]mainly historically involved.

ADAGRO – Agricultural pest control and monitoring; AGB Peixe Vivo – executive agency of the watershed committee; ANA – national water agency; ANEEL – electric energy agency; APAC – state water agency; ASA – network promoting sustainable development policies in the semiarid region; BB/BNB/BNDES – banks; CBHSF – São Francisco watershed committee; CHESF – hydropower company; CEMIG – electricity company; COMPESA – state sanitation company; CPP – church council for fishermen; CPRH – state environment agency; CCR Submédio – regional representation of the watershed committee; CODEVASF – regional development agency; EMBRAPA – agricultural research corporation; FAO – food and agriculture organization of the United Nations; FETAPE – rural workers' federation; FUNAI – Indian foundation; IBAMA – environment and national resources institute; IBGE – geography and statistics institute; IFPE – technical college of Pernambuco; INCRA –institute for colonization and agrarian reform; IPA – state agricultural extension and research service; IRPAA – institute for adapted smallholder technologies; ITEP – state technology institute of Pernambuco; MAB – movement of people affected by dams; MST – landless rural workers' movement; MMA/MI/MME/MDA/MAPA/MPLOG/M transport/MCTI – ministries; Pólo sindical – farmers' union; Oxfam – NGO confederation to combat poverty and injustice; STR – farmers' union; Território – regional administrative unit; UNCCD – UN convention to combat desertification; UNIVASF/UNEB/UFPE/UFRPE/UFMG/UFAL/UFBA – universities (including scientists and international partners); WOCAT – global network of soil and water experts.

predictable crop harvests and the subsequent provision of crop by-products to livestock; the availability of water for various purposes (e.g. drinking water, irrigation water, water for aquaculture, and bathing water, as well as water to dilute wastewater); and a contribution to climate regulation via carbon storage in soil and plants and restriction of further GHG emissions. The three services are interlinked. Irrigation water enables crops to grow, albeit generally not along a linear relationship. Fresh water is being contested by various uses, such as hydropower generation, domestic water supply, and irrigation under very diverse conditions. Many crops, especially when densely cultivated in a monoculture plot, require more protection from pests. This can be achieved by pesticides, which need energy for production and dispersal and can potentially pollute water sources, or via biological pest control. Yet, high returns from crops may lead to the intentional reduction of natural habitats — where beneficial predators thrive — in order to increase land used for farming. The reduced habitats may create a reduced capacity to store carbon, since sequestration is generally higher and more persistent in natural habitats than in crop plots. The final benefits, produce for consumption or sale and contribution to halting climate change, can likely be increased only up to a point. The adequate balancing of services and benefits is the ultimate goal of the research project. To achieve this, a number of studies are underway to quantify and value the selected regulating services and goods and to reveal relevant pathways of information and decision-making (Table 2).

SCENARIOS FOR STUDYING AND GOVERNING THE REGION

Using scenarios in scientific and practical fields is a widespread and diverse practice. Some authors apply scenarios that study single sectors. Maneta *et al.* (2009) analyzed the expansion potential for irrigation

Table 2 – Ongoing studies of the INNOVATE project and preliminary results on selected ecosystem services.

Ecosystem service	Ongoing studies in the frame of the project			
	Quantification	Valuation	Main rules and stakeholders	Decisions
Biological pest control	Land users know several key species; safeguarding habitats is important for control; farmers often rely on vast pesticide quantities though using the service could be more economically efficient.	Economic efficiency of smallholder production patterns.	Agricultural policy, law on pesticides, national and regional conservation laws, law on environmental crimes, development paradigm; farmers, extension services, local pesticide sellers, CODEVASF, EMBRAPA.	At national government level: which type of agriculture to promote and support and how. At local action scale: conserving habitats to enhance service benefits and limit pesticide use.
Reduction of GHG emissions	CH_4 emissions measured at different points in the reservoir. Results suggest less concern than anticipated. C stocks determined in soil and biomass, modeled within soil.	...	National law on climate change, national and regional conservation laws, law on environmental crimes; farmers, extension services, CODEVASF, EMBRAPA.	At governmental level: Realize monitoring and control of conservation areas, promote conservation measures. At local action level: refrain from slashing vegetation, use alternative fuels and amend soils.
Provision of fresh water	Water quantity and quality in basin models affected by climate change; "green liver system" to purify water by macrophytes; local water quality studies. During low water level crisis: water quality can be critical, water quantities harshly reduced, separation of man-made from natural causes still contested.	Cost efficiency of sanitation measures; economic efficiency of the "green liver system".	National water law, CONAMA regulation, national energy matrix, law on basic sanitation; local water users, sanitation agencies, CBHSF, ANA, ONS, CHESF, CEMIG.	Realize governance adaptations in line-organizations in consonance with the Water Law. On local action level: reduce water spoilage, improve water use efficiency, prioritize low water demand applications, improve wastewater disposal.

Notes: Information derived from project seminars and project reports. Abbreviations: compare notes of Table 1.

in the upper and middle portion of the São Francisco watershed, but also acknowledged the impact on fishery and hydropower. Companies, such as the electric power grid company ONS, have the mission to distribute the electricity supply nationwide, hence, their models focus on available resources, such as hydropower. The National Water Act (BRASIL, 1997) prescribes the principle of various water uses of equal importance, which requires integrated planning of water resources when resources are scarce. The regional development agency developed prospective mid-term scenarios for the period of 2009 until 2028, distinguishing three main scenarios and applying them to the four sub-regions of the watershed, assuming that these may not develop in the same direction or pace (CODEVASF & FUNDAÇÃO GETÚLIO VARGAS, 2011). Scenario one has been called "the march" (*A Marcha*) and depicts a slow, though steady, development pathway. Scenario two is "the flight of the hyacinth macaw" (*O Vôo da Arara Azul*), indicating an ambitious and innovative way forward. Scenario three is "the flight of the potoo" (*O Vôo do Urutau*), a nocturnal species with a painful cry, demonstrating that the situation may also worsen, putting development at risk.

Considering water as a scarce resource entails a paradigm change from the previously promoted "culture of abundance", which meant little awareness of the impacts on the life supporting system by human activities (ROMANO & CADAVID GARCIA, 1999). Integrated natural resource management is increasingly framed as a nexus problem, which involves systemic thinking and integrated solutions (HOFF, 2012). Interdependencies and competition among sectors have been described as the major challenges in nexus problems which call for a cross-sectorial approach (KARLBERG *et al.*, 2015). Managing the cross-sectorial approach requires a common understanding of tools. A scenario discussion within the project revealed that the scientists involved had very different perceptions of what a scenario entails. Therefore, the type of scenario had to be made explicit first. While natural scientists tended to prioritize exploratory models, which forecast trends in simulation runs, the social scientists considered primarily back casting models, searching for best methods to reach or avoid vision in an anticipatory, strategic way. The group of project scientists explored both ways, finding that optimization potentially plays a role in both, and offered a set of three major scenarios, which reflect both approaches (Table 3).

Table 3 – Project scenarios used by INNOVATE in studying the São Francisco watershed.

Scenario label	Modeled frame conditions	Climate scenarios	Case-specific storylines
Baseline	Planned and started irrigation projects fully implemented.	No CC	Development will continue approximately as it was during the years 2012 to 2015.
A2[a]—Social fragmentation	High population growth, little environmental awareness, increasing divide between rich and poor people.	More humid Drier No CC	Technical divide in irrigation techniques widens, focus on engineering solutions, more water diversion projects pushed through, strong increase in cropping area and aquaculture, crops with high water demand, strong overall increase of nitrogen surplus, governance becomes even more fragmented.
B1[a]—Global awareness	Globalization along with higher environmental awareness, leading to less population growth and a fairer, sustainable economic growth.	More humid Drier No CC	Increased irrigation efficiency, more conservation of natural vegetation, accounting for ecological water flow demand, some increase in cropping area and aquaculture, crops with lower water demand, lower nitrogen surplus increase, effective monitoring and control systems, policies are developed and implemented across sectors.

Note: The storyline entries are not fully corresponding with particular other row entries; they are meant as approximations.
[a]According to SRES climate scenarios; UKMO HADCM3 used for modeling land use and crop mix.
No CC – no climate change modeled.

Special Report on Emissions Scenarios (SRES) climate scenarios have been used for simulating and downscaling global changes in land use and crop mix for the São Francisco basin (MAgPIE). The next model (SWIM) used the resulting information on land use and crop mix and simulated possible future surface-water quantities within the watershed under climate change conditions. The downscaling of land use scenarios and the hydrological simulations are described in Koch *et al.* (this issue). Again, results are being fed into following models at lower scales (compare for instance Silva & Moraes (this issue)). First results have been discussed with stakeholders leading to adjustments within modeled scenarios. These top-down, interconnected and primarily exploratory model applications are based on quantitative data using a range of data sources, consisting mainly of open access data sets. The storylines also describe qualitative characteristics plausible for the São Francisco basin and align with the global scenario ideas. Likewise, scenarios serve to discuss or further test experimental study results under different future conditions. In the beginning, a fourth scenario had been discussed in which conditions worsen, but it was not explicitly pursued. Nevertheless, the quantitative runs of models will not necessarily always reflect the assumed qualitative characteristics and may introduce other projections and externalities in further analyses. So far, the question addressed by using the scenarios is not how probable these scenarios are, but to demonstrate different path dependencies, as well as opportunities for action and limits to action. Quantitative models will primarily produce results for a 20-year period (up to the year 2035, forming the middle point of the years 2021 to 2050). Since climate change and run-off processes are generally slow, these will additionally be modelled until the end of the 21st century. Both scenario applications, forward and backward, can guide decision-making. The project scenarios are widely compatible with the earlier presented scenarios. Through their quantitative application, they are introducing the effect of climate change, using diverse scenario predictions. Societal or regional differences are not modelled by separately treating the basin's sub-regions but by model-inherent features, such as social fragmentation.

HOW THE SCENARIOS AFFECT ECOSYSTEM SERVICES AND RURAL LIVELIHOODS

How the scenarios possibly shape the ecosystem services and people's wellbeing is explored in a qualitative, projective analysis (Table 4). The baseline scenario characterizes the fate of ecosystem services under current conditions: low or only slowly growing consideration of the studied ecosystem services. Under social fragmentation they are even less valued, counteracting positive externalities, leading to increased loss of biodiversity, higher emissions, higher soil degradation, and higher demand in water. This will ultimately negatively affect the sectors that depend on these natural resources, widening the gap of social fragmentation even more. Due to global awareness, the positive view of ecosystem services conservation is prevailing; measures are undertaken that reduce negative effects, though they cannot be stopped altogether. As long-term benefits are considered at expense of short-term benefits, compensatory measures might be needed to bridge the time gap.

RESEARCH RESULTS SERVING SOCIETAL DECISION-MAKING

INNOVATE's mandate is not only to produce new knowledge but also to connect and cooperate with stakeholders who can benefit from the scientific results. Some of our research areas rely on the interaction with stakeholders. We have held a series of workshops to undertake constellation analysis (compare Rodorff *et al.* in this issue). Other studies were based on resource user surveys. To support both the production of useful knowledge and work towards the implementation of future results, the project developed a concept involving three elements:

1. a written guidance document,
2. face-to-face workshops with stakeholders, and
3. cooperation on-demand.

The latter can involve both written and live elements. While the written document is in its infancy as data analyses and interpretations are still ongoing, a num-

Table 4 – Provision and use of ecosystem services under different scenario conditions (conceptual overview, INNOVATE project).

Ecosystem services	Scenario		
	Baseline	A2 – Social fragmentation	B1 – Global awareness
Biological pest control	Little used and no incentives to use.	Does not play any role; potential faunal populations decrease.	Becomes a large-scale, actively supported solution; increased research activities trigger new options.
Possible trade-offs	Inefficient smallholder farming.	Reflects biodiversity loss; pesticide industry needs large amounts of water and energy.	On average smaller yields need compensatory measures such as reducing post-harvest losses.
Reduction of GHG emissions	Almost no awareness.	Not taken into account; emissions increase greatly.	Adoption of measures to reduce emissions; at maximum a slow increase of emissions.
Possible trade-offs	Counteracting unintended mitigation.	Release of carbon and methane deteriorates climate forecasts; soil degradation and biodiversity loss.	Conservation measures might be beneficial in the long term but in the short term, income might be lost.
Provision of fresh water	Perceived unfair allocation of scarce water resources; slowly growing public awareness of resource scarcity.	Management favors large water users including additional water diversion projects; pollution is considered secondary.	Adaptive water management; more and better sanitation; restoration projects contribute to water flow regulation.
Possible trade-offs	Conservation is considered contrary to production. Different development paradigms exist.	Crop choice according to world market prices – use of water-demanding crops worsens water use efficiency, as do precarious smallholder systems; commercial shipping may stop altogether.	Shift in crops enhances agrobiodiversity; restoration projects support biodiversity; wind power and solar energy complement energy matrix, levelling out shortages.

GHG: Greenhouse gas.

ber of stakeholder workshops have already ocurred. At the watershed scale, project members organized several meetings with stakeholders at different hierarchical scales and located in different areas of the watershed. One series focused on data sets and missing data in modeling and scenario analysis, with the intention to find some of the missing data. It also served to discuss scenario storylines with stakeholders. Another series focused on already set up models and their initial results. The intention was to learn which data and results might be most useful for which stakeholders. A third series centered on the multiple uses of water at the river basin scale. It covered benefits and duties of public participation, how decision rules affect water availability, which practical conclusions one can draw from hydrodynamic modelling, and the risk of phosphorous losses from soils and how to reduce them. At reservoir (local) scale, project members also held three series of meetings. Series one primarily addressed students in the municipalities of focus, while series two aimed to involve adult stakeholders as well. Most of the project members working at the local level had prepared short summaries to provide highlights of their studies in accessible language, and they engaged with attendees on these topics. A written summary is being prepared for teachers to help them share the information locally. A third set of four meetings addressed farmers, with a focus on livestock keepers. Topics included civil society engagement and adaptation strategies for farmers to better and more sustainably cope with their natural and economic environment.

The third element, cooperation on demand, has two lines at the watershed scale, which are both related to the committee of the São Francisco watershed and its executive agency, the AGB Peixe Vivo. First, we are cooperating with the appointed international consulting group, which is renewing the basin plan. One meeting served to exchange data, documents, and concepts. Further exchange took place during seminars and a conference. Second, the project has been asked to cooperate in the network of basin-related researchers to help consolidate access to datasets and information on finished and ongoing studies. On the local and regional scale, the governmental development agency of the São Francisco basin (CODEVASF) in Petrolina, a regional agency, asked the project to formulate development projects derived from the ongoing studies. This request still needs to be broken into feasible tasks for respective project scientists. Another cooperation attempt combines a written document for discussion and comments with stakeholders by e-mail.

Which management options or questions can finally be addressed by the project results and are these of real interest to stakeholders today or in the future? The tasks of a basin plan are according to the Water Act (BRASIL, 1997):

1. diagnosis of current situation;
2. analysis of demographic dynamics, development of productive activities, and land use changes;
3. future water supply and demand, including quantity and quality aspects, and potential conflicts;
4. targets for efficient water use, increasing quantity, and improving quality;
5. measures, programs and projects to address the previous targets;
6. priorities for assigning water use rights;
7. directives and criteria for water pricing;
8. proposals for creating conservation areas to protect water resources.

The project addresses several of these targets, at least partly. Since the studies have been set up neither to serve only the plan and the ongoing management of the basin, nor the management at the reservoir scale, some adaptation of the contents is necessary. This work is currently under way.

LESSONS LEARNED FROM COOPERATIVE PRACTICE

Exchange among scientists has revealed inspiring cases of contradictory results or conclusions. This clearly shows the value of a comprehensive project and its effective cooperative practice. The practice of interdisciplinary and transdisciplinary research does however involve cultural challenges and change, promoting debate about contradictions. This is common to scientific work, but not always feasible to this extent. A diverse group of disciplines broadens the potential divergences and new insights. Finally, a complex synthesis is better than forced consensus, as it profits from an integrated view and is better informed (DELGADO *et al.*, 2009).

Vocabulary commonly causes confusion in interdisciplinary cooperation. We were required to make differences in definitions explicit, which led participants to deeply reflect on statements and meanings. Some linguistic pitfalls are:

- Technical or field-specific language: some terms are uncommon to almost all people unfamiliar with the respective discipline or even branch of discipline. Examples include “trophic upsurge” or “drawdown agriculture”.
- Simple words: while some scientists use words with their popular meaning in mind, others just make use of a very particular term. Thus, a “significant” difference can be understood as an apparently clear difference or a tested and approved statistical difference.

- Graduated differences: a term might be popular in one discipline, whereas in another the differentiation is not central to analysis. Examples are "participation" (ranging from asking stakeholders questions, to defining the degree of power and control of people involved in knowledge generation). Another example is "grazing intensity" (distinguishing more roughly light from heavy grazing, or analyzing e.g. stocking rates, along with inter-annual and species' composition differences).
- Synonyms: words may be used interchangeable by some, while others attach clear, though maybe small, differences in their meanings. Such a word group is for instance: management, regulation, and control.
- Tradition: terms might be used according to major disciplinary traditions without specification. Talking about "scenarios" revealed that some were, per default, thinking in terms of forecasting, while others had back casting in mind.
- Geographical-cultural background: researchers originating from a temperate region learned that a "forest" is not necessarily characterized by a green, dense, and high vegetation cover, but that Caatinga, with its small and sparse vegetation, is also a forest though a dry one. International classification of land cover may however classify Caatinga as a savanna or even open area, leading to the assumption that the area is unused, which is often a false conclusion.
- Neutrality: a term in one discipline can have a neutral connotation, while in another it may sound value-laden. The nutrient "load" of a lake is just the quantification of nutrients in limnology, sometimes attributed to water pollution, while in soil or plant sciences it may sound negative as especially "macro" nutrients are considered valuable and are often a scarce resource for plant growth and soil fertility.

Interacting with non-scientist partners, or those who briefly attended school, similarly calls for a clear formulation and awareness of potential differences in vocabulary. Furthermore, openness to new terms and different ways of reasoning and communicating is important. In general, conclusions should be drawn with a clear context-connotation. Awareness of the various probable effects, relations, and potential boundary problems is vital. These can result from choices concerning or relationships with:

- Spatial location: biophysical, socioeconomic, political or cultural differences;
- Sector: e.g. aquaculture, agriculture, energy, transport, or sanitation;
- Jurisdictional scale: local, municipal, regional, state, national, international;
- Temporal dynamics: sequence, speed of changes, length of period;
- Knowledge scale and type: historical, current and future, local and scientific;
- Value system: the researchers' or stakeholders' own discipline, previous research projects, socialization, and personal preferences and beliefs.

FINAL CONSIDERATIONS

The multi-disciplinary project reflects the still far more complicated and complex existing governance challenges of the São Francisco watershed: different perspectives and separate interests are being pursued, cooperation activities have been arranged, some members are temporary, and the overall integration is complicated. The sustainability paradigm draws attention to the dimensions of people, planet, and profit. Merely mentioning the complex interconnections and benchmarks is not enough. How can people strategically and effectively deal with different aspirations and impacts? Possible approaches, for instance, are river basin development planning and management (RBDPM), integrated water resource management (IWRM), or strategic environmental assessment (SEA). An early RBDPM was attempted in the São Francisco watershed as early as 1948, with the founding of *Comissão do Vale do São Francisco*, and was promoted by international organizations (BARROW, 1998). Barrow concludes from a range of early national examples that RBDPM showed poor results in achieving integrated area development due to implementation and management flaws. More specifically, he criticizes focusing on single-purpose development in a too centralized setting while neglecting communication, lacking adequate data and often leadership, and not being sufficiently flexible and adaptive. McDonnell (2008) similarly acknowledges poor results of implementing IWRM, mentioning similar pitfalls as Barrow for RBDPM, though she concludes that a major pitfall is the purely techno-scientific approach of knowledge production and decision-making. She argues that the "networks and flows of power between the various actors/stakeholders involved with governance" are often neglected and that the complex challenges of integrated management need a concerted cooperation of different disciplines and stakeholders. SEA is still voluntary in Brazil, though the Ministry of Environment has recommended it for more than ten years for strategic decisions and there have been recent attempts to institutionalize it in federal plans and programs (MALVESTIO & MONTAÑO, 2013). Therefore, it appears appropriate to study the potential of methods related to SEA and IWRM to guide the integrated management of the São Francisco watershed. Testing multi-criteria decision-making and identifying more clearly how to cope practically with integration seems useful for the future.

At stake is a conflict-sensitive adaptation to climate change and governance challenges. The nexus of competing sectorial demands, along with the attempt to balance social, economic, and environmental goals in a sustainability framework is regularly affected by the issues of equity and unfavorable power relations (KUMI *et al.*, 2014). The authors argue that proposals for solutions will fail as long as the undermining incidents, such as corruption, are not addressed. This is not only rather pessimistic, but also out of the scope of our type of research, though it is important to draw attention to the need for broader institutional and cultural change. A collaborative research project is not able to induce substantive changes in society, though small steps are being pursued. Finally, a substantial contribution might be capacity building for both the young and experienced scientists involved. This is especially true for those who took advantage of the additional offers and benefits and who contributed to resolving conflicts inherent to the comprehensive consortia work.

ACKNOWLEDGEMENTS

We would like to acknowledge the commitment and contributions of the numerous members of the INNOVATE project during seminars, workshops, project conference, fieldwork sessions, and manifold discussions. We would like to thank a few colleagues as representatives. The preparation of this paper draws specifically on collaboration with Hagen Koch, Márcia Alcoforado Moraes, Arne Cierjacks, Jarcilene Almeida-Cortez, Roberto Azevedo, Volkmar Hartje, Sarah Gottwald, Maike Guschal, Verena Rodorff, Gerald Souza da Silva, Heinrich Hagel, Anne Biewald, Maricela Rodriguez, Florian Selge, and Gérsica Silva. The work was supported by the German Ministry of Education and Research (BMBF; Sustainable Land Management program) as the INNOVATE project under grant number 01LL0904A, and the grants of the Brazilian Ministry of Science, Technology and Innovation (MCTI) as well as Brazil's Council for Scientific and Technological Development (CNPq). Thanks to Kimberly Tatum for the English language revision.

REFERENCES

AGAM TECNOLOGIA LTDA. & CHESF. Estudo Ambiental da Barragem de Itaparica - Usina Hidro Elétrica Luiz Gonzaga. Unpublished report, 2003.

AGB PEIXE VIVO & CBHSF (Org.). Guardiões do Velho Chico. CBHSF - Comitê da Bacia Hidrográfica do São Francisco, 2001-2011. Companhia de Comunicação, 2011.

ANA; GEF; PNUMA; OEA. Plano Decenal de Recursos Hídricos da Bacia Hidrográfica do Rio São Francisco - PBHSF (2004-2013): Síntese do Resumo Executivo do PBHSF com Apreciação das Deliberações do CBHSF. Brasília, 2004.

BARROW, C.J. River basin development planning and management: A critical review. World Development, v. 26, n. 1, p. 171–186, 1998. doi:10.1016/S0305-750X(97)10017-1.

BRAGA, B.P.F.; GONDIM FILHO, J.G.C.; SUGAI, M.R.v.B.; COSTA, S.V.d.; RODRIGUES, V. Impacts of Sobradinho Dam, Brazil. In: TORTAJADA, C.; ALTINBILEK, D.; BISWAS, A.K. (Org.). Impacts of large dams: A global assessment. Berlin: Springer, 2012,p. 153-170. (Water resources development and management). ISBN 3-642-23570-0.

BRASIL. Lei n° 9.433, de 8 de janeiro de 199. Brasília: DOU de 9.1.1997, 1997.

CERNEA, M.M. Involuntary resettlement: social research, policy, and planning. In: CERNEA, M.M. (Org.). Putting people first: Sociological variables in rural development, 2. ed. New York [etc.]: Oxford University Press, 1991, p. 188-215. ISBN 0-19-520465-4.

CHESF. Descrição do Aproveitamento de Luíz Gonzaga. Disponível em: https://www.chesf.gov.br/SistemaChesf/Pages/SistemaGeracao/LuizGonzaga.aspx, n.y. Acesso em: 10 Jul. 2013

CODEVASF & FUNDAÇÃO GETÚLIO VARGAS. Cenários prospectivos para os vales do São Francisco e do Parnaíba: 2009 a 2028. Brasília: CODEVASF, 2011. ISBN 978-85-89503-10-5.

DAILY, G.C.; POLASKY, S.; GOLDSTEIN, J.; KAREIVA, P.M.; MOONEY, H.A.; PEJCHAR, L.; RICKETTS, T.H.; SALZMAN, J.; SHALLENBERGER, R. Ecosystem services in decision making: Time to deliver. Frontiers in Ecology and the Environment, v. 7, n. 1, p. 21-28, 2009. doi: 10.1890/080025.

DELGADO, L.E.; MARÍN, V.H.; BACHMANN, P.L.; TORRES-GOMEZ, M. Conceptual models for ecosystem management through the participation of local social actors: The Río Cruces wetland conflict. Ecology and Society [online journal], v. 14, n. 1, p. 50, 2009.

EMBRAPA-SOLOS. Levantamento de Reconhecimento de Baixa e Média Intensidade dos Solos do Estado de Pernambuco. Rio de Janeiro: EMBRAPA, 2000. (Boletim de Pesquisa, 11).

EPPINK, F.V.; WERNTZE, A.; MÄS, S.; POPP, A.; SEPPELT, R. Land management and ecosystem services: How collaborative research programmes can support better policies. GAIA, v. 21, n. 1, p. 55-63, 2012.

FOLEY, J.A.; DEFRIES, R.S.; ASNER, G.P., BARFOR, C.; BONAN, G.; CARPENTER, S.R.; CHAPIN, F.S.; COE, M.; DAILY, G.C.; GIBBS, H.K.; HELKOWSKI, J.H.; HOLLOWAY, T.; HOWARD, E.A.; KUCHARIK, C.J.; MONFREDA, C.; PATZ, J.A.; PRENTICE, I.C.; RAMANKUTTY, N.; SNYDER, P.K. Global consequences of land use. Science, v. 309, n. 5734, p. 570-574, 2005. doi:10.1126/science.1111772.

HAINES-YOUNG, R. & POTSCHIN, M. The links between biodiversity, ecosystem services and human well-being. In: RAFFAELLI, D.G.; FRID, C.L.J. (Org.). Ecosystem Ecology: A New Synthesis. Cambridge [etc.]: Cambridge University Press, 2010. p. 110-139.

HOFF, H. Managing the water-land-energy nexus for sustainable development. UN Chronicle, XLIX, 1 & 2, 2012.

KARLBERG, L.; HOFF, H.; AMSALU, T.; ANDERSSON, K.; BINNINGTON, T.; FLORES-LÓPEZ, F.; BRUIN, A.; GEBREHIWOT, S.G.; GEDIF, B.; ZUR HEIDE, F.; JOHNSON, O.; OSBECK, M. Tackling complexity: Understanding the food-energy-environment nexus in Ethiopia's Lake Tana sub-basin. Water Alternatives, v. 8, n. 1, p. 710-734, 2015.

KOCH, H.; BIEWALD, A.; LIERSCH, S.; AZEVEDO, J.R.G.; SILVA, G.S.d.; KÖLLING, K.; FISCHER, P.; KOCH, R.; HATTERMANN, F.F. Scenarios of climate and land-use change, water demand and water availability for the São Francisco river basin. Revista Brasileira de Ciências Ambientais, this issue.

KUMI, E.; ARHIN, A.A.; YEBOAH, T. Can post-2015 sustainable development goals survive neoliberalism? A critical examination of the sustainable development–neoliberalism nexus in developing countries. Environment, Development and Sustainability, v. 16, n. 3, p. 539–-54, 2014. doi:10.1007/s10668-013-9492-7.

MA. MA Conceptual Framework. In: Island Press (Org.). Millennium Ecosystem Assessment Report: Ecosystems and Human Well-being. Washington, DC: Island Press, 2005.

MALVESTIO, A.C. & MONTAÑO, M. Effectiveness of strategic environmental assessment applied to renewable energy in Brazil. Journal of Environmental Assessment Policy and Management, v. 15, n. 02, p. 1340007, 2013. doi: 10.1142/S1464333213400073.

MANETA, M.; TORRES, M.; WALLENDER, W.; VOSTI, S.; KIRBY, M.; BASSOI, L.H.; RODRIGUES, L. Water demand and flows in the São Francisco River Basin (Brazil) with increased irrigation. Agricultural Water Management, v. 96, n. 8, p. 1191–1200, 2009. doi:10.1016/j.agwat.2009.03.008.

MCDONNELL, R.A. Challenges for Integrated Water Resources Management: How do we provide the knowledge to support truly integrated thinking? International Journal of Water Resources Development, v. 24, n. 1, p. 131–143, 2008. doi: 10.1080/07900620701723240.

MMA. Diagnóstico do macrozoneamento ecológico-econômico da bacia hidrográfica do Rio São Francisco. Brasília: Ministério do Meio Ambiente, 2011.

MOLLE, F. Water, politics and river basin governance: Repoliticizing approaches to river basin management. Water International, v. 34, n. 1, p. 62-70, 2009. doi: 10.1080/02508060802677846.

MOLLE, F.; WESTER, P.; HIRSCH, P. River basin development and management. In: MOLDEN, D. (Org.). Water for food - water for life: A comprehensive assessment of water management in agriculture. London, Colombo: Earthscan Publ; IWMI, 2007, p. 585-624. ISBN 978-1-8447-396-2.

MUTOKO, M.C.; SHISANYA, C.A.; HEIN, L. Fostering technological transition to sustainable land management through stakeholder collaboration in the western highlands of Kenya. Land Use Policy, v. 41, p. 110-120, 2014. doi:10.1016/j.landusepol.2014.05.005.

REED, M.S.; GRAVES, A.; DANDY, N.; POSTHUMUS, H.; HUBACEK, K.; MORRIS, J.; PRELL, C.; QUINN, C.H.; STRINGER, L.C. Who's in and why? A typology of stakeholder analysis methods for natural resource management. Journal of Environmental Management, v. 90, n. 5, p. 1933-1949, 2009. doi: 10.1016/j.jenvman.2009.01.001.

REED, M.S.; STRINGER, L.C.; FAZEY, I.; EVELY, A.C.; KRUIJSEN, J. Five principles for the practice of knowledge exchange in environmental management. Journal of Environmental Management, v. 146, p. 337-345, 2014. doi:10.1016/j.jenvman.2014.07.021.

RODORFF, V.; ARAÚJO, G.; GOMES, E.T.A.; KÖPPEL, J.; SIEGMUND-SCHULTZE, M.; SOBRAL, M.C. Driving forces and barriers for a sustainable management of the Itaparica reservoir region - basic milestones towards a constellation analysis. In: GUNKEL, G.; SILVA, J.; SOBRAL, M.C. (Org.). Sustainable Management of Water and Land in Semiarid Areas. Recife: Universidade Federal de Pernambuco, Editora Universitária, 2013. p. 254–268.

RODORFF, V.; SIEGMUND-SCHULTZE, M.; KÖPPEL, J.; GOMES, E.T.A. Governança da bacia hidrográfica do rio São Francisco: Desafios de escala sob olhares inter e transdisciplinares. Revista Brasileira de Ciências Ambientais, this issue.

ROMANO, P.A. & CADAVID GARCIA, E.A. Policies for water-resources planning and management of the São Francisoc river basin. In: BISWAS, A.K.; CORDEIRO, N.V.; BRAGA, B.P.F.; TORTAJADA, C. (Org.). Management of Latin American river basins: Amazon, Plata, and São Francisco. Tokyo: The United Nations University, 1999. p. 245-271. ISBN 92-808-1012-X.

SIEGMUND-SCHULTZE, M.; RODORFF, V.; KÖPPEL, J.; SOBRAL, M.C. Paternalism or participatory governance? Efforts and obstacles in implementing the Brazilian water policy in a large watershed. Land Use Policy, v. 48, p. 120-130, 2015. doi:10.1016/j.landusepol.2015.05.024.

SILVA, G.S. & MORAES, M.M.G.A. Curvas de demanda pelos recursos hídricos dos principais usos consuntivos no Submédio da bacia do São Francisco. Revista Brasileira de Ciências Ambientais, this issue.

WESTIN, F.F.; SANTOS, M.A.; MARTINS, I.D. Hydropower expansion and analysis of the use of strategic and integrated environmental assessment tools in Brazil. Renewable and Sustainable Energy. Reviews, v. 37, p. 750–761, 2014. doi:10.1016/j.rser.2014.04.071.

WORLD BANK. Recent Experience with Involuntary Resettlement: Brazil - Itaparica. Document of the World Bank, Report No. 17544, 1998.