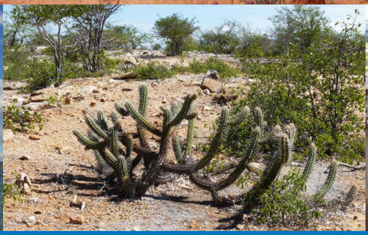
Guidance Manual



Marianna Siegmund-Schultze (ed.)

A compilation of actor-relevant content extracted from scientific results of the **INNOVATE** project

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Guidance Manual—A compilation of actor-relevant content extracted from scientific results of the INNOVATE project

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Fasanenstr. 88, 10623 Berlin
Tel.: +49 (0)30 314 76131 / Fax: -76133
E-Mail: publikationen@ub.tu-berlin.de

Editorial assistance: Sonja Hölzl

English language editing: Jonah Landor-Yamagata

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We apologize for any grammatical or content-related errors.

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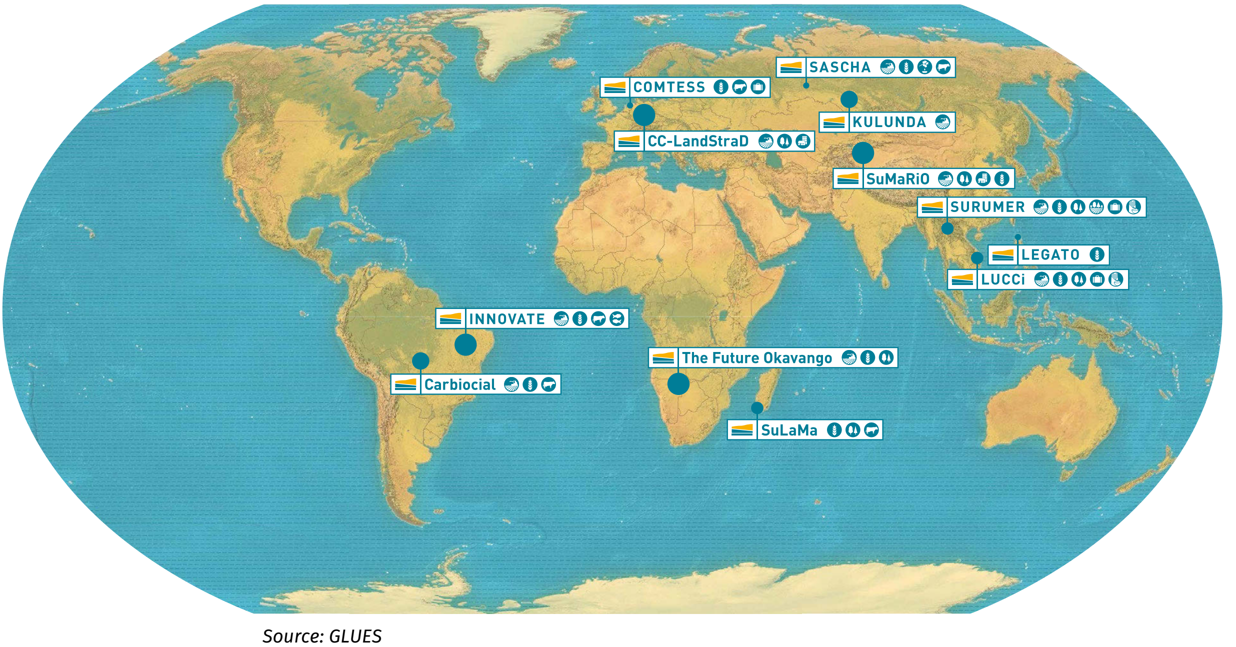
Water Quantity *Water Quality* *Flora* *Fauna* *Agriculture* *Society*

Preface

The purpose of this manual is to provide guidance for improving governance and management of natural resources, with the overarching goal of facilitating sustainable use and conservation of the environment. The manual addresses the watershed scale (the São Francisco River Basin in Brazil), and sub-systems within it, with a special focus on semi-arid conditions. Most recommendations put forward can be adapted as principles and standards to regions elsewhere in the world.

The Guidance is based on research carried out in the frame of the Sustainable Land Management funding measure in the Research for Sustainability (FONA) framework program of the German Federal Ministry of Education and Research (BMBF). The INNOVATE project (funding codes 01LL0904 A–E), one of 12 regional projects in module A of the funding measure, was co-funded by the Brazilian Ministry of Science, Technology, Innovation and Communication (MCTIC, formerly MCTI) through the Brazilian National Council for Scientific and Technological Development (CNPq).



Source: GLUES
INNOVATE was one of 12 regional projects funded by BMBF

More than 50 Brazilian and 50 German researchers collaborated on this scientific project in its core period from January 2012 to December 2016. The involved institutions and respective sections are listed in the annex. Many stakeholders contributed substantially to the Guidance content through transdisciplinary knowledge production in numerous workshops, surveys, and individual interactions.

The chapters of the Guidance can be read separately. Each recommendation chapter starts with basic information on who may be interested in the chapter and the contacts of those who prepared it. Some chapters just give short descriptions of products which can be accessed elsewhere; others are more comprehensive and present the essence and recommendations of the topic in the chapter itself. Many chapters point to further written documents with in-depth information, such as scientific papers, congress contributions and theses prepared in the frame of the research project. Most parts of the Guidance have been presented and discussed with related stakeholders. These stakeholder workshops helped to improve the content—thank you for your collaboration.

While the Guidance primarily intends to serve stakeholders searching for information relevant to their purposes, the whole manual likewise summarizes major research results of scientific interest, making it a compendium of the scientific project.

The recommendations put forward should be interpreted and applied in accordance with existing obligations, and adapted to the specific environmental, social, economic and political context they will be implemented in. We hope that the content will prove useful for many people, contributing to a more sustainable land management.

Berlin, January 2017
Marianna Siegmund-Schultze

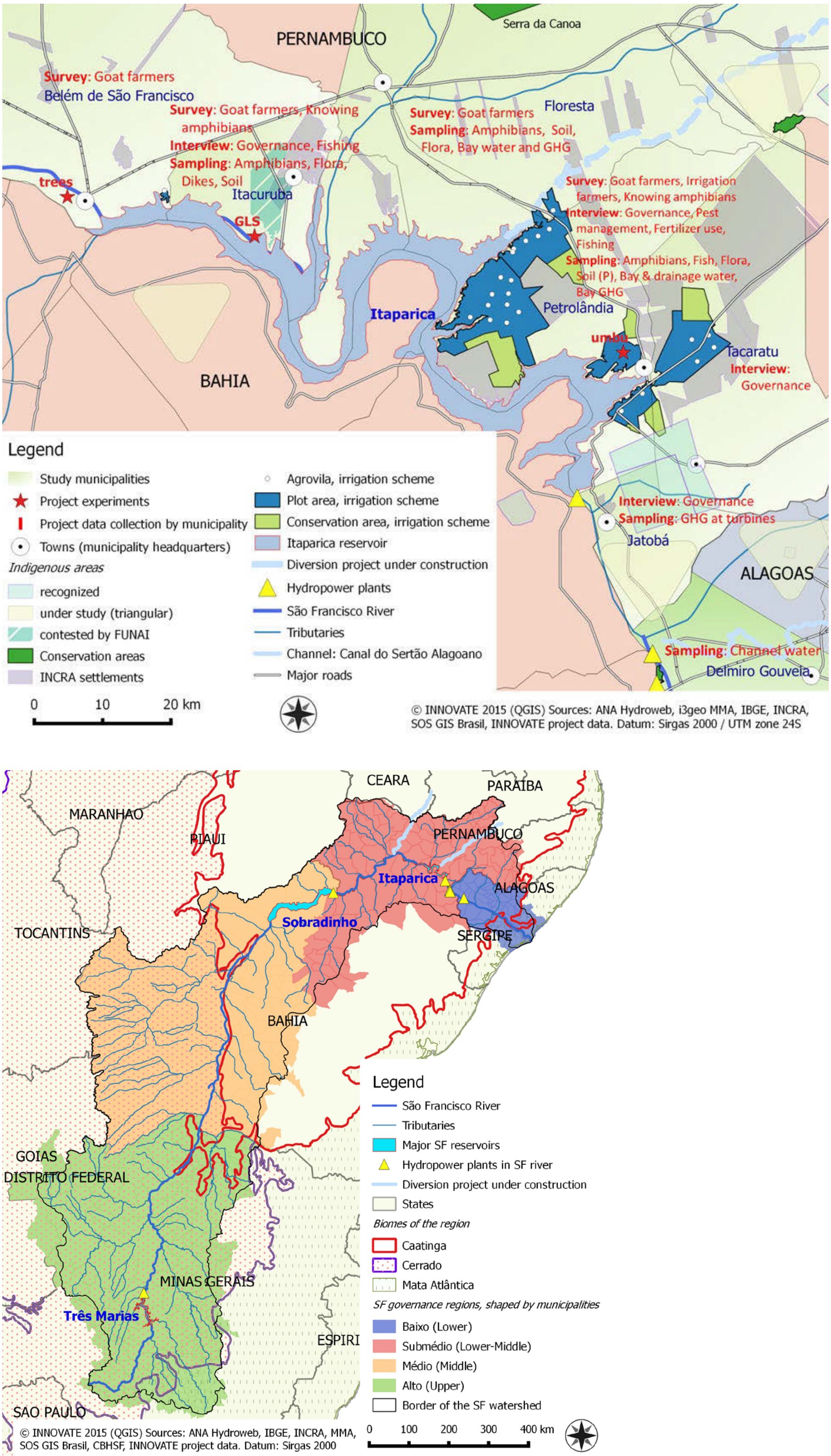
What is **INNOVATE** and why does it propose recommendations?

INNOVATE was a comprehensive collaborative research project. It ran from January 2012 to December 2016. Brazil and Brazil's Northeast in particular was suffering from a severe drought period from 2012 onwards. Management and governance of natural resources faced serious problems related to access to water. Important drivers appear to be land use change, climate change, and conflicts from the multiple uses of water. The scientific project INNOVATE addressed this complex situation through research aimed at suggesting practices and pathways towards ecologically and socially sound management of natural resources. The INNOVATE project had one focus on the whole watershed of the São Francisco River and another one on a portion of the watershed—the Itaparica Reservoir and the semi-arid area north of the artificial lake (Figure 1).

The INNOVATE project studied the aquatic and terrestrial land use systems, with their underlying ecosystem functions and services. Management decisions on the allocation of scarce water resources proved as the major driver of land use discourses and practices. A major challenge involves better interaction of the more recent and regional (e.g., watershed committee) with the established governance bodies (often federal agencies). The primarily hydroelectricity focused water management might not be maintained in the same size in the long run, as it has ever more become adverse towards competing water usages. Major initial concerns about the river and reservoir water quality and possible greenhouse gas emissions have presently not been confirmed in this semi-arid study region. Water quality issues matter primarily in off-stream reservoir bays. Water uptake should avoid such bays; from a limnologic perspective the daily and seasonal water level amplitudes of the reservoir should be kept as limited as possible. The land-water nexus has further been addressed with the 'green liver' approach, purifying effluents from land-based fish production, or alternatively of drainage water from irrigated agriculture. Further monitoring of this experimental system and subsequent approval by practitioners might allow for substantial implementation of this approach in the future.

The major question for the non-irrigated Caatinga (agro)ecosystem was to which degree the grazing intensity could be adjusted to safeguard socio-economic outcomes on the one hand, and the ecosystem's biodiversity, biomass allocation and carbon storage capacity on the other hand. INNOVATE researchers recommended limited grazing loads and preserving natural habitats. Restoration measures for endemic trees

The lower course of the São Francisco River. *Photo: M Siegmund-Schultze*



Source: Siegmund-Schultze et al. (2015)

Figure 1 **Regional characterization of the São Francisco River Basin (below) and experimental sites of the INNOVATE project around the Itaparica Reservoir (above)**

Desiccated area and submerged trees of the Itaparica Reservoir. *Photo: F Selge*

were demonstrated, including studies on acceptance and implementation conditions. Much will depend on whether such initiatives will actually be backed-up e.g., from the Brazilian rural development agency. Locally available and economically feasible substrates for soil amelioration have been identified and tested to improve the productivity of the agroecosystems; such practices require further guidance from the Brazilian Agricultural Research Corporation. Other innovations, so far practiced by only a few smallholders might be up-scaled (e.g., drought-tolerant livestock breeds and forage, pasture rotation). Major phenomena have been identified as driving forces or relevant barriers for a sustainable land and water management. This involves the multi-level governance challenges with manifold actors involved on different scales, often not sufficiently cooperating horizontally as well. The persistent drought crisis acts as a driver for change, initiating e.g., a discourse on payments for irrigation water. Strategic and participatory land use planning, including environmental and social impact assessments, remain a missing link so far in Brazil. The making of a new ten-year river basin management plan served as a focus, and a well-established communication process evolved between INNOVATE and the responsible actors, including the watershed committee.

German partners were the Berlin Institute of Technology ("Technische Universität Berlin", TUB), the University of Hohenheim ("Universität Hohenheim", UHOH), the Leibniz Institute of Freshwater Ecology and Inland Fisheries (IGB), the Potsdam Institute for Climate Impact Research (PIK) and the Senckenberg Natural History Collections Dresden (SNSD). The Brazilian partners comprised of two federal universities in Recife (UFPE and UFRPE), three further universities (UNEB, UFRN, UFC), the Institute for Technology of Pernambuco (ITEP), the Federal Institute for Education, Science and Technology of Pernambuco (IFPE), and the Soil Section of the Brazilian Agricultural Research Corporation at Recife (EMBRAPA Solos).

The German call "Sustainable Land Management" and its module "Interactions between land management, climate change, and ecosystem services" focused on practical solutions (BMBF: http://modul-a.nachhaltiges-landmanagement.de/en/module-a/). Classical desk or laboratory research can be scientifically sound but irrelevant or unfeasible in reality. Interacting with like-minded persons can pave the way to meaningful inter-disciplinary research, though this alone is not sufficient. Exposure to stakeholders and their real-world conditions is needed, though often not considered the mandate of scientists and therefore neglected. The premises of the call were to produce new knowledge by inter- and transdisciplinary research. INNOVATE tackled this by setting up a comprehensive bi-national research consortium, promoting exchange and cooperation among Brazilian and German researchers, and facilitating their interactions with stakeholders during the whole research process (Table 1). Making science meaningful to stakeholders was a new mandate for most of the scientists, and involved considerable effort and learning by scientists and stakeholders alike.

Different series of stakeholder workshops were realized through cooperation among disciplines in Brazil, addressing stakeholders at various scales and locations. A PhD candidates' initiative developed a further format, inviting crowds of local people to so-called Education Days, where science presentations occurred. There, students interacted with local people in order to make research activities tangible and discuss the relevance of preliminary results. Electronic interaction completed the set of communication tools developed by the project: a website (innovate.tu-berlin.de) and social media (facebook.com/innovate2012). The present manual (and its supplementary materials) summarizes major topics discussed with stakeholders with the aim of processing and presenting the research results—the knowledge produced—in such a way that it can be accessed and used by the various stakeholders.

Our propositions for joint knowledge production processes are: (i) Communication is crucial for apprehending context, questioning certainties, checking conclusions with reality, and advancing knowledge by deliberation, (ii) The roles of the participants in knowledge generation have to be clarified, and (iii) Research results should reach their target groups, and researchers can play a role in this.

Table 1 **Interactive collaboration of scientists with stakeholders: INNOVATE's experience**

Goal or hypothesis	Format	Example from INNOVATE	Assessment of practice	Role of stakeholders	Role of scientists
Reaching out and informing a lot of local residents	Education Days	Stands where individuals or groups could get information or actively participate in small actions.	Very well-received. Could be a regular activity of the municipal town hall.	Primarily information receiver	Presenting summarized research
Discussing thematic details	Constellation Analysis workshops	Big events with parallel working groups, and smaller sessions.	The participants liked the method, as it allows a holistic and structured view of a topic. Can be used by local groups.	Exchange, high involvement	Moderating and steering the process
Presenting and discussing thematic details	Presentation and discussion	Focus group seminars of about 10–20 (or more) invited stakeholders, different levels, different topics.	Many interesting discussions. Dynamics depend on group composition and preparation of the material.	Exchange, no to high involvement	Presenting summarized research, exchange
Discussing thematic details	E-Mail consultation	Being asked or asking individuals to elaborate on topics, several feedback loops.	Time intensive. It yields in-depth reasoning of individuals.	Exchange, no to high involvement	Exchange, high involvement
Gathering household information	Survey	Questionnaire-based data collection, e.g. among farmers in irrigation schemes.	Good for deriving key numbers (restrictions to general validity by specific year, season or sample).	Primarily information provider	Politely asking questions

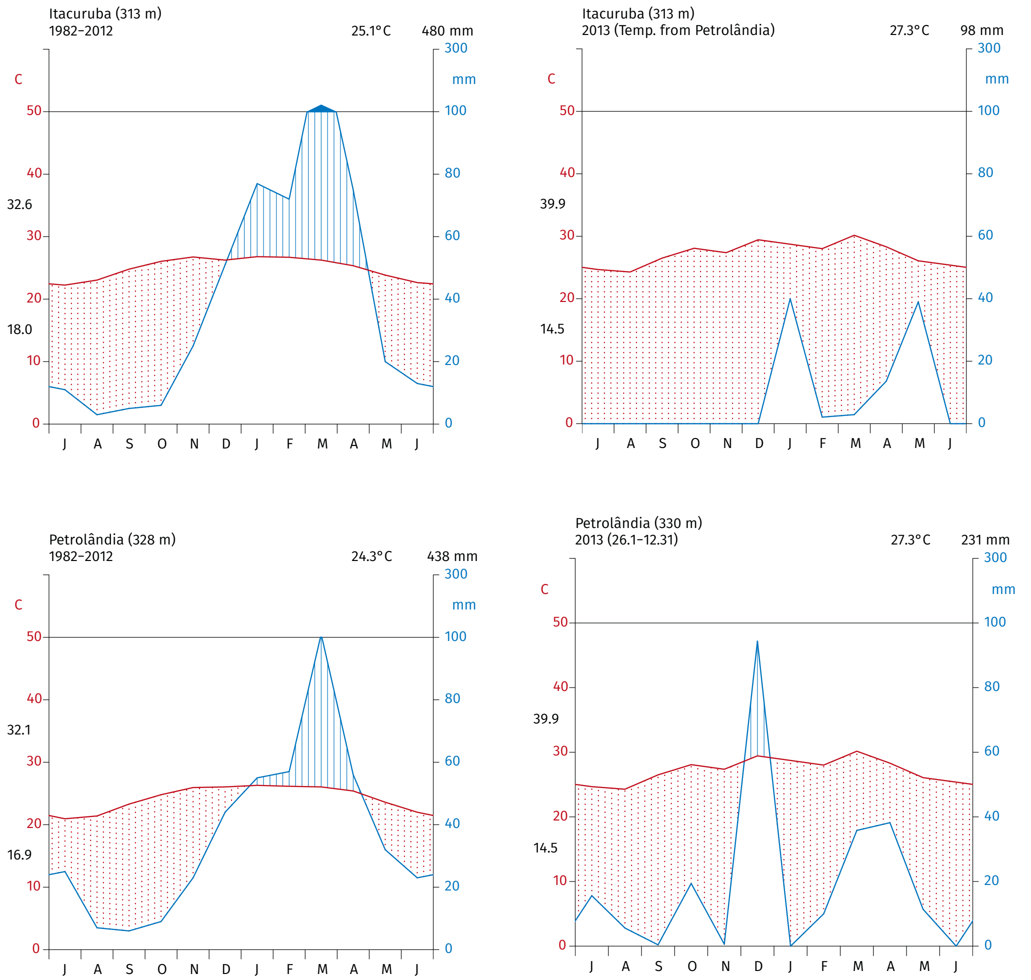
Goal or hypothesis	Format	Example from INNOVATE	Assessment of practice	Role of stakeholders	Role of scientists
Gathering household or organizational information	Key person interviews	Questionnaires with closed or open questions, or topic lists. Used at all levels.	Good for in-depth and non-individual information, primarily qualitative.	Primarily information provider	Applying a questionnaire or open exchange
Stakeholder feedback on research	Conference participation	Rapporteurs in INNOVATE Status Conference.	Concrete and immediate feedback. Only few people can be heard.	Providing analysis and opinion	Feedback receiver
Informing and promoting	Field day	Info day with practical planting of *umbuzeiro* trees.	A continuous follow-up would be necessary to respond to upcoming difficulties with the new technology.	Implementing	Presenting and guiding
Gathering farm information	On-farm measurements	Weighing of animals.	Could be done on a regular basis by farmers as record keeping to build a solid basis for decision-making.	Joint activity, informal	Collaborating in joint activity
Testing under field conditions may increase visibility and acceptability of a new technique	On-farm experiment	Soil amendments added to planting holes of umbuzeiro trees; assessment of soil and tree responses.	Unplanned interaction with owner and neighbors. Options to explain and discuss the techniques.	No expectation or aiming at having an informal advocate who implements	Realizing technical field work
Testing under controlled conditions	On-station experiment	Assessing native and exotic forest species with soil amendments (lake sediment, biochar, sludge from land-based aquaculture).	The technical feasibility and functioning can be tested. The contact to the station personnel may enhance continuation of the research ideas.	Realization	Supervising technical field work
Aiming at a general understanding of the local situation	Informal daily contact	Unplanned interaction during carrying out measurements in the field and while staying for longer time at place.	Detection of new players and processes, deepening of contacts and trust building.	No expectation	Curiosity, openness, flexibility

Compilation: M Siegmund-Schultze

The starting points of the research: regional introduction

The main water source for the semi-arid region is the **São Francisco River**. Along with the Parnaiba River, these are the only rivers in the Northeast Region that have perennial flows. The São Francisco River is almost 3,000 km long and its watershed encompasses about 630,000 km². The São Francisco River Basin covers 8 % of Brazil's land area, and around 48 % of the basin is semi-arid. Damming the river started in 1961 with the opening of the Três Marias Reservoir in the river's upper course. The Itaparica Reservoir was added in 1988. Tens of thousands of local residents were involuntarily dislocated due to the flooding, including entire towns and fertile floodplain areas. Today, the main consumptive water use is irrigated agriculture with more than 70 % of the water withdrawals in 2008, compared to a national average of 60 % (FAO 2016). Irrigation, public water supply and industry are the primary water use sectors in the basin, along with the hydroelectricity generation sector. Huge amounts of water are stored in the three large reservoirs in the area, and in order to ensure electricity generation during low flow periods, low amounts of water are released, which leads to conflicts with downstream users. The minimum discharge of the Sobradinho and Itaparica Reservoirs is 1,300 m³ per second. During the last severe drought (starting in 2012, coinciding with the beginning of the INNOVATE research project) it has been gradually reduced to about half of the defined minimum flow. The severe drought has shown that water quantity and quality was insufficient under these conditions and led to a water crisis. Consequently, there is a need for better coordination and communication between water users in the basin, especially during drought periods.

Caatinga vegetation in the *"Serra da Canoa"*. *Photo: M Siegmund-Schultze*



Data sources: climate-data.org, INNOVATE measurements. Prepared by J Landor-Yamagata.

Figure 2 **Climate diagrams of Itacuruba and Petrolândia: thirty-year averages (left) and the drought year 2013 (right)**

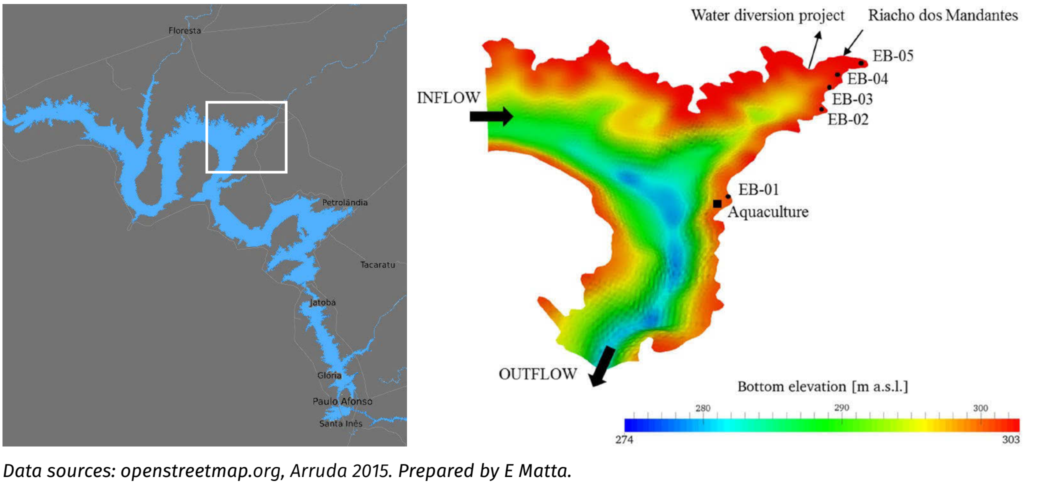
In the following we briefly describe the land and water resources of the study region, characterize the water quality and quantity of primarily the Itaparica Reservoir, illustrate aspects of the socio-economic situation and selected economic activities, and conclude by depicting the multi-level governance situation faced.

The Sub-Middle is one of the four hydro-geographic regions of the São Francisco River Basin *(compare the characterizations of the regions in Siegmund-Schultze et al. 2015)*. The Sub-Middle, covering about 17% of the basin's area, is the driest among the four and contributes about 4% to water availability in the overall basin, and water demand in the region represents about 39% of the entire basin's available water (ANA et al. 2004). Public irrigation schemes, domestic water supply, and hydropower generation are major water uses. Nine hydropower plants were built in the São Francisco River to generate electricity; the two largest reservoirs in the semi-arid portion of the watershed have high rates of evaporation.

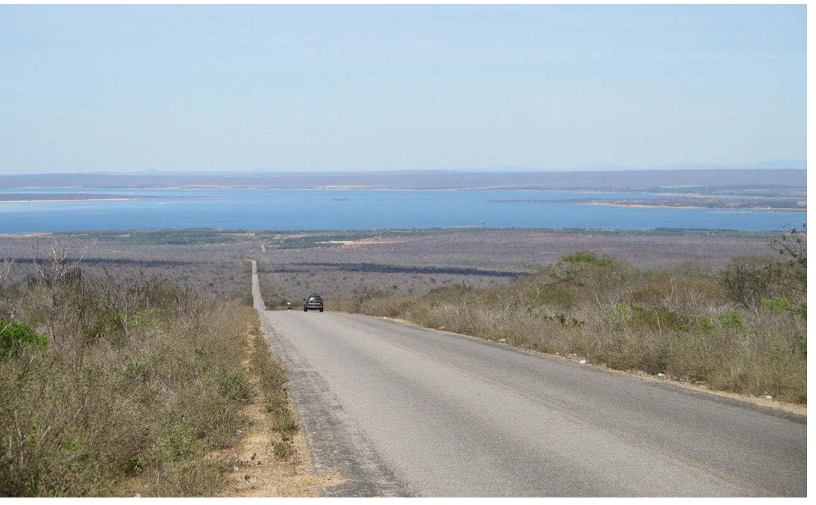
The Sub-Middle (as also parts of the Middle and Lower regions) is the home to the **Caatinga biome** with its unique biodiversity, which is being threatened by the indiscriminate removal of native vegetation for farming or infrastructure and housing. The Forest Act (Brasil 2012) defines areas of conservation; a monitoring policy is however widely absent. The native vegetation type is seasonally dry forest which covers more than 80 % of the study area (Schulz et al. 2017). The most important plant families of Caatinga forests are Fabaceae, Euphorbiaceae and Cactaceae (Sampaio 1995). Grazing of livestock and feral animals is a major driver for vegetation status. Land clearing and tree harvesting is also a common land use, although their impact on vegetation cover in the past decades was low (Schulz et al. 2017).

The rainy season of the semi-arid study region extends from January to April, with the driest period between June and November (Figure 2). The rainfall is generally irregular with severe droughts occurring every 40 to 50 years (Sampaio 1995). The **climate** diagrams from 2013 clearly show the drought situation in the study region with its local disparities (Figure 2). The two stations displayed are about 60 km apart. According to the IPCC (2014), climate change will enhance the risks of water scarcity in the future. During the 21st century a significant reduction of renewable superficial and subterranean water resources as well as risks of reductions in the quality of drinking water quality are projected. The semi-arid region of Brazil's Northeast as a whole is in a critical situation concerning the replenishment of the reservoirs. The length of the rainy seasons may shrink, as well as the number of consecutive rain days and total annual precipitation. The government and non-governmental actors are therefore challenged to promote activities that enhance the drought resilience of the population.

Until now the Global Circulation Models (GCM) and Regional Climate Models (RCM) are not consistently or properly simulating the temporal and spatial distribution of precipitation in the Northeast Region of Brazil as evidenced by simulating a reference period with recorded data (Lange et al. 2015, Silveira et al. 2016). The latest climate scenarios of the IPCC (so-called CMIP5-runs) were analyzed for the São Francisco River Basin: In general there is a clear sign of **increasing air temperatures** but no clear sign regarding precipitation, i.e., some models suggest a wetter future (+10–20 % in annual precipitation) while other models suggest a drier future (–10–20 %). However, even in the scenarios that predict wetter conditions on average, drought periods of two to three years occur (Koch et al. 2015). Overall, the occurrence of weather extremes will increase in the future.



Data sources: openstreetmap.org, Arruda 2015. Prepared by E Matta.
EB = pumping stations of the Icó-Mandantes public irrigation scheme.
Figure 3 **The Itaparica Reservoir (left), and the Icó-Mandantes Bay featuring different uses (right)**

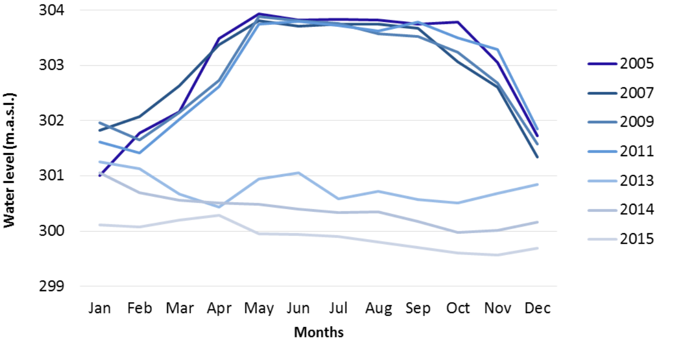


View of the Itaparica Reservoir from Tacaratu. *Photo: M Siegmund-Schultze*

The Itaparica Reservoir (Figure 3) is located 290 km from the Atlantic Ocean. The upstream Sobradinho Reservoir controls potential flood events and the inflow into the Itaparica Reservoir. The Itaparica Reservoir has a regulated long-term mean inflow of 2,060 m^3 per second, a length of 149 km, a surface area of 828 km^2, and a sub-basin of 93,040 km^2. Its maximum depth is 42 m (mean depth = 13 m), and the reservoir's total capacity is 10.7 × 109 m^3. Annual water level variation is up to 5 m due to reservoir operations, causing the periodical desiccation of the reservoir margins. Itaparica is a large tropical reservoir; it constitutes an artificial ecosystem and thus differs significantly from natural lakes. In general, primary productivity is enhanced in tropical reservoirs due to year-round high temperatures and solar radiation as there is a mono-dominance of cyanobacteria as well as a high likelihood of eutrophication. Due to these features, management strategies for reservoirs in the semi-arid climate zone have to take into consideration water uses when water is scarce, as well as strong inter- and intra-annual variation in discharge and periodic flood events.

The reservoir cascade within the São Francisco River has strong impacts on the **river's discharge**. The large amplitude between high and low natural flows is leveled to a relatively stable discharge regime throughout the year with subsequent effects on downstream conditions and processes, such as habitat changes, river mouth erosion, and salt water intrusion. Currently, the inflow and water level changes of the Itaparica Reservoir are not significantly correlated, which means that water storage is not managed in terms of water availability, but rather for optimized hydroelectricity generation. The management priority is also shown by the weekly trend of reduced water release on weekends due to reduced energy demand from industries.

During the severe drought (Figure 2), which lasted for about four years during the study period, the reservoirs could not be refilled during the (almost absent) rainy seasons. The reduction of the upper water level in the reservoir (Figure 4), due to both the



Data source: CHESF. Prepared by G Nogueira da Silva.
Figure 4 **Water level of the Itaparica Reservoir during the years 2005–2015**

decrease in rainfall and considerable utilization of water resources, can put electrical energy production at risk once it reaches the minimum level for electricity generation of 299 m.a.s.l. To minimize this risk and to maintain electricity generation capacity the reservoirs administered by the hydroelectric company CHESF, which on average have a regulated outflow of 2,060 m³ per second, operated with special authorizations by IBAMA and consecutive resolutions of the National Water Agency ANA at throughflows below the set minimum of 1300 m³ per second. The gradual reduction began in April 2013, resulting in a situation full of uncertainties for the riparian users and the population during at least four years. In January 2017 (during the finalizing of this manual), the water outflow from the Sobradinho (upstream from Itaparica) and Xingó (downstream from Itaparica) reservoirs was allowed to be a meager 700 m³ per second, almost half of the standard minimum. The reported throughflow of single days in the Itaparica Reservoir has even been below this temporary minimum average value.

The Itaparica Reservoir is used for hydropower generation; reservoir water is also withdrawn for people, livestock and irrigated agriculture. Fishery and aquaculture are further users, which show an increasing trend. The multiple uses of the reservoir (protected by law, Brasil 1997) have environmental, social, economic and political impacts, provoking a number of debates on the allocation of water and its quality. The interactions between the reservoir water and its surroundings pose special challenges. The reservoir provides freshwater for various uses while also being contaminated with agrochemicals, nutrients from agricultural production processes and aquaculture activities, and the release of untreated domestic and industrial wastewater. The nutrient input and the internal nutrient mobilization from deposited organic sediments and periodically desiccated margins triggers the temporary eutrophication of the water, which affects the production of submerged macrophytes, algae, and cyanobacteria (respectively cyanotoxins).

The macrophyte *Egeria densa*. *Photo: D Lima*

The water quality of the Itaparica Reservoir is characterized by high temperatures between 24 and 33°C, slight basic pH values (7.0–9.3), low conductivity (36–260 µS per cm), and oxygen concentrations > 6.4 mg per Liter. Nutrient concentrations (dissolved inorganic nitrogen, soluble reactive phosphorus, and total phosphorus) and chlorophyll are usually low, but are seasonally enhanced indicating seasonal effects on water quality. Sediment retention of the upstream Sobradinho Reservoir is high. Water quality of the Itaparica Reservoir is mainly driven by: (i) processes induced by rainfall in the nearby region where erosion and soil leaching contributes to the seasonal variation, (ii) rainfall in the upper watershed, and (iii) seasonal water level changes, inducing a flood/drying cycle in littoral areas, which alters mineralization, nutrient turnover, wave erosion, macrophyte distribution and resuspension processes.

An ongoing environmental degradation of water resources has been observed. As an example, the Moxotó River (a tributary to the São Francisco River about 20 km downstream of the Itaparica Dam) had been classified as class 1 in 1989. The ten-year management plan for the São Francisco River Basin (2004–2014) projected that 54 km of the total river's extension of 226 km would fall to class 2. But measurements suggest that now the entire Moxotó River has to be reclassified as class 2, whereas some parameters (total phosphorus, among others) suggest even class 3 (Rossiter et al. 2014).

An exploratory in-depth INNOVATE study was located at **Icó-Mandantes Bay** (Figure 3). The bay is particularly interesting as it borders the Icó-Mandantes public irrigation scheme and is the starting point of the so-called eastern channel of the controversial water diversion project. The bay has very low flow velocities and water movement and exchange is mainly caused by southeast wind (the most frequently occurring), and by rare but intense flow events from the ephemeral tributary Riacho dos Mandantes. Southeast wind does not create favorable currents to enhance the quick dilution of substances from the area. Consequently, water exchange between the Itaparica main stream and Icó-Mandantes Bay is very slow.

The Brazilian semi-arid region as a whole is increasingly affected by **water scarcity**. The agricultural sector of the study region in particular, however, relies heavily on water for irrigation. The growth of the population and incomes are creating a growing demand for water also in non-agricultural sectors and often non-rural areas. Temporal and spatial variability of rainfall and high evaporation rates along with the prolonged droughts characterize the region *(compare the local differences displayed in Figure 2)*. Climate change may further increase the existing water problems in the region. The overexploitation of available water resources and the management of the reservoirs also affect the quality of fresh water supplies, for example, through salt water intrusion at the mouth of the river.

Grape cultivation in the *Pólo Petrolina-Juazeiro*.
Photo: H Koch

A conflict exists between irrigated agriculture and electricity production, and this conflict has the potential to become even more severe in the future. The **water demand and withdrawal** will increase significantly with the implementation of both channel systems of the water diversion project. In parallel, many public irrigation schemes in the Northeast Region are planned. The majority of the water for these new irrigation projects will either come directly from the São Francisco River or from the channels being constructed. There are estimates that in about three decades, the area under irrigation supplied by the Sub-Middle could increase on average by more than 10 times (CODEVASF 2006). Besides better management of existing projects, new projects (e.g., for irrigated agriculture, aquaculture, hydroelectricity generation) need to be planned in a coordinated way, as these projects affect each other.

Two major clusters of **public irrigation schemes** exist in the Sub-Middle, where water supplies and infrastructure are subsidized by government funds: the irrigation schemes located around Petrolina and Juazeiro municipalities, known as *Pólo Petrolina-Juazeiro*, and the region known as *Complexo de Itaparica* around the Itaparica Reservoir. The areas under public irrigation schemes will increase in both regions in the future (estimates up to 2035) but maintain about the same shares: 75 % in Pólo Juazeiro-Petrolina and 25 % in the *Complexo de Itaparica* (ANA 2011). The public irrigation schemes of *Pólo Petrolina-Juazeiro* were able to significantly increase their agricultural production value since 1990 and are now a major production center for fruits (Sampaio et al. 2004). Sugar cane production has increased recently in areas with fertile soil, using sophisticated irrigation infrastructure, doubling the productivity (Amaral et al. 2012). See Moraes et al. (2016) for more details on water used for irrigation, the critical role of energy crops, and the related pricing of water.

The *Complexo de Itaparica* region is located on both sides of the Itaparica Reservoir (Pernambuco and Bahia). The construction of the Luiz Gonzaga Dam hydropower plant (with an installed capacity of 1,480 MW) and the Itaparica Reservoir by CHESF (the regional hydroelectric company) came along with profound challenges for the local population. About 40,000 citizens were affected by the involuntary relocation due to flooding the area when forming the artificial lake in 1988. Among the affected citizens were several indigenous tribes, for instance, the Pankararu and Tuxá in Pernambuco. Four municipal capitals were inundated and rebuilt (in Pernambuco: Petrolândia and Itacuruba). The seven municipalities, which lost land area, receive a continuous flow of compensation payments according to the amount of electricity generated. The individual situation of the relocated citizens was addressed in different ways, depending on their situation, status, and preferences.

In Petrolândia, flood agriculture was an important sector along the river edges and fishery activities prevailed inside the São Francisco River. The manufacturing sector, before the creation of the reservoir, included ceramics and the processing of agricultural products. CHESF, as the entity responsible for the construction of the hydroelectric power plant, was to provide housing alternatives and economic activity options for the resettled families. The process was mainly driven and facilitated by the farmers' union *(compare Rodorff et al. 2013 in German or Rodorff et al. 2015 in Portuguese for more*

Coconut plantation in the *Complexo de Itaparica.*
Photo: M Venohr

details on the resettlement process and its planning).

The resettlement of the rural population into public irrigation schemes in Pernambuco adjacent to the reservoir was concentrated in and around Petrolândia. The irrigation schemes of Apolônio Sales, Barreiras and Icó-Mandantes comprise 5,190 ha (World Bank 1998). There are two types of schemes: housing and nearby agricultural plots spread over the area (Apolônio Sales), and the agrovilas system (housing in villages, separated from their relatively distant plots; such as Icó-Mandantes and Barreiras). The urban residents were compensated with new houses or at least space in the new urban centers. Urban and rural residents could also opt for compensation payments to leave the region. The halfway submerged church in Petrolândia is a symbolic memory that is always referenced in discourses of the resettled population.

Today, the municipality of Petrolândia has a population of over 35,000 inhabitants (Table 2). The strongest economic sectors that use natural resources are **irrigated agriculture** and fishing. In the public irrigation schemes, coconut, banana, mango and guava are major perennial fruit crops, while annual crops grown are, for instance, pumpkin, melon and onion. Icó-Mandantes

Table 2 **Brief characterization of the study municipalities**

	Belém de SF	Itacuruba	Floresta	Petrolândia	Tacaratu	Jatobá	Source
Population (2016 estimate)	20,672	4,807	32,152	35,731	25,003	14,646	1
Gini (2010)	0.63	0.46	0.52	0.55	0.49	0.57	2
Area in km² (2015)	1,830.802	430.033	3,644.168	1,056.595	1,264.530	277.862	1, (2)
Population density (caput/km²)	11.3	11.2	8.8	33.8	19.8	52.7	calculated
River sub-basin	Terra Nova, G14, Pajeú	G14, Pajeú	Pajeú, G13	G13	G13, Moxotó	G13, Moxotó	3
Territorial sub-division	3 districts	Capital district	3 districts	Capital district and 10 villages	2 districts	2 districts	1

The columns are sorted by approximate geographic sequence of the municipalities.
1 *http://cidades.ibge.gov.br/ © 2013 IBGE*
2 *http://www.bde.pe.gov.br*
3 *http://www.cpatsa.embrapa.br:8080/bhsf/index.php?opcao=g14*
Compilation: M Siegmund-Schultze, S Hölzl

has a focus on temporary crops (though perennials appear to be coming to the fore), while perennial crops clearly prevail in Apolônio Sales, where a coconut processing factory exists. Fields are monocultures; intercropping is only carried out during the first three years after coconut planting with peanut, beans or manioc. Fertilization is most commonly performed organically with sheep and goat manure or with a mixture of chemical fertilizers (containing nitrogen, phosphorus and potassium in different proportions) and manure. In the area, different irrigation techniques are present: drip, spray, and micro-spray—the latter applying water to tree crops with high precision, which makes the irrigation system more water efficient and reduces the risk of salinization. Irrigation is conducted continuously the whole year round. A frequent problem in irrigated farming is the outbreak of pests such as whitefly.

Important temporary employment occurs at the construction sites of the water diversion project of the São Francisco River and the Transnordestina railroad project.

The rural-urban relationship has changed considerably in the last thirty years. Several farmers possess a house in the municipal capitals. The proximity to the urban center of Petrolândia has partly transformed the irrigation scheme of Apolônio Sales into an urban dwelling or second residence location.

Itacuruba is the smallest of the study municipalities in terms of population. Its capital is located off the main road connecting neighboring municipalities. The compensation measures had foreseen the establishment of a public irrigation scheme (World Bank 1998), though its construction was suspended. Several net-cage systems have been setup in the lake. Today, these are partly owned by international companies. An astronomical observatory is present and there is a controversially discussed plan for erecting a nuclear power plant. A delimited area for indigenous people is located in the vicinity of the town of Itacuruba. As in other municipalities, there are some settlements developed by INCRA in the frame of the agrarian reform. These often consist of housing with only limited access to farmland.

Livestock production plays an important role in the livelihoods of many farmers in the semi-arid region. It is mainly characterized by extensive and semi-intensive goat, sheep and cattle production systems. The Caatinga rangeland is the main forage source. Generally, livestock densities are substantially higher than the carrying capacity of the Caatinga (2.3 livestock units per ha versus 0.07–0.1 livestock units per ha; Schulz et al. 2016, Tiessen et al. 1998), which may foster the loss of soil carbon stocks and biodiversity. Especially during droughts, farmers cut bromeliads (*"macambira"*) and cacti for livestock fodder, which further reduces important habitats for reptiles and amphibians. The drought during the study period caused a severe loss of livestock for many farmers.

The prolonged dry seasons and frequent drought events associated with the degradation of the Caatinga vegetation are major limiting factors for livestock production. Moreover, the generally low management and technological levels of the poorly adapted systems limit livestock production, particularly on farms without irrigation infrastructure. Furthermore, interests and needs of livestock farmers find little support in local politics, which primarily focus on irrigation agriculture. The access to farmer credit, along with the technical assistance and rural extension offered, hardly matches the needs of small-scale livestock keepers.

Some farmers have converted to an intensive production system. Intensive production generally requires more farm inputs, such as a higher work load, and higher implementation and maintenance costs, provided that these additional inputs are attainable. The suitability of such a system has to be scrutinized for each farm as the successful implementation depends on many factors like financial capacity, know-how and interest of the farmer, as well as land and irrigation availability. Therefore, an intensive system is no universal solution and it appears more suitable to maintain and support different systems in parallel, matching the characteristics of the diverse farmers and their circumstances.

The fishing activities are realized by traditional communities, small-scale private enterprises, and small- to middle-sized companies (aquaculture). The **artisanal fishery** is characterized by technological simplicity with low production costs, associated with subsistence and low income generation. In the study area of the INNOVATE project, artisanal fisheries constitute the second most common economic activity in the municipalities surrounding of the São Francisco River. Areas of conflict exist, which are mainly triggered by the duality of the sector: The installation of aquaculture with net-cages along the edges of the lake competes with already practiced artisanal fishery at the same locations. The control of flows (including their reduction in order to mitigate the effects of the drought on the energy sector) can negatively influence the reproduction success of migratory fish in different stretches of the river, including

A farmer with his goat and sheep flock. *Photo: M Siegmund-Schultze*

Aquaculture with net-cages. *Photo: V Rodorff*

alterations of the periodicity of the breeding period, which makes adaptions of the closed fishing season necessary (Nogueira da Silva et al. submitted).

Aquaculture is a rapidly growing business at the Itaparica Reservoir. However, aquacultural wastewater has negative impacts on waterbodies, affecting its quality when not well managed. The introduction of feeds, antibiotics, other pharmaceuticals, and chemical or organic fertilizers can impair both the aquacultural production and the surrounding ecosystem. High levels of feed and fertilizer inputs can promote eutrophication when the nitrogen and phosphorus content in the water become too high, which reduces fish growth and threatens the fish farming business. A further environmental threat of aquaculture to the larger aquatic ecosystem is the use of exotic fish species, as they can escape and displace native species. Assessment and regulation are however limited in the region. CONAMA resolution nº 357/2005 establishes the conditions and standards for the discharge of effluents. Many fish farms operating in the Itaparica Reservoir do not even have the Operation License (LO) or the periodic limnological monitoring required by law for its operation.

The management of the natural resources in the study region and the implementation of any innovation rely on the existing **multi-level governance system**. Understanding the system is the basis for successfully using it. Multi-level governance systems are a widespread challenge all over the world. In general, they are the result of organization and reorganization of space over time. Table 3 compiles the different planning and administrative levels in the case of Petrolândia. While seven official administrative scales exist (from the whole nation to the municipal district), there are additional scales in between which are not always a spatial excerpt of the higher scale but follow a different spatial rationale. Major challenges of governance in the study region are: incoherence of policies among scales, unclear competencies of governmental bodies, and spatial misfits.

Table 3 **Scales of planning and action: superimposition of the administrative and development regions**

*	Scale	Name	Selected organizations	Land and water governance highlights
1	Union (*"União"*)	Brazil	Ministries, agencies and other federal institutions; e.g., ANA (national water authority), CNRH (national water council)	National Plan on Water Resources: Priorities 2012–2015 (2011). Multiannual Plans—PPA
2	Macroregion	Northeast	SUDENE	Development projects
n	Sub-region[a]	Hinterland (*"Sertão"*)		

*	Scale	Name	Selected organizations	Land and water governance highlights
n	Climatic region	Semi-arid	DNOCS	Infrastructure projects, e.g., reservoirs
n	Biome[b]	Caatinga	IBAMA, ICMBio, Caatinga National Commission	(conservation units exist; biome as such has no official conservation priority)
n	River basin	São Francisco River	CBHSF (river basin committee), executive agency of the committee, CODEVASF (development agency)	Water Resources Plan of the São Francisco River Basin—PRHBSF (2016–2025). Multiannual Plans—PPA. Directive Plan for Regional Development—PLANVASF (1989)
c	Physiographic region of the SF River Basin[c]	Sub-Middle (*“Submédio”*)	CCR of CBHSF	(regional section of the river basin committee, reports to the plenary)
3	State	Pernambuco	Ministries, agencies and state companies	State Plan on Water Resources—PERH (1998)
n	Zones[d]	Hinterland (*“Sertão”*)		
4	Mesoregion[e]	Pernambucan São Francisco		(primarily statistical role)
c	Citizen territory	Itaparica	Forum of the Territory Itaparica (PE and BA)	Territorial Plan on Sustainable Rural Development (2009)
5	Microregion[f]	Itaparica		(primarily statistical role)
5	Development region[g]	Itaparica Hinterland *“Sertão de Itaparica”*)		(statistical and planning role)
n	Sub-basin	G13	None?	
6	Municipality	Petrolândia	Government departments, associations, NGOs, schools, institutions of higher education (IF)	Participatory Directive Plan (2006)
7	Districts	Municipal capital district and 10 villages (*“agrovilas”*)		

**Number: Official administrative scales, which form a sequence from largest to smallest. Letter n: areas defined naturally (which might be revised with new evidence). Letter c: regions based on some common features, which can be natural, cultural or administrative, or respectively a mixture of these.*
a *There are four sub-regions in Brazil’s Northeast: Meio-Norte, Sertão, Agreste, Zona da Mata.*
b *There are six biomes in Brazil: Amazônia, Caatinga, Cerrado, Mata Atlântica, Pampa e Pantanal.*
c *Special case because of the size of the São Francisco River Basin.*
d *Zones of Pernambuco: Sertão, Agreste, Zona da Mata, Região Metropolitana do Recife.*
e *Mesoregion: five in Pernambuco. The macro, meso, and microregions are also called ‘regiões geográficas’.*
f *Microregion of Itaparica: includes seven municipalities—Belém de São Francisco, Carnaubeira da Penha, Floresta, Itacuruba, Jatobá, Petrolândia, Tacaratu.*
g *The same municipalities as the Itaparica microregion: Belém de São Francisco, Carnaubeira da Penha, Floresta, Itacuruba, Jatobá, Petrolândia, Tacaratu. (The development regions do not generally coincide with the microregions.)*
Compilation: M Siegmund-Schultze

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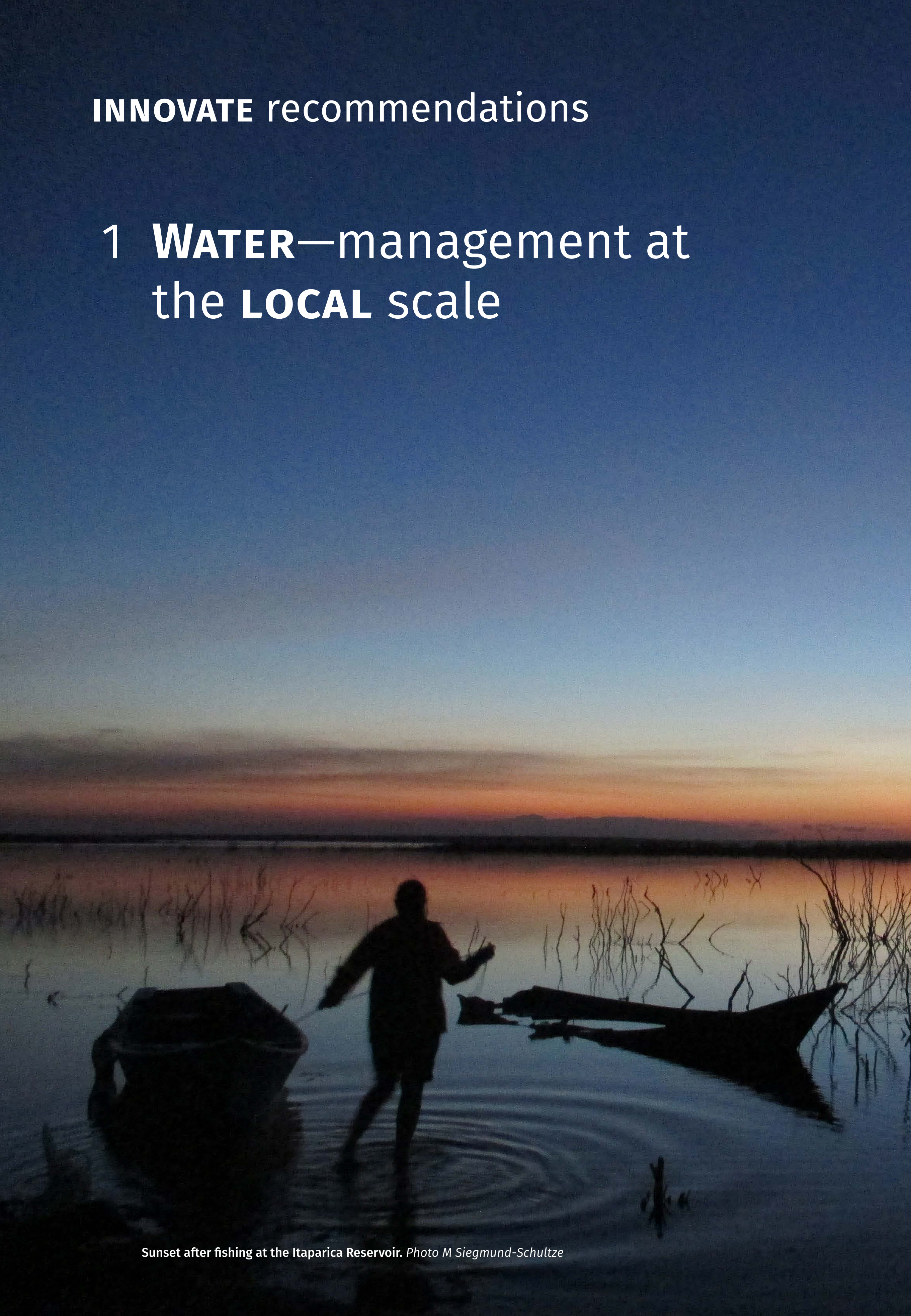
1 **WATER**—management at the **LOCAL** scale



Sunset after fishing at the Itaparica Reservoir. *Photo M Siegmund-Schultze*

1.1 Nutrient load management

For whom: Watershed committees (e.g., CBHSF), Municipal government departments, ONS, O & M (operation and management units of irrigation schemes), Water supply and sanitation organizations—especially in the upper river parts (e.g., COPASA for Minas Gerais), CODEVASF, ANA, Hydropower plant operators (e.g., CHESF), Institutions of higher education

From whom: Florian Selge (florian.selge@tu-berlin.de)

Problem: Environmental and human drivers at different spatial scales influence the aquatic ecosystems of the Itaparica Reservoir. Therefore, management strategies have to cross scales—a task not easily realized. Additionally, regulations for nutrient input reduction (as an eutrophication control strategy) are lacking.

Key message: A diverse set of measures should be implemented to sustainably manage nutrient loads.

Explanation: Large irrigation schemes are located along the São Francisco River, especially in the stretch between the Sobradinho and Itaparica Reservoirs. The associated farms need large amounts of water for the production of fruits, mainly dedicated for export. Water drainage on farms is important to prevent soil degradation. The drainage water is however often contaminated due to the application of mineral fertilizers and agrochemicals, particularly if not managed well. An optimized water demand-consumption relationship with good water usage practices could safeguard water quantity, and well-managed application of chemical inputs would further reduce the nutrient load to the river. Additionally, drainage water could be re-used, if water quality is applicable or diluted, to reduce water withdrawal and fertilizer consumption. Furthermore, decentralized drainage water treatment by artificial wetlands *(compare chapter 1.9 on page 39)* or other techniques could decrease the contamination risk posed by irrigation schemes.

Large-scale nutrient emission modeling by MONERIS (part of the INNOVATE project) identified untreated sewage water year-round as well as erosion and washout from agricultural land during the rainy season as major contamination sources of nutrients for the entire São Francisco River and the Itaparica Reservoir. Moreover, the sub-basin of the Itaparica Reservoir, dominated by the Caatinga biome, is impacted by deforestation, overgrazing, agricultural expansion and desertification, which all lead in summary to land degradation and consequently to soil erosion. Hence, nutrients are transported from the topsoil into surface waters with run-off, enabling eutrophication processes.

Desiccated area and waste disposed into the reservoir.
Photo: F Selge

Formerly submerged tree trunks exposed by low water levels. *Photo: F Selge*

Recommendations:

1. An increased connection to wastewater treatment facilities in the upper basin and improved fertilization practices would reduce the total amount of nutrient emissions into the river and therewith into downstream reservoirs.

2. Nutrient loads can be further reduced through improved soil conservation practices, which by decrease the nutrient export from farmlands *(compare chapter 2.3 on page 51)*.

3. A reduction of the nutrient pulses to the Itaparica Reservoir *(compare chapter 1.3 on page 32)* can be achieved through enhanced water retention in decentralized small reservoirs, dams or barriers. Additionally, retained suspended matter can be used for soil amendment to enhance agricultural production. Another option is the construction of pre-dams in bays with low exchange rates of water to reduce the sub-basins' export effects by water retention and sedimentation in a separated basin at the river inflow. The "dike" technique *(compare chapter 3.1 on page 69)* is under further investigation to reduce suspended load and nutrients from surface run-off by using porous stone walls.

4. The management of water quantity is one important driver of physicochemical and biological processes within the reservoir *(compare chapter 4.3 on page 79)*. Particularly, the desiccation of macrophytes and sediments followed by mineralization and nutrient release impact negatively biodiversity in and around the reservoir, a process triggered by the current hydropower generation management. In contrast, a relatively stable water level would decrease these nutrient cycle alterations and would enhance aquatic and riparian vegetation. The latter could serve as buffer strip around the reservoir to reduce nutrient loads from non-point contamination pathways.

5. Limit and enforce the limitation of aquaculture production within net-cages in the reservoir *(compare chapter 1.3 on page 32) (compare chapter 1.5 on page 34)* on the basis of the calculated carrying capacity of the reservoir. A site-specific assessment should complement the licensing process by taking into account the velocity of water exchange and respective water residence time *(compare chapter 1.2 on page 31)*.

6. The clear-cutting and removal of inundated vegetation could reduce the nutrient load to the Itaparica Reservoir, as well as allow enhanced navigation, particularly in shallow areas.

Further reading:

Selge F (2016) Aquatic ecosystem functions and oligotrophication potential of the Itaparica reservoir, São Francisco River, in the semi-arid Northeast Brazil. Doctoral Thesis, Technische Universität Berlin, Germany.

1.2 Residence times of water and dissolved contamination

For whom: Local farmers' and fishermen's associations, O & M (operation and management units of irrigation schemes), Municipal government departments, CODEVASF, ANA, Watershed committees (e.g., CBHSF), ONS, Hydropower plant operators (e.g., CHESF), Institutions of higher education

From whom: Elena Matta (elena.matta@wahyd.tu-berlin.de), Florian Selge (florian.selge@tu-berlin.de), Günter Gunkel, Reinhard Hinkelmann

Problem: Prolonged residence times of polluted water in isolated bays.

Key messages:

- Bays can be rather isolated from the reservoir's main stream.
- Pollutants remain in such bays longer than in the main body of the reservoir.
- High water levels increase isolation of these bays.
- Flushing the reservoir is not as effective as may be expected in such isolated bays.

Explanation: From some distance, the Itaparica Reservoir looks like a long stretch of river with some more width to it. When zooming in, one can see a multitude of bays, artificially formed when the river valley was flooded. Icó-Mandantes Bay is one such bay. It is quite isolated from the reservoir's main stream: in fact, the bay and the reservoir main stream behave as two separated systems with different flow velocities (ca. 1 order of magnitude lower for the bay, i.e. mm/s) and exchange of water hardly occurs. A longer residence time promotes eutrophication processes and the occurrence of algae blooms.

In addition, due to climate conditions, hydropower generation and evaporation rates, water level variations are quite high and also contribute to the eutrophication processes *(compare chapter 1.1 on page 29)*.

Studies of water residence times were conducted for the first time in Icó-Mandantes Bay for different water levels and discharges. The values of residence time estimated for the bay were much higher (> 6 months) than the ones obtained for Itaparica Reservoir (ca. 2 months) and higher retention was observed when assuming a wet climate in "the modeling system". Varying water level or higher inflow to the Itaparica Reservoir does not relevantly encourage the exchange between the bay and the main stream. High discharges released by the Sobradinho Reservoir (higher than 3,000 m^3/s) and high water level conditions even lead to increased isolation of such bays, whose hydrodynamics are different from the reservoir main stream.

Further reading:

Matta E, Koch H, Selge F, Simshäuser MN, Rossiter K, Nogueira da Silva GM, Gunkel G, Hinkelmann R (submitted 2016). High resolution two-dimensional modeling of flow and transport in Icó-Mandantes Bay to support water management. Regional Environmental Change.

1.3 Impacts of potential flash floods from ephemeral and intermittent tributaries

For whom: Local farmers' and fishermen's associations, O & M (operation and management units of irrigation schemes), Municipal government departments, Watershed committees (e.g., CBHSF), Hydropower plant operators (e.g., CHESF), CODEVASF, EMBRAPA, ANA, IBAMA, Institutions of higher education (e.g., UFPE, IF)

From whom: Elena Matta (elena.matta@wahyd.tu-berlin.de), Hagen Koch, Florian Selge (florian.selge@tu-berlin.de), Günter Gunkel, Reinhard Hinkelmann, Nailza O. Arruda, Gérsica M. Nogueira da Silva (gersicamns@hotmail.com)

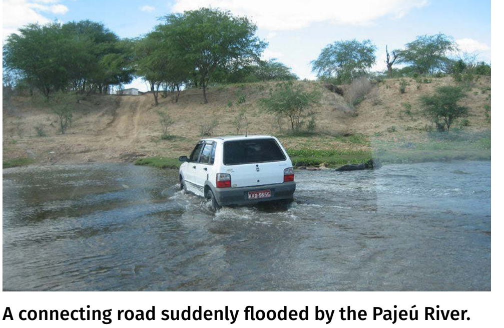
PROBLEM: Flash floods can negatively affect water quality.

KEY MESSAGES:

- Water withdrawal should be interrupted in case of nearby flash floods.
- Flushing the reservoir is not effective in isolated bays.

EXPLANATION: During intensive rain events large amounts of nutrients enter water bodies through erosion, washout, leaching and run-off. Especially isolated bays, such as Icó-Mandantes Bay in the Itaparica Reservoir, are particularly vulnerable to eutrophication processes with mass development of cyanobacteria, followed by serious health risks for drinking and irrigation water. Water users who are located near to ephemeral tributaries are affected, such as the Riacho dos Mandantes. In the case of Riacho dos Mandantes, water use involves water withdrawal for drinking water, irrigated agriculture, and for the eastern channel system of the water diversion project (Figure 3, page 9). Flash floods may occur more often in the future due to climate change.

The effects of a 3-day flood from the ephemeral stream Riacho dos Mandantes were investigated in regard to water quantity and quality, considering different climate conditions. The water flow was impacted by the event mainly in the area near to the stream's inflow to the bay and not relevantly in the reservoir main stream. High concentrations of transported material water pollution were registered near the pumps, which extract water for irrigation, and near the eastern channel of the water diversion project in the short term under drought conditions (up to 1 week), while retention time of the material was longer in a wet scenario, which means at a higher water level the pollution takes even longer to dissipate. Consequently, attempting to clean the reservoir through flushing will not work, as the water exchange rate between the bay and the reservoir main stream is not high enough to be effective.



A connecting road suddenly flooded by the Pajeú River.
Photo: M Siegmund-Schultze

FURTHER READING:

Matta E, Koch H, Selge F, Simshäuser MN, Rossiter K, Nogueira da Silva GM, Gunkel G, Hinkelmann R (submitted 2016) High resolution two-dimensional modeling of flow and transport in Icó-Mandantes bay to support water management. Regional Environmental Change.

1.4 Limit the nutrient emissions from net-cage aquaculture

For whom: MPA, CPRH, Fishermen's communities, Municipal government departments, SPU, IBAMA, ANA, EMBRAPA, CODEVASF, Institutions of higher education

From whom: Elena Matta (elena.matta@wahyd.tu-berlin.de), Gérsica M. Nogueira da Silva (gersicamns@hotmail.com), Günter Gunkel, Florian Selge (florian.selge@tu-berlin.de), Reinhard Hinkelmann

Problem: Net-cages are nutrient and pollution emitters.

Key messages:

- Do not install net-cages in isolated bays.
- Allow approximately 10 m beneath net-cages.

Tilapia in a net-cage. *Photo: M Venohr*

Explanation: It is necessary to guarantee enough space beneath net-cages to allow translocation and dilution of particulate organic material and consequently avoid extreme sediment increase (Gunkel et al. 2015). This negative effect is higher in eutrophicated and isolated bays such as Icó-Mandantes Bay, where the mean concentration of total dissolved phosphorus is ca. 24.9 µg/L (Selge et al. 2016)—almost reaching reservoir maximum limits established by CONAMA 357/05 of ca. 30 µg/L. It is recommended to not install aquaculture systems in such isolated bays, especially when the measured nutrient mean concentrations are near ecological limitations (reservoir carrying capacity in terms of nutrient load from aquaculture limits the implementation of new aquaculture systems). If a new aquaculture installation is however considered necessary for reasons such as economic development and/or sustenance, it is necessary to ensure enough of a water column beneath the cages (min. 10 m) and it must be implemented in a strategic location (e.g. near intakes for irrigated agriculture and far from withdrawal sites for human consumption). Collaboration with experts and management adaptation is recommended.

Our study: Nutrient emissions of phosphorus and nitrogen were simulated in a hypothetic aquaculture system located in Icó-Mandantes Bay on the short-term (days) and long-term (months) for dry and wet climate scenarios, considering a small fish production of 130 t/y. The phosphorus increase due to emissions of ca. 8 µg/L was registered already after a 1 week simulation under drought conditions. Lower nutrient intensities were obtained for the wet scenario, but they were retained longer in the bay (still 64 % after 6 months) (Matta et al. 2016).

Further reading:

CONAMA (Conselho Nacional do Meio Ambiente) (2009) Resolução 413/2009 (Law resolution № 413 of the Brazilian Environment Council, published on the 26th of July, 2009). Brazilian Ministry of the Environment. http://www.mma.gov.br/port/conama/legiabre.cfm?codlegi=608 (accessed 7th March 2016).

Gunkel G, Matta E, Selge F, Nogueira da Silva GM, Sobral MC (2015) Carrying capacity limits of net cage aquaculture for Brazilian reservoirs. Revista Brasileira de Ciências Ambientais 36: 128-144. doi: 10.5327/Z2176-947820151008.

Koch H, Liersch S, Azevedo JRG, Silva ALC, Hattermann FF (submitted 2016). Modeling of water availability and water management for the São Francisco river basin, Brazil. Revista Brasileira de Recursos Hídricos.

Matta E, Selge F, Gunkel G, Rossiter K, Jourieh A, Hinkelmann R (2016) Simulations of nutrient emissions from a net cage aquaculture system in a Brazilian bay. Water Science and Technology 73(10): 2430-2435. doi: 10.2166/wst.2016.092.

Selge F, Matta E, Hinkelmann R, Gunkel G (2016) Nutrient load concept-reservoir vs. bay impacts: a case study from a semi-arid watershed. Water Science and Technology 74(7): 1671-1679. doi: 10.2166/wst.2016.

1.5 Managing the diverse ecological impacts of aquaculture

For whom: IBAMA, MPA, Fishermen's communities, CHESF, Municipal government departments, CPRH, ANA, SPU, CODEVASF, Institutions of higher education

From whom: Gérsica Nogueira da Silva (gersicamns@hotmail.com)

Problem:

- Fish farming enterprises are operating without licenses and/or reports on water quality monitoring.
- Production systems for fish within a reservoir always impact the water quality as well as the nutrient intake of the sediments.
- Tilapia farming in net-cages is responsible for constant introduction of undesired species into the environment.

Key messages:

- Promote legal installation of enterprises.
- Conduct monitoring of the enterprises' impacts.

Context: In recent years net-cage aquaculture has increased rapidly in the Itaparica Reservoir. Although it has clear economic benefits, its social and environmental impacts should receive sufficient attention in order to counteract major negative outcomes in the future.

Recommendations:

1. Instead of using exotic species, aim (also) at the production of selected native species. Advance research on alternative native species that can be cultivated in the region.

2. Study the carrying capacity of the lake in regard to nutrient loads coming from fish farming enterprises', and taking action for the legalization of the enterprises.

3. Evaluation of the physico-chemical parameters and modelling sources of diffuse pollution, including fish farming enterprises located in shallow areas with poor circulation, as they foster zones of high nutrient concentration and thus eutrophication processes.

4. Supervision and control of sources of punctual and diffuse pollution to avoid the risk of eutrophication in the reservoir.

5. Incentivize fish production in land-based aquaculture since it is possible to control the environment and the diffuse pollution,

and include the insertion of technologies for treating the effluents (avoiding simple dilution of nutrients, pharmaceuticals and other chemicals). One option could be the Green Liver System *(compare chapter 1.9 on page 39)*.

Net-cages in the reservoir. *Photo: G Nogueira da Silva*

FURTHER READING:

Gunkel G, MattaE, Selge F, Nogueira da Silva GM, Sobral MC (2015) Carrying capacity limits of net cage aquaculture in Brazilian reservoirs. Revista Brasileira de Ciências Ambientais 36: 128-144. doi: 10.5327/Z2176-947820151008.

Nogueira da Silva GM (2016) Zoneamento da pesca artesanal no reservatório de Itaparica, Rio São Francisco, Brasil. Trabalho de Conclusão de Curso (Tecnólogo em Gestão Ambiental)—Instituto Federal de Pernambuco, DASS, Recife.

Nogueira da Silva GM, Marques EAT, Case M, Sobral MC (2016) Influence of a fish farm wastewater located in Pernambuco, Brazilian Semiarid, on phytoplankton community. IWA Regional Conference on Diffuse Pollution and Catchment Management, 23-27 October 2016, Dublin.

1.6 Realizing environmental monitoring in fisheries

For whom: IBAMA, MPA, Fishermen's communities, CHESF, Municipal government departments, CPRH, ANA, SPU, CODEVASF, Institutions of higher education

From whom: Gérsica Nogueira da Silva (gersicamns@hotmail.com)

PROBLEM: Fish stocks are threatened due to the non-enforcement of regulations.

Artisanal fishery in the reservoir. *Photo: M Siegmund-Schultze*

CONTEXT: Deficiency in environmental monitoring concerning artisanal fishing activities, referring to the closed fishing season (decree Nº 50/2007), net size and captured fish species (decree Nº 18/2008).

EXPLANATION: The closed fishing season exists in order to secure the reproduction of migrant fish. On the one hand, the closed season no longer matches up with the migrations related to fish reproduction *(compare chapter 4.1 on page 76)*. On the other hand, fishermen do not always respect the time period during which commercial fishing is prohibited (fishing for personal consumption always remains legal). Some cases of fraud occur by registering as a fisherman in order to take advantage of the seasonal financial compensation.

The regulations on net size (to avoid catching young fish) as well as on not fishing for certain fish species are other measures to secure fish stocks. These regulations are not always respected for financial reasons, lack of awareness or lack of understanding the reasons.

Recommendations:

1. A more active role of the municipalities (municipal governments and fishery departments) in environmental monitoring.

2. Developing steps to enhance environmental education and awareness together with fishermen and associations of other regions.

3. Determining the economic reasons for non-conformity with the rules and the development of alternatives for income generation.

Further reading:

Nogueira da Silva GM (2015) Avaliação do período reprodutivo de peixes nativos de importância econômica em reservatório do semiárido brasileiro. MSc Thesis, Programa de Pós-Graduação em Ecologia, UFRPE, Recife.

Nogueira da Silva GM (2016) Zoneamento da pesca artesanal no reservatório de Itaparica, Rio São Francisco, Brasil. Trabalho de Conclusão de Curso (Tecnólogo em Gestão Ambiental)—Instituto Federal de Pernambuco, DASS, Recife.

1.7 Preserving aquatic biodiversity

For whom: IBAMA, MPA, Fishermen’s communities, CHESF, Municipal government departments, CPRH, ANA, SPU, CODEVASF, Institutions of higher education

From whom: Gérsica Nogueira da Silva (gersicamns@hotmail.com)

Problem: Aquaculture, fishing, and reservoir management can have negative side effects on fish populations.

An exotic species in the Itaparica Reservoir: Tucunaré (*Cichla sp.*). *Photo: M Guschal*

Key messages:

- Reintroduction of native fish species.
- Establishment of priority areas for safeguarding sustainable use of fishing grounds by artisanal fishermen.

Context: Damming a river and building reservoirs affects the biodiversity of the waterway. The use and management of the river and the artificial lake (reservoir) further affects the composition and population sizes of its fauna and flora such as the fish species, zooplankton, invertebrates, and macrophytes.

Currently, the majority of constantly harvested species in the Itaparica Reservoir are exotic. Tilapia (*Oreochromis niloticus*) is the predominant species in aquaculture. Escaped fish from net-cages, if not captured by artisanal fishers, develop further in the reservoir and contribute to changes in the species composition. Compared with the whole basin, the species richness is low in the Itaparica Reservoir and the species of great economic importance have become ever rarer (spotted sorubim—*Pseudoplatystoma corruscans*—*"surubim"*, dorado—*Salminus franciscanus*—*"dourado"*, leporinus—*Leporinus sp.*—*"piau"*, spotted pimelodella—*Pimelodus maculatus*—*"mandí"*, *Brycon orthotaenia*—*"matrinchã"*, *Lophiosilurus alexandri*—*"pacamã"*). The introduction of species impacting native species with similar ecological niches has resulted in an observable disequilibrium in the aquatic community.

Endemic species of economic importance, *Prochilodus argenteus*, at risk due to environmental impacts.
Photo: G Nogueira da Silva

Recommendations:

To reestablish the fish community, principally the species endemic to the São Francisco River Basin, by providing consequently more balance into the trophic chain. Additionally, a friendlier environment for the artisanal fishery sector should be promoted. This needs to include the development of environmental education programs to raise awareness for proper behavior regarding the environment. A prerequisite is to guarantee space for fishing *(compare chapter 1.11 on page 45)* as well as to improve the fishermen's' conformity with the regulations *(compare chapter 1.6 on page 35)* and the adequacy of these regulations *(compare chapter 4.1 on page 76)*.

Further reading:

Nogueira da Silva GM (2015) Avaliação do período reprodutivo de peixes nativos de importância econômica em reservatório do semiárido brasileiro. MSc Thesis, Programa de Pós-Graduação em Ecologia, UFRPE, Recife.

Nogueira da Silva GM (2016) Zoneamento da pesca artesanal no reservatório de Itaparica, Rio São Francisco, Brasil. Trabalho de Conclusão de Curso (Tecnólogo em Gestão Ambiental)—Instituto Federal de Pernambuco, DASS, Recife.

Nogueira da Silva GM, El-Deir ACA, Sobral MC, CARVALHO RMCMO (2015) Pressões ambientais sob ictiofauna e a atividade pesqueira artesanal no Submédio do rio São Francisco. In: XXI Encontro Brasileiro de Ictiologia, 2015, Recife.

Nogueira da Silva GM, Felix RTS, Lima AC, Silva EM, El-Deir ACA (2015) Avaliação do período reprodutivo do peixe migrador Prochilodus argenteus Agassiz, 1829 em reservatório do Semiarido Brasileiro. In: XXI Encontro Brasileiro de Ictiologia, 2015, Recife.

Nogueira da Silva GM, Carvalho RMCMO, El-Deir ACA, Felix RTS, Sobral MC, Gunkel G (2016) O período de defeso na bacia do Rio São Francisco. In: I Simpósio da bacia Hidrográfica do Rio São Francisco, 2016, Juazeiro.

1.8 Reinforcing water resources management

For whom: Hydropower plant operators (e.g., CHESF), Sanitation organizations (e.g., COMPESA), State Governments, Municipal Departments of Infrastructure, Institutions of higher education (e.g., UFPE, UFRPE, UPE, UNIVASF, IF)

From whom: Maiara Melo (maiara.desouzamelo@yahoo.com.br), Nailza Arruda (nailza-arruda@hotmail.com)

Problems:

- Lack of information on water quality and the impacts of activities in the São Francisco River Basin.
- Lack of transparency in water quality monitoring.
- Deficiency in basic sanitation.
- Water scarcity and difficulties in attaining water sustainability.

Key messages:

1. Expanding the water quality monitoring network in the reservoirs and river stretches of the Sub-Middle São Francisco River, with emphasis on the Itaparica Reservoir in proximity to the catchment location of the water diversion project (PISF).

2. Expanding and renovating the existing basic sanitation system with the intention of reducing water losses from distribution and fostering the construction of systems for the collection and treatment of waste in order to avoid the contamination of water bodies.

3. Investing in water reuse technologies, thus incentivizing this alternative practice to reduce the pressure by demand, and creating programs for suitable rainwater collection and storage technologies.

4. Realizing research of water quality development in the Itaparica Reservoir, including the prospective operation of the water diversion project.

Further reading:

Arruda NO (2015) Controle do aporte de fósforo no reservatório de Itaparica localizado no semiárido nordestino. Doctoral Thesis, Universidade Federal de Pernambuco, Brazil.

Melo MGS (2015) Modelagem multi-segmentar para governanca de perímetros públicos de irrigação de base familiar no semiárido nordestino. Doctoral Thesis, Universidade Federal de Pernambuco, Brazil.

Desiccating littoral zone with aquatic macrophytes.
Photo: F Selge

1.9 The Green Liver System (GLS)—an approach to purify water

For whom: People interested in establishing a GLS (e.g., fishfarmers, farmers using irrigation), CODEVASF, EMBRAPA Semiárido, Municipal government departments, Rural extension services

From whom: Érika Marques (erikatmbio@gmail.com), Stephan Pflugmacher-Lima

The experimental Green Liver System (GLS) in Itacuruba.
Photo: M Siegmund-Schultze

Problem: Pollution of a vital natural resource: water.

Solution: Use land-based aquaculture instead of net-cages in the reservoir and an eco-friendly water purification system (green liver). The green liver can also purify agricultural drainage water.

Context: The recent development of commercial aquaculture (mainly in net-cages within the Itaparica Reservoir, but also land-based in nearby ponds using water from the reservoir) is threatening water quality in the water body through surplus fish feed, droppings, fish pharmaceuticals (including antibiotics) or when effluents from fish tanks enter the reservoir without prior cleaning. A similar situation occurs with drainage water from agricultural irrigation. Among others, reservoir water is used for drinking water and leisure activities.

Key message: It is important to recognize when pollution from productive activities begins to have negative impacts—and then to control this through biological means wherever possible, without compromising production and the environment.

The technology: The Green Liver System (GLS) is a structural and vegetative measure—a constructed wetland—to purify water. Flooded zones are based on the biological symbiosis of

Table 4 **"SWOT" analysis of the green liver approach in the context of Brazil's semiarid Northeast**

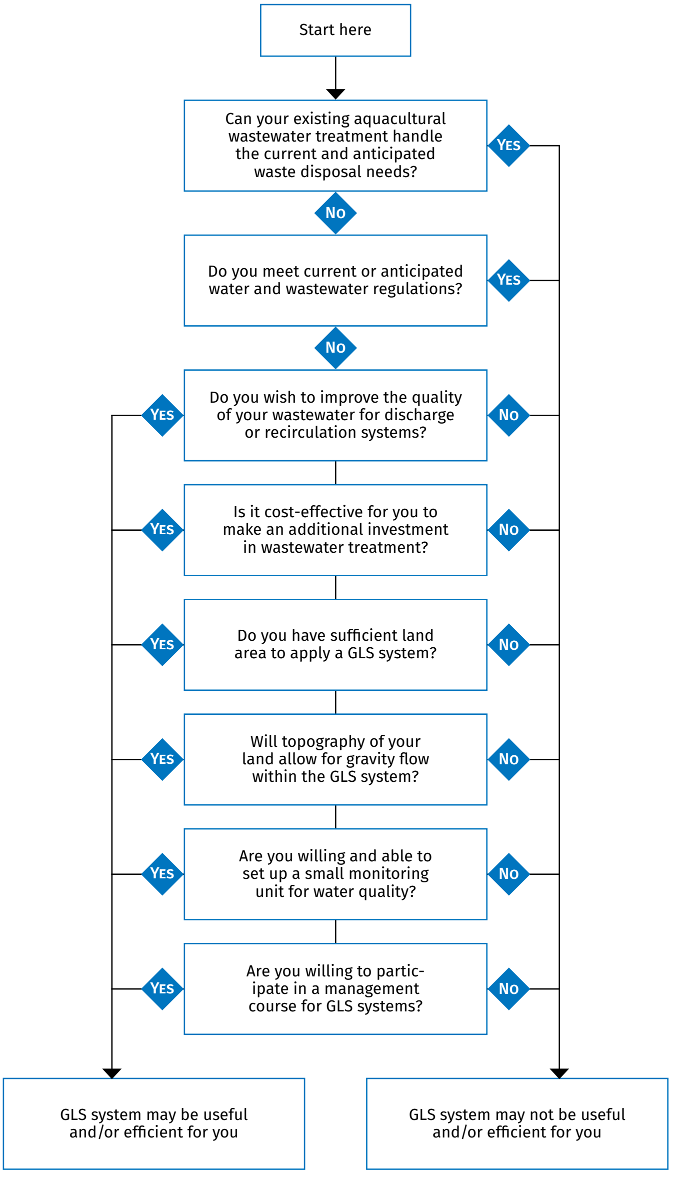
Strengths	Weaknesses
Clean technology	Requires periodic maintenance
Sustainable use of natural resources	The efficiency of the system varies depending on season
Compliance with legislation	Water quality degradation due to plant senescence
Reduction of harmful environmental impacts of fish farming	Can be invaded by fish (and fish feed on the macrophytes)
Cheaper implementation costs as compared to other purification technologies	Can create a deadly trap for small free-roaming ruminants in the region
Opportunities	**Threats**
Favorable climate	Seasonality (rainy season vs. dry season)
Hundreds of dams	*Eichhornia crassipes* can invade the reservoir and become a plague if not well-managed
Income and work opportunity for local population	
Macrophytes are locally available	

Compilation: E Marques

macrophytes and micro-organisms (such as bacteria, fungi, and algae) and their interaction with the soil chemistry. The GLS (certain plants called macrophytes are used to purify water contaminated with toxic substances in a system, taking advantage of their capacity to absorb the pollutants) is an example of a "swamp", constructed with the purpose of reducing or eliminating harmful substances. The macrophytes used are chosen in regard to their potential for accumulating the specific toxic substances at hand.

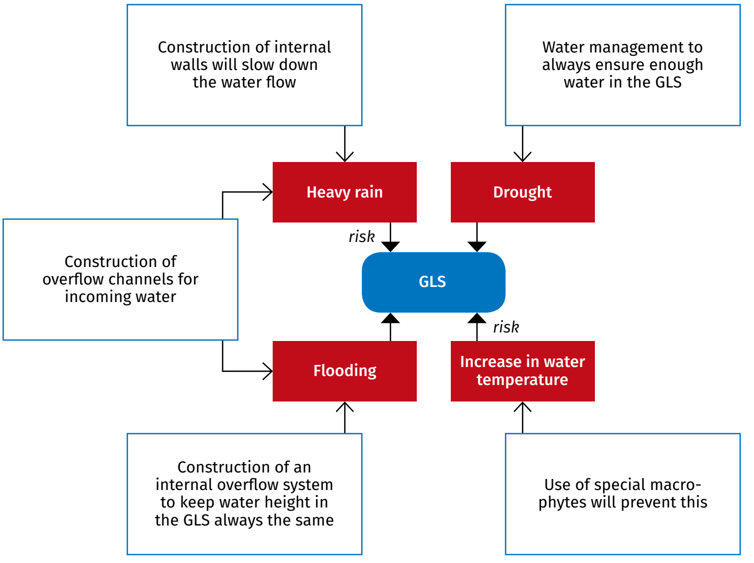
The technology can be established in diverse land use types, for instance, adjacent to irrigated agriculture or land-based aquaculture. The technology has ecological, ecotoxicological, and toxicological impacts. Submerged aquatic macrophytes, preferably those non-rooting or having only minimal roots, are used in ponds without sediment. The macrophytes take up, transform and metabolize contaminants. In order to prevent the decaying plants from releasing contaminants back into the water, the system has to be monitored and renewed constantly. In a second step, the removed plant material could be used in a biodigestor to produce electricity.

Managing the technology: Before implementation, the technology needs to be assessed against a number of criteria, such as specific needs and resources of the operator and the local frame conditions under which the operator may establish and run the system. In the following, we first present an analysis which looks into strengths, weaknesses, opportunities, and threats of the approach, and here specifically under conditions in Brazil's Northeast (Table 4). Then, we present a decision tree which helps to decide whether the approach may fit (Figure 5). Finally, we exemplarily investigate potential risks and how these can

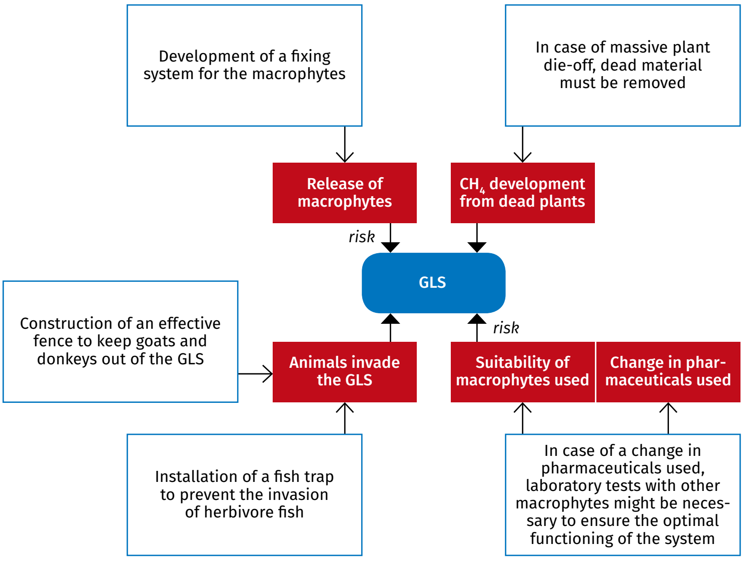


Source: S Pflugmacher-Lima (adopted from Miller et al, 2003)

Figure 5 **A decision tree to determine whether a Green Liver System might be suitable for a site**



Notes: Red boxes—potential weather extremes. Blue boxes—actions to increase preparedness.
Source: S Pflugmacher-Lima
Figure 6 **How operators of a GLS (Green Liver System) can increase preparedness when facing weather extremes**



Source: S Pflugmacher-Lima
Figure 7 **How to deal with possible risks during a operation of a GLS**

be addressed. Figure 6 looks into potential risks accruing by weather irregularities and Figure 7 addresses a number of operation-related risks.

Constructing overflow channels increases the undisturbed functioning of a GLS. Overflow channels protect the GLS against floods. Flooding might not be a high risk in a semi-arid area, but if too many fish ponds are opened at the same time, a similar

The experimental GLS with macrophyte stands.
Photo: J Köppel

effect is probable. Furthermore, the plants in the system will help slow down water flow up to a certain velocity. Macrophytes such as *Eichhornia* reduce high water temperatures. *Eichhornia* also reduces the oxygen level of the water beneath the plants. Finally, evapotranspiration is increased using macrophytes, which is not necessarily an advantage.

In case of a severe drought, the operator must decide how much water can still be channeled to the GLS. Quite common would be the fish first, then the water clean-up system. If the drought persists for a long time, the GLS may have to be closed temporarily.

Each GLS may face different and very context-specific challenges. In our test GLS, an effective goat and donkey fence had to be constructed, but still young goats entered the system; appropriate spacing on the bottom section of the fence is required. Plant-eating birds were not seen in the area during the project time. If such birds would prove too numerous, potentially threatening the system by removing too much plant material, then putting a net over the system could be a solution.

Two fish traps were installed in the test GLS using concrete basins and gravel, as well as a "fish escape" channel to prevent accumulation of possible dead juvenile fish in front of the traps. Effectiveness can be tested after the GLS is emptied with the help of an electronic fish stunner.

If the composition of the effluent to be cleaned changes, for instance by changing the pharmaceuticals applied in the aquaculture system, then the operator of the system may have to change the macrophyte species in use. The functioning of the macrophytes can be tested in the laboratory in order to judge their purification efficacy.

Further reading:

Check out a leaflet explaining the technology, prepared in cooperation with WOCAT (World Overview of Conservation Approaches and Technologies https://www.wocat.net). The leaflet introduces the technology briefly, describes land use problems in the region, outlines the natural and human environment, summarizes establishment and maintenance activities of the technology and presents a rough evaluation.

Find it in the WOCAT technologies database: https://qcat.wocat.net/en/wocat/list/?type=technologies

Download it from the INNOVATE website: http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/text_files/flyer/Tech_Wocat_Green_Liver_EN_INNOVATE.pdf

Pflugmacher S, Kühn S, Choi J-W, Baik S, Kwon K-S, Contardo-Jara V (2015) Green Liver Systems® for water purification: Using the phytoremediation potential of aquatic macrophytes for the removal of different cyanobacterial toxins from water. American Journal of Plant Sciences 6: 1607-1618. doi: 10.4236/ajps.2015.69161.

1.10 The aquaponics approach

For whom: Those who want to make use of nutrient-rich water in a sustainable way and occupying just little space, farmers, fishermen, CODEVASF, Municipal government departments, Institutions of higher education

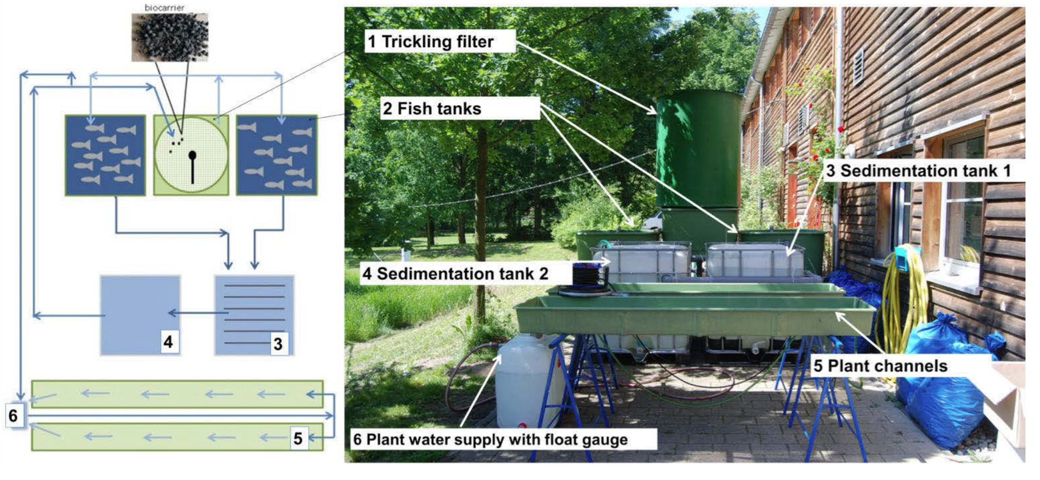
From whom: Frederike Gröner, Christin Höhne, Érika Marques (erikatmbio@gmail.com), Werner Kloas (werner.kloas@igb-berlin.de)

Problem: Waste of nutrients and pollution of waterways.

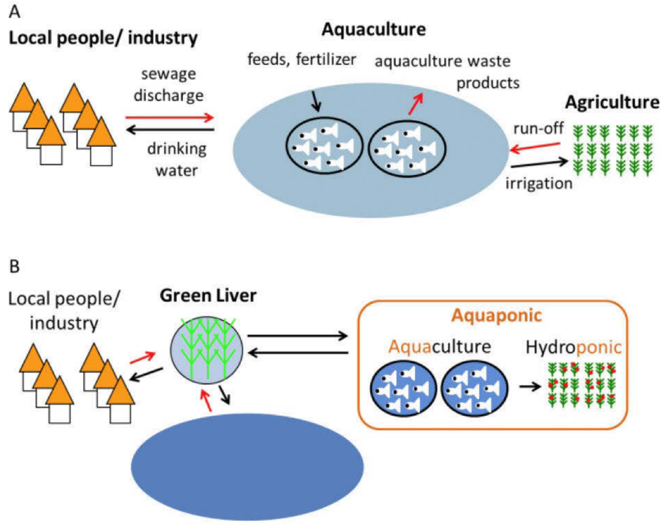
Solution: An integrated aquaculture and plant production system that recycles nutrients.

Context: Open and semi-open aquaculture installations directly exchange or discharge water with high nutrient concentrations (nitrate, nitrogen, phosphate, phosphorus, etc.) and solid material (particles) in nearby waterbodies such as streams, rivers, and reservoirs. The main sources of residues coming from aquaculture installations are unconsumed food and fish excretions (but also other contaminants can be present, such as residuals of antibiotics). If effluents are discharged without treatment, the environment can become heavily polluted. Only a small share of the distributed nutrients is bound, the majority is, however, freely discharged.

Many methods and technologies of mechanical separation or sedimentation have been developed in order to reduce the nutrient load in aquacultural effluents. The reduction of dissolved nutrients, such as ammonium, urea and compounds of soluble phosphorus or carbon, as well as technologies for water treatment, are often expensive to construct and maintain. Instead of considering the nutrients negatively (necessity to reduce), a reuse should be considered.



Arrows in dark blue represent water rich in nutrients, arrows in light blue represent purified water. The model system is composed of a trickling filter (1), fish tanks (2), sedimentation tanks (3 & 4), plant channels (5) and a plant water supply with float gauge (6).
Source: Gröner F, Höhne C, Kunow M, Kloas W (2016) Aquaponic Model System. Technical instructions and potential research questions. IGB Berlin. (pictures adapted)
Figure 8 **Schematic design of an aquaponic model system showing water circulation paths (left); a model aquaponic system installed in Germany (right).**



Source: Gröner F, compiled for the booklet on Education Days (compare chapter 3.4 on page 74).

Figure 9 **Traditional water use with open aquaculture (A) and diagram of an integrated system with water purification through the GLS together with a terrestrial aquaponic system (B)**

Alternatives include: i) construction of flooded zones—Green Liver System/GLS *(compare chapter 1.9 on page 39)*, and ii) systems of recirculation in combination with hydroponics ("aquaponics"). Aquaponics are recirculation systems with combined cultures of fish and plants in which the effluents from aquaculture provide most of the nutrients required by the cultivated plants (Figure 8). A Green Liver System (GLS) could be integrated into the aquaponic system in order to reduce the pollution and eutrophication of the Itaparica Reservoir resulting from effluents. Terrestrial aquaponic systems, together with a purification system (such as the GLS), can help to close nutrient cycles, reduce environmental impacts of aquatic production systems and decrease negative impacts on cultivated organisms. Among the benefits for the local population is the access to clean drinking water and food of high quality (fish and vegetables). The local aquaculture farmers, with additional income from the vegetable production through the hydroponics (Figure 9), could acquire a better quality of life. To demonstrate the functioning of a GLS and an aquaponic system, experimental systems have been installed in a tilapia farm in the Itacuruba municipality.

A manual providing technical instructions and potential research questions can be accessed on the INNOVATE website: http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/images/RM_pics/RM-Guidance/Aquaponic_Model_System_INNOVATE.pdf.

Further reading:

Karimanzira D, Keesman K, Kloas W, Baganz D, Rauschenbach T (2016) Dynamic modeling of the INAPRO aquaponic system. Aquacultural Engineering, 75: 29–45. doi: 10.1016/j.aquaeng.2016.10.004.

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Kloas W, Groß R, Baganz D, Graupner J, Monsees H, Schmidt U, Staatks G, Suhl J, Tschirner M, Wittstock B, Wuertz S, Zikova A, Rennert B (2015) A new concept for aquaponic systems to improve sustainability, increase productivity, and reduce environmental impacts. Aquaculture Environment Interactions, 7: 179-192. doi: 10.3354/aei00146.

Suhl J, Dannehl D, Kloas W, Baganz D, Jobs S, Schreibe G, Schmidt U (2016) Advanced aquaponics: Evaluation of intensive tomato production in aquaponics vs. conventional hydroponics. Agricultural Water Management, 178: 335–344. doi: 10.1016/j.agwat.2016.10.013.

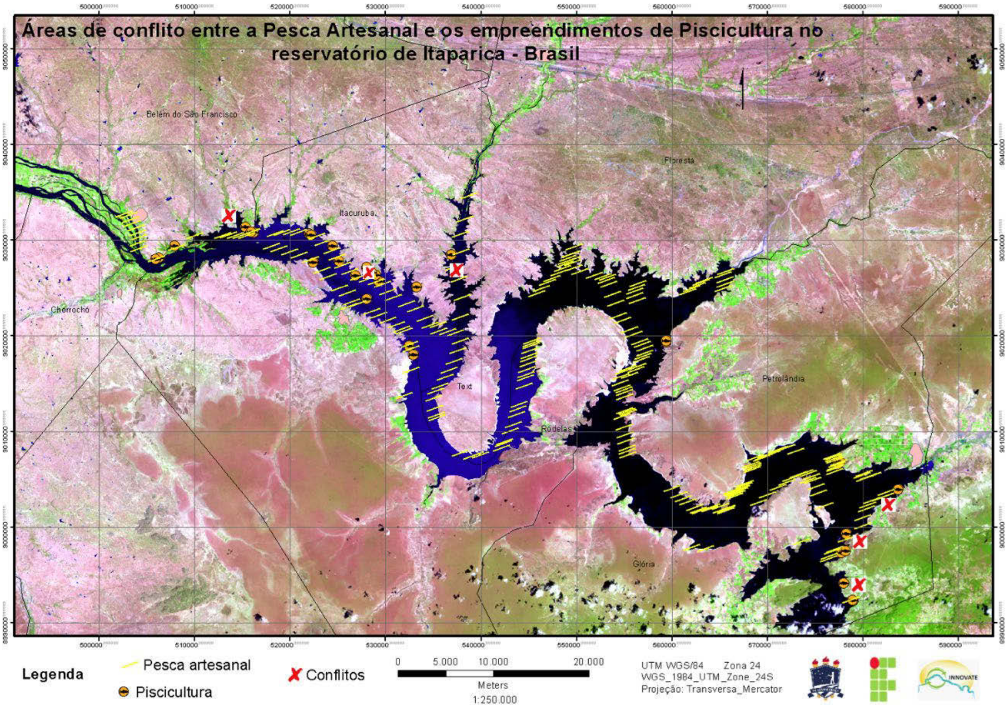
1.11 Delimitation of conflict areas for land use planning around the Itaparica Reservoir

For whom: Fishermen's communities and councils, SPU, Ministry of Fishery and Aquaculture, Municipal government departments, Watershed committees

From whom: Gérsica M. Nogueira da Silva (gersicamns@hotmail.com)

Problem: Artisanal fisheries compete with commercial net-cage aquaculture: primarily a territorial conflict about the use and access to shoreline and reservoir areas. The increased use of the waterbody increases water pollution and eutrophication risk, threatening fish stocks for artisanal fishing. The conflict is complex and has environmental, social, economic, and politico-institutional dimensions.

Recommendations and current action: Propose mitigating measures that help maintain the activity of artisanal fishing in the Itaparica Reservoir. The georeferenced database, realized in collaboration with the fishermen, is already being used by the fishermen's communities to obtain water rights—the Authorization Terms for Sustainable Use (TAUS). The Pastoral Council of Fishermen (CPP) of the Petrolândia municipality, in collaboration with the Federal Properties Management Office (SPU), initiated a process of granting the TAUS to the fishermen in the priority areas in accordance with decree Nº 89/2010.



Source: Nogueira da Silva GM (2016) Zoneamento da pesca artesanal no reservatório de Itaparica, Rio São Francisco, Brasil. Trabalho de Conclusão de Curso (Tecnólogo em Gestão Ambiental)—Instituto Federal de Pernambuco, DASS, Recife.

Figure 10 **Areas of conflict between artisanal fisheries and commercial fish farming in the Itaparica Reservoir**

Context: Net-cage aquaculture has grown significantly in the region since 2010. During this time period, artisanal fishery has weakened in the Itaparica Reservoir. In 2014, only 870 fishermen were registered for the Itaparica Reservoir in the State of Pernambuco (and further artisanal fishermen registered on the Bahia side of the reservoir).

Environmental Zoning is one of the basic instruments of the National Law for the Environment which, besides regulating the preservation of natural resources, is appropriate for settling conflicts arising from the simultaneous development of various activities in a given region. By identifying the representative areas of ecosystems, the zoning depicts the territorial ecological profile and exhibits the activities, uses and occupation types that should be prevented, restrained or allowed in diverse areas. The data enable the recognition of the environmental reality in the region and the establishment of ways in which community-environment interaction takes place through the planning of the fishing activities.

The study: Existing fishing locations have been mapped inside the Itaparica Reservoir; direct conflict areas between artisanal fishery and aquaculture are highlighted (Figure 10). The mapping was realized on four excursions to the Itaparica Reservoir during 2014, in cooperation with local fishermen and with the support of the CPP. A Global Positioning System (GPS) was used through the Garmin Etrex device with the purpose of georeferencing the target areas, which were recorded through photographs and field notes.

The vector and matrix data were georeferenced in the projection of UTM, WGS 84 zone 24. For the visualization of the georeferenced points, images of the sensor Oli654/LANDSAT 8 orbit-point 216-066 of 13th February 2014 were used. A database of the primary data was developed, and a map elaborated using the ArcGIS 10.1 software.

Further reading:

Nogueira da Silva GM (2016) Zoneamento da pesca artesanal no reservatório de Itaparica, Rio São Francisco, Brasil. Superior Course Conclusion Work, Instituto Federal de Pernambuco, Brazil.

Nogueira da Silva GM, Carvalho RMC, El-Deir ACA, Sobral MC, Siegmund-Schultze M (submitted 2016) Artisanal fisheries of the Itaparica reservoir, São Francisco River, Brazil: socioeconomic profile, environmental dynamics, and management recommendations. Regional Environmental Change.

Access the map online: http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/images/RM_pics/RM-Guidance/Innovate_Mapa_conflitos_pesca_PT.tif

2 LAND—management at the LOCAL scale

Coconut palms and squash grown in a public irrigation scheme. *Photo: M Siegmund-Schultze*

2.1 Strengthening the organization of public irrigation schemes

For whom: Cooperatives and associations of rural producers, Municipal Governments (Departments of Agriculture, Environment, Infrastructure), State Governments, CPRH, CODEVASF, ANA, COMPESA, IPA, Regional development banks (e.g., Banco do Nordeste, BNDS), Watershed committees (e.g., CBHSF)

From whom: Maiara Melo (maiara.desouzamelo@yahoo.com.br), Nailza Arruda (nailza-arruda@hotmail.com)

Problem:

- Irregular use and expansion of public irrigation schemes.
- Water scarcity but excessive water use.
- Water erosion of soil.
- Deficiencies in the storage and transport infrastructure of agricultural products.
- Social separation of the society.
- Inadequate disposal of solid residues.
- Social conflict over multiple water uses.

Context: The uncontrolled use of the reservoir margins for agricultural activities and urban settlements has caused environmental problems in the study area. Inadequate irrigation and soil fertilization practices, the accumulation of agrochemical residues in soil water, and the release of effluents without or with too little treatment contribute to the deterioration of water quality. The inflow of nutrients from anthropogenic sources is considered the main cause of the (temporary) eutrophication of waterbodies, promoting excessive growth of aquatic macrophytes and algae, as well as cyanobacteria blooms, which can be toxic and entail a risk for human and animal health and threaten economic activities.

"EB5" pumping station channel. *Photo: W Souza*

Explanation: Plowing and harrowing during soil preparation imply the disaggregation of the topsoil layer and increases the risk of water erosion, along with unintended nutrient export. Observations made in the field (e.g., in the Icó-Mandantes irrigation scheme) showed that erosion processes can be intensified though the illegal expansion of cropland in public irrigation schemes, especially in the areas designated for dry farming and as legal reserves (i.e., conservation areas according to the Forest Act). In particular, in legal reserves near agricultural plots, the Caatinga vegetation is sometimes removed to provide space for crops, which benefit from the nearby irrigation infrastructure.

In order to sustain the growth of agricultural revenues, which is an important issue for the population and the municipal and state governments, it is crucial to optimize the water use efficiency within the irrigation schemes, i.e., to reduce water use while maintaining the same production. Actions which are devoted to the improvement of resource use efficiency, water conservation, and commercialization of products are important cumulative elements towards minimizing the negative environmental impacts from unadapted agricultural practices. It is further necessary to promote and mainstream "Good Agricultural Practices", which involve techniques to reduce soil erosion, maintain nutrients in the soil and increase organic matter content, as well as to reduce superficial water runoff into water bodies.

Recommendations:

1. Estimate potential negative consequences of current agricultural methods and encourage farmers to take on the responsibility of adopting Good Agricultural Practices.

2. Finalize issuing land ownership titles to the farmers in the Itaparica irrigation schemes.

"EB5" pumping station infrastructure. *Photo: W Souza*

3. Install water meters to monitor each farm separately and install irrigation infrastructure according to the needs of the predominantly grown crop types in order to make water use more efficient.

4. Consolidate and establish a water fee system within the public irrigation schemes as a contribution consumption reduction, with a special price for family farmers.

5. Incentivize organic agricultural practices.

6. Create a permanent campaign incentivizing the adequate disposal of the packaging of agrochemicals by store owners. Monitor the trade, stocks, and use of agrochemicals and disposal of their packaging.

7. Improve and secure the rural extension services for the farmers (trainings and practical advice).

8. Adoption of integrated nutrient management practices, with an emphasis on the importance of systematic soil analysis and the nutrient demand of each crop as well as on crop rotation techniques and principles of fertilization practices.

9. Incentivize the utilization of more efficient irrigation technologies, such as drip irrigation instead of furrow irrigation and conventional sprinklers.

10. Prioritize farmers' associations in programs such as the Family Agriculture Food Purchase Program (PAA) and the National School Nourishment Program (PNAE).

11. Establish and monitor the suggested Managing Committee for the Governance of the Public Irrigated Perimeters (COGEPPI) as a forum for discussion and collegial decision-making assisting local governance *(compare Melo 2015)*.

12. Coordinate the management of socio-environmental conflicts between the multiple water users in times of scarcity, optimizing uses and avoiding losses.

Further reading:

Arruda NO (2015) Controle do aporte de fósforo no reservatório de Itaparica localizado no semiárido nordestino. Doctoral Thesis, Universidade Federal de Pernambuco, Brazil.

Melo MGS (2015) Modelagem multi-segmentar para governanca de perímetros públicos de irrigação de base familiar no semiárido nordestino. Doctoral Thesis, Universidade Federal de Pernambuco, Brazil.

2.2 Measures to improve the economy of irrigated cropping

For whom: Agricultural extension services, O & M (operation and management units of irrigation schemes), CODEVASF, Farmers' associations and cooperatives

From whom: Heinrich Hagel (hagel@uni-hohenheim.de), Christa Hoffmann (christa.hoffmann@lsz.bwl.de), José Ferreira Irmão (jfi43@hotmail.com), Reiner Doluschitz (reiner.doluschitz@uni-hohenheim.de)

Problem: Insufficient infrastructure, high dependence on middlemen, low producer prices, high input costs, inappropriate application of fertilizers and agrochemicals, excessive use of irrigation water, insufficient farm income.

Key messages:

- Improve market access.
- Re-establish agricultural extension services.
- Offer specific educational programs (increase human capital).
- Support value-adding facilities.
- Implement the volumetric water price.
- Promote water-saving technologies.

Context: Despite relatively favorable production conditions and good yields in the irrigation schemes, in many cases farm income is too low to sustain a family. Farmers face insufficient market access and lack of organization. Agricultural extension services were not available for almost the whole duration of the study project (from 2013 to 2016). Low market access leads to low producer prices and high input costs. Lack of experience and agricultural extension favor inappropriate farming practices such as overuse of agrochemicals. Off-farm income alternatives are little explored. Irrigation water is currently free of charge in some of the public irrigation schemes. Lack of capital and missing support hampers the implementation of water saving irrigation technologies and leads to an extreme overuse of irrigation water in the irrigation schemes of the Itaparica system.

Our studies: We conducted several qualitative and quantitative surveys to analyze the production practices in the region and to estimate socio-economic effects on farm income. We recorded all relevant outputs (yields, by-products) and inputs (labor, capital, fertilizer, etc.) of 192 farms in the Itaparica and Petrolina mesoregions. We interviewed 192 farmers about their irrigation practices and collected data from CODEVASF, HIDROSONDAS, and local retailers of irrigation technology in Petrolina and Petrolândia. Finally, we used a farm optimization model to determine optimal resource allocation on the farm level, and estimated the effects of water pricing on water consumption and farm income.

Our recommendations:

1. We strongly recommend re-establishing agricultural extension in the irrigation schemes. This service should be complemented by the provision of farming-specific applied education.

2. Farmers should be highly encouraged to create agricultural cooperatives or associations. This requires both financial support and promotion of the benefits of associations.

3. We also recommend, a) increasing efforts to improve market access for selling agricultural products at better prices, and

b) promoting the establishment of value-adding facilities, such as food processing, to provide off-farm income alternatives. Labeling of good agricultural practices and products could be one way to improve participation in markets and increase farmer income.

4. It should be recommended that farmers diversify their production in order to reduce susceptibility towards price shocks.

5. Implementing tiered volumetric water pricing is strongly recommended if appropriate producer prices are given. Water prices should be defined according to actual consumption and be in line with water prices in other public irrigation schemes in the region.

6. Promoting modern irrigation technology (drip and micro-sprinkler, depending on the predominant crop type) would help to match management practices to the scarce water resources.

FURTHER READING:

Hagel H, Hoffmann C, Doluschitz R (2014) Mathematical programming models to increase land and water use efficiency in semi-arid NE-Brazil. International Journal on Food System Dynamics 5(4): 173-181. doi: 10.18461/ijfsd.v5i4.542.

Hagel H (2016) Socio-economic benefits and limitations of irrigated family farming in Brazil's semi-arid region. PhD Thesis, University of Hohenheim. http://opus.uni-hohenheim.de/volltexte/2017/1326/.

2.3 Soil amendments can enhance the nutrient retention capacity of sandy soils

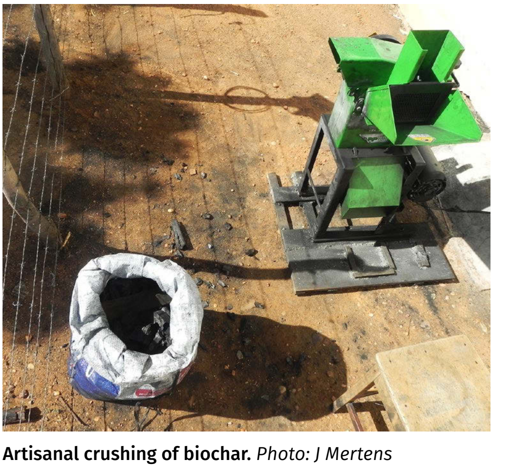
For whom: Farmers' associations and cooperatives, Municipal Department of Agriculture and the Environment, Agricultural extension services

From whom: Christine Beusch (christine.beusch@tu-berlin.de), Arne Cierjacks (arne.cierjacks@tu-berlin.de), Martin Kaupenjohann (martin.kaupenjohann@tu-berlin.de)

PROBLEM: Low crop yields due to sandy soils with low fertility and low ability to retain nutrients.

KEY MESSAGES: The addition of biochar and clay can increase the nutrient retention of sandy soils. This minimizes the use of costly fertilizers and sustains higher crop yields.

CONTEXT: The predominantly sandy soils, so-called Arenosols, which occur in the Jatobá basin (where the study took place), are of low soil fertility and low nutrient and water retention capacity. They are easy



Artisanal crushing of biochar. *Photo: J Mertens*

Soil profile of a typical Arenosol. *Photo: C Beusch*

to work but need regular inputs of water and fertilizer if used for cropping. Addition of amendments that increase the holding capacities for water and nutrients may enhance the yield and save irrigation water and fertilizer. However, to make valid statements about the long-term effects of the soil amendments tested, more experiments on a longer time scale are needed.

Our study: We conducted a field experiment testing nutrient retention of an Arenosol compared to an Arenosol amended with biochar and/or clay. Soil physical and hydrological parameters of the amendments were studied as well as the tree seedling performance of *umbuzeiro (Spondias tuberosa Arr.)*. The biochar was produced by a local charcoal maker, using *algaroba (Prosopis juliflora* (Sw) DC) as feedstock, which is an invasive species in the region. The clayey material used was collected from the bottom of a parched lake nearby. With the biochar addition we found a significant increase of nitrate retention at the beginning of the field experiment, but this effect only lasted for the first eight months after the application of biochar. After 1.5 years this effect was no longer significant. Biochar also led to an increase of ammonium retention, but this effect was not significant. The biochar addition had no significant effect on the retention of potassium.

Clay addition led to a significant increase of ammonium and potassium retention, which lasted over the entire period of the field study of 1.5 years. Amending the Arenosol with clay led to higher nitrate leaching about one year after clay application. This might be due to transformation processes of ammonium to nitrate. Within this field experiment the retention of phosphorus was also studied, but the phosphorus fluxes were too low to draw any conclusions about the effects of clay or biochar amendment on phosphorus retention. However, our study showed that there is no risk of phosphorus leaching from deep sandy soils into groundwater or nearby water bodies due to high immobility of phosphorus in the studied soils.

Neither biochar nor clay amendments had a significant impact on the soil physical parameters of total porosity, bulk density, nor water capacity compared to the unamended sandy soil. The mixture of biochar and clay led to lower soil water content and significantly reduced the retaining period of the atmospheric water. For the *umbuzeiro*, none of the applied amendments showed any significant effects on seedling survival or stem growth over 23 months.

Our recommendations:

As biochar addition to the Arenosol showed no significant increase in the retention of ammonium and potassium, and as our results assume only a short-lasting increase in nitrate retention, we cannot recommend a biochar amendment at this stage. In further long-term experiments the persistence of biochar-induced nitrate retention should be studied.

We recommend a clay amendment for improving the soil fertility of sandy soils as it significantly increased the retention capacity of the soil for ammonium and potassium. Due to high initial costs and substantial effort we only recommend clay application on intensively-used agricultural areas, with annual crops and multiple harvests per year. Application is also possible in planting holes during the set-up of perennial tree plantations. As the clay does not markedly degrade over time, its soil-improving effects will presumably last for several decades.

Clayey material for amending soils could, for example, be taken from locally available sediments with a high content of fine, clayey material. Before application, the material should be tested for possible toxic substances. Within our field experiment we applied 10 vol% clay; however, for practical reasons we suggest the application of smaller amounts—up to 5 vol%. The investment for such clay application has to be considered in the long term. High initial costs and efforts will potentially pay off in the long-term and lead to increased yields and savings in fertilizer application.

The seedling performance of *umbuzeiro* is independent on soil management practices, which underlines its non-domesticated character. Therefore, we recommend *Spondias tuberosa* for plantations of low-input orchards and for reforestation within the Caatinga.

FURTHER READING:

Beusch C, Böhm J, Cierjacks A, Bischoff WA, Mertens J, Araújo Filho JCd, Kaupenjohann M (in preparation) Biochar and clay amendments improve nutrient retention of a tropical Arenosol in NE-Brazil.

Mertens J, Germer J, Araújo Filho JCd, Sauerborn J (2016—online first) Effect of biochar, clay substrate and manure application on water availability and tree-seedling performance in a sandy soil. Archives of Agronomy and Soil Science, 1-15. doi: 10.1080/03650340.2016.1249473.

2.4 Technologies for an environmentally and economically sound irrigated agriculture

For whom: Farmers' associations, Municipal Departments of Agriculture and the Environment, Rural extension services, EMBRAPA, IPA, CODEVASF

From whom: Arne Cierjacks (arne.cierjacks@tu-berlin.de), Jarcilene Almeida-Cortez (jacortez@ufpe.br), Katharina Schulz (katschul@gmail.com), Déborah Oliveira (deborahalani@gmail.com), Maike Guschal (maike.guschal@gmail.com)

PROBLEM: Decreasing crop yields, salinization of soils, and high use of herbicides.

KEY MESSAGES:

- Use micro-spray irrigation in tree plantations.
- Reduce or avoid chemical herbicides and pesticides.
- Maintain or establish field margins, which provide habitat for pest predators.
- Let goats or sheep feed on weeds in plantations.

- If needed, give preference to organic pesticides (e.g., manioc extract (*manipueira*), chili (*pimentão*), neem extract (*óleo de neem*)).
- In banana fields, use organic potassium, phosphorus and nitrogen sources.
- In banana fields, remove dead leaves from the field, e.g. piles of leaves.
- Plant coconut trees which are resistant against whitefly.
- Produce different crops in one field.
- Protect seedlings of the *umbuzeiro* tree.

Context: Irrigated farming often goes along with the intense use of herbicides and pesticides as well as with poor irrigation systems that may lead to soil salinization. In irrigated farming schemes, farmers have to cope with pests (e.g., whitefly), which can significantly reduce crop yields.

Our studies: We carried out several studies within different tree crop orchards (banana, coconut), where we analyzed the effect of irrigation type (micro-spray, normal spray, drip), the use of organic and chemical fertilizers, herbicides and weed biodiversity on crop yield. Whitefly significantly negatively affected yield in coconut fields. Coconut trees with higher leaf polyphenol content were significantly less affected by this pest compared to trees with a lower content. Higher weed diversity in orchards and at their edges significantly increased banana and coconut yield.

Our Recommendations:
Research on coconut varieties that have high polyphenol content in their leaves should be undertaken, taking into account parameters such as productivity, taste, and durability of products. Based on our studies, we recommend the use of micro-spray irrigation, which leads to significantly higher yields and low overall water consumption in comparison to other irrigation techniques.

Further, we recommend the reduction of herbicide use, since higher weed diversity leads to higher crop yield—probably due to complementarity in resource acquisition (phosphorus uptake) and a higher amount of pollinators. This is supported by the finding that herbicides had no effect on crop yield. Therefore, we also recommend keeping field margins with a high richness of weed species. This also provides habitat for pest predators (Figure 11). Beneficial frogs, depending on their type, either need trees or low vegetation. Goats and sheep could be used to reduce the weeds inside the plantations to an optimal level.

Dimensions of Ecological Pest Management								
Improve the ecological conditions and health of the crop							**Reduce specific pests**	
Biodiversity					Balanced fertilization		Alternative pest control	
Management of spontaneous vegetation			*Crop diversification*				*Biocontrol agents*	*Plant extracts*
Maintain or establish species-rich field margins	Leave weeds in plantation, let livestock feed on them	Maintain or establish water sources	Add understorey in tall plantations	Use polyculture where possible	Use manure if available	Check for specific deficiencies and compensate	Encourage the presence of natural enemies (see vegetation management, left)	Use locally available resources (e.g., manioc, chili, garlic, marigold)

Compilation: M Siegmund-Schultze
Figure 11 **Ecological management of crop pests is multifactorial: an example of reinforcing actions**

Arboreal frog *(Hypsiboas raniceps)*. *Photo: M Guschal*

Surprisingly, we found no evidence for any effect of pesticides on crop yield. Instead of chemical ones, organic pesticides (e.g., manioc extract, chili, neem oil) should be used if necessary. In banana orchards, it is important to use potassium and phosphorus to obtain the best crop yields. Dead leaves from banana trees should be completely removed from the field as leaf litter was negatively correlated with yield and P nutrition of banana plants. As litter is important for frogs and toads, which reduce the numbers of pest species, it should be placed at the field margin.

Within our study area, seedlings of the threatened endemic fruit tree *umbuzeiro* (*Spondias tuberosa*) could exclusively be found on agricultural land, whereas within the Caatinga, there is a pronounced lack of natural regeneration of *umbuzeiro*. Therefore, it is very important to protect the seedlings present within agricultural lands.

Further reading and watching:

Leaflet on issues of irrigated cropping: http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/text_files/flyer/Cartilha_Agricultura_INNOVATE_2016.pdf (Portuguese)

Leaflet on biological pest control (WOCAT): http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/text_files/flyer/Tech_Wocat_Biological_Pest_Control_EN_INNOVATE.pdf (English) or find it directly in the WOCAT technologies database: https://qcat.wocat.net/en/wocat/list/?type=technologies.

Leaflet in comic style—Zé da Jia explains biological pest control—find the leaflet and further reading: chapter 3.2.5 below on page 37.

Video on biological pest control and related video on constellation analysis. Links to the videos are available at www.wocat.net and http://www.innovate.tu-berlin.de/v_menue/materials_for_stakeholders/parameter/en/. The direct paths are: https://vimeo.com/208127666 (Biological Pest Control) and https://vimeo.com/208126454 (Constellation Analysis).

Cierjacks A, Pommeranz M, Schulz K, Almeida-Cortez J (2016) Is crop yield related to weed species diversity and biomass in coconut and banana fields of northeastern Brazil? Agriculture, Ecosystems & Environment 220: 175-183. doi: 10.1016/j.agee.2016.01.006.

Feigs JT (2016) What can landscape genetic analyses of *Spondias tuberosa* Arr. Câm. tell us about anthropogenic disturbance on the seasonally dry forest Caatinga? Master Thesis, University of Hamburg.

Marr S (2016) Be prepared: impact of plant phenolic content and herbal biodiversity on ‘whitefly’ infestation level in *Cocos nucifera* L. in Pernambuco. Master Thesis, University of Hamburg.

Pfaffenberger V (2016) Interactions between functional biodiversity, phosphorus cycling and banana yield in northeastern Brazil. Master Thesis, University of Hamburg.

2.5 *Zé da Jia*—A comic leaflet explaining biological pest control

For whom: Children in rural areas and fans of *cordel* literature and comics, Farming families with irrigated agriculture, Local schools

From whom: Eliza Maria Xavier Freire (elizajuju@ufrnet.br), Iaponira Sales de Oliveira, in collaboration with: Marcos Medeiros (Editora LerMais), Marcelo Quirino

The leaflet is a comic interpretation of local "*cordel* literature". The young *Zé da Jia* character explores the benefits of amphibians in combating crop pests. He explains the advantages of amphibians over the use of pesticides—which not only threaten insects, but also other animals, as well as human health. Amphibians play an important role in maintaining equilibrium between predators and prey. This means that farmers can take advantage of biodiversity by maintaining habitats for amphibians instead of applying pesticides (or at least reduce their application). In this way, they contribute to biodiversity conservation as well as environmental and human health. The leaflet seeks to mediate an understanding of biodiversity-friendly agricultural practices leading to the depicted win-win situation, benefitting both farmers and the environment.

Read the leaflet here:

https://drive.google.com/file/d/0B0tWL8jSAQQFaEVLcjNFWlEyaGs/view?pref=2&pli=1 (leaflet in Portuguese)

Or access the INNOVATE project's website:

http://www.innovate.tu-berlin.de/v_menue/subprojects/sp4_biodiversity_and_ecosystem_services/sp4_rm1_amphibian_biodiversity/parameter/en/ (webpage in English, leaflet in Portuguese)

Source: see indications above
The first pages of the leaflet, read online

2.6 Good governance in implementing biological pest control

For whom: Farmers, Associations and cooperatives, Organizations related to irrigated agriculture, Rural extension services, CODEVASF, EMBRAPA, IPA, Municipal government departments

From whom: Verena Rodorff (verena.rodorff@tu-berlin.de), Maike Guschal (maike.guschal@gmail.com), Marianna Siegmund-Schultze (m.siegmund-schultze@tu-berlin.de)

Problem: Beneficial technologies for farmers and the environment exist; however, they are rarely adopted. This is often not just due to unfavorable conditions of the locality itself, but also related to governance processes and non-transparent interests. Biological pest control is a recognized technology, but rarely part of rural extension.

Key messages: Local knowledge (about biological pest control) has to be valued more. Combining local with scientific knowledge (about, for example, modes of action and decision-making) in a transparent process has a great chance to identify and implement concrete solutions for the sustainable use of natural resources.

The study: Two workshops about biological pest control practices were realized with the participation of farmers and representatives of organizations related to agriculture. Guided through the criteria of good governance *(compare chapter 6.5 on page 105)*, the workshop participants discussed determinants and options for the implementation of biological pest control in the region.

Recommendations:

According to the participants, clear proposals have to be defined in guidance for farmers, research institutions, and other agricultural organizations.

1. Despite being based on the principle of "sustainable rural development compatible with an adequate utilization of natural resources and the preservation of the environment", concrete recommendations are still not found in the rural extension law (Brazilian law Nº 12.188/2010): agroecological practices should be incorporated into rural extension plans. The agroecological transition was declared in a national decree (Brazilian decree Nº 7.794/2012); however, its implementation is barely visible at the various administrative levels.

2. A social discourse is necessary to define responsibilities, visions and opportunities in the process of establishing agroecological practices. This discourse is needed on the municipal, state and federal levels.

3. Environmental education has to be included in the curricula of regional schools. The INNOVATE project, for example, conducted two series of Education Days in the study region *(compare chapter 3.4 on page 74)*. This type of outreach and interaction can serve as an example for future events realized in the municipalities. We prepared didactic material stemming from those events for download: http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/text_files/Books/Cartilha_Dias_de_Educacao_INNOVATE.pdf (in Portuguese).

4. Education and knowledge about environmental sustainability are key factors for farmers. The rural extension law aims at "constructing sustainable production systems stemming from scientific, empirical and traditional knowledge". Collaborative production of knowledge has to be promoted and strengthened. Brazilian universities, for example, have three pillars (teaching, research, and extension); however, the

A selection of state, national, and international regulations. *Photo: M Siegmund-Schultze*

extension pillar is currently little valued in evaluations, and often not put into practice. In regard to the collaborative production of knowledge (see above), having the pillars is advantageous; hence combining extension with research is within the mandate of the personnel.

5. A pilot project or a model farm, or at least aplot, is essential to gain more local experience with new practices and to develop criteria for quality control. Monitoring would serve to create confidence in a practice that can generate ecological and economic success.

6. Public and private research institutions already conducted a lot of relevant research; however, results often do not reach the farmers. It is necessary to spread the research results locally in a transparent and understandable manner. The research results then need further local adaptation by the farmers.

7. Various farmers do not get rural credits because of lacking land titles. Credits could support the adoption of new technologies and new forms of management.

Two videos were prepared within the frame of this study. The first shows techniques of biological pest control applied in Petrolândia and explains further practices of habitat conservation to support predator animals, which feed on pests. The second video describes the constellation analysis process, using the scenario of implementing biological pest control as an example.

Links to the videos are available at www.wocat.net and http://www.innovate.tu-berlin.de/v_menue/materials_for_stakeholders/parameter/en/. The direct paths are: https://vimeo.com/208127666 (Biological Pest Control) and https://vimeo.com/208126454 (Constellation Analysis).

Further reading:

Rodorff V, Siegmund-Schultze M, Guschal M, Hölzl S, Köppel J (submitted 2016) What makes governance fair in the implementation of sustainable land management? The scenario of biological pest control in Brazil's Northeast. Regional Environmental Change.

Rodorff V, Siegmund-Schultze M, Köppel J, Hölzl S (2016) Dimensões da boa governança dos recursos naturais para a implementação de boas práticas na gestão sustentável da bacia hidrográfica do rio São Francisco. Resumo expandido. I Simpósio da Bacia Hidrográfica do Rio São Francisco, Juazeiro-BA, Brazil.

2.7 What favors and hinders the adoption of *umbuzeiro* tree planting as a new technology?

For whom: Farmers, Associations and cooperatives, NGOs, IPA, ICMBio, INCRA, CODEVASF, EMBRAPA, IPA, Municipal government departments, SEBRAE, Rural extension services

From whom: Verena Rodorff (veren.rodorff@tu-berlin.de), Liron Steinmetz (liron@web.de), Jan Mertens (j.mertens@uni-hohenheim.de), Marianna Siegmund-Schultze (m.siegmund-schultze@tu-berlin.de)

Problem: There is a gap between developing a new technology and its adoption. A practical approach to quantifying major context-specific entry points is needed.

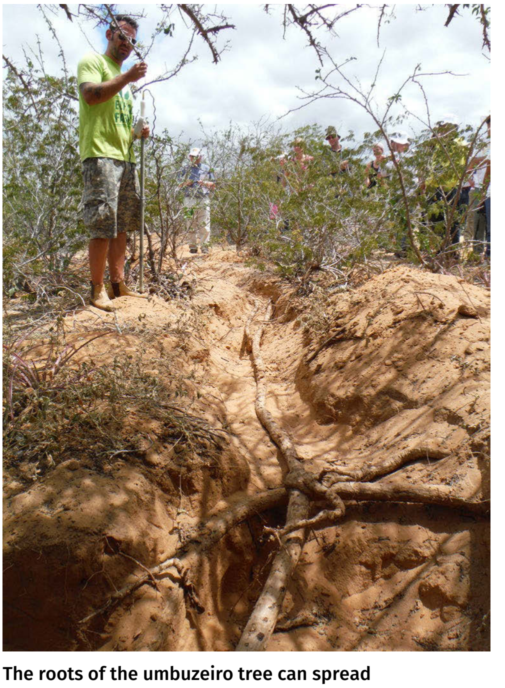
Key messages:

- Before proposing new technologies, context analyses have to be carried out to evaluate in which form a new technology is effective or not under specific conditions.
- A Bayesian Network serves as a method to estimate and quantify the practical conditions relevant for the implementation of an innovation.

Explanation: Various innovative practices were analyzed within the INNOVATE project. The premise was that the innovations benefit farmers (e.g., family farmers) as well as the environment. It is common in academics to lament about a lack of adoption by farmers of new technologies, which were tested in scientific research. We tested a methodology to analyze the adoption potential of an innovation. Hereby we exemplarily analyzed the planting of *umbuzeiro* trees developed to benefit family farmers and the ecosystems.

The example: Drought affects the local (agro) ecosystems, and thus, the income sources of the rural populations. In this respect, agronomists tested measures to meliorate soil for plantations of an endemic species—the *umbuzeiro* tree. However, what are the important aspects for them to be adopted in practice?

The study: We created a Bayesian Network (BN) model to visualize the probabilities of different scenarios and discussed the possibilities of adopting the planting of *umbuzeiro* trees with various actors. The actors filled in a questionnaire concerning the elements of the BN model, which served to calculate the probabilities through a BN program. The aim was to find the leverage points of the innovation tested. Ultimately, the innovation shall strengthen



The roots of the umbuzeiro tree can spread extremely far, contributing to its drought resistance.
Photo: C Beusch

The experimental planting of *umbuzeiro* seedlings.
Photo: J Mertens

the sustainable conservation of natural resources and at the same time guarantee the income of family farmers.

The results: We concluded that in order to support the planting of umbuzeiro trees successfully it is necessary to:

1. Facilitate the access to financial support (via public policies, NGOs);

2. Select the type of plants well: grafted seedlings are to be preferred, however, a mixture of grafted and non-grafted seedlings can be beneficial in the long-term;

3. Modify the soil and the size of the planting hole, aiming at increased nutrient and water storage capacity;

4. Fence out free-roaming animals, mainly goats and wild donkeys (especially in the first years of production);

5. Organize the commercialization and marketing well (through cooperatives, NGOs, governmental training programs).

Evaluation of the method: A close cooperation, right from the beginning, with research institutes and entities of rural extension might be crucial in order to set up the necessary adaptive administrative measures for development, which are relevant for the efficacy of the innovations in the future. In the case of planting the *umbuzeiro* tree, EMBRAPA, IPA and local institutes of higher education (in the study region: IF) would be suitable research partners and, including the rural extension institutions, for implementation as well. Model and scenario validation as well as the monitoring of the management process are important research fields, providing more evidence for the potential of the analytic method as well as of the sustainable and innovative practice.

Further reading:

Check out a leaflet that explains the Bayesian Network approach, prepared in cooperation with WOCAT (World Overview of Conservation Approaches and Technologies): http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/text_files/flyer/App_Wocat_Bayesian_Network_EN_INNOVATE.pdf (English) or find it directly in the WOCAT approaches database: https://qcat.wocat.net/en/wocat/list/?type=approaches.

Rodorff V, Steinmetz L, Siegmund-Schultze M, Mertens J, Köppel J (2015) Using Bayesian Networks to Depict Favouring Frame Conditions for Sustainable Land Management: Umbuzeiro-tree Planting by Smallholders in Brazil. Tropentag, September 16-18, 2015, Berlin, Germany. Abstract available at: http://www.tropentag.de/2015/abstracts/links/Rodorff_aoY5l0Gc.php.

Rodorff V, Steinmetz L, Mertens J, Siegmund-Schultze M, Köppel J (submitted 2017) Sustainable land management probabilities—Improving benefits for small-scale farmers in Brazil´s semiarid Caatinga biome. Regional Environmental Change.

Steinmetz L (2016) Strategien des nachhaltigen Landmanagements in Nordost-Brasilien—Können Bayesian Networks helfen, einen kooperativen Zusammenschluss von Kleinbauern zu fördern? Bachelor Thesis, Humboldt University (HU Berlin), Germany.

2.8 Livestock husbandry: better use of local resources matters

For whom: Livestock farmers of dryland and irrigated production systems, Farmers' associations and cooperatives, Rural extension services, IPA, INSA, ADAGRO, IF Sertão-PE, IFPE, UFRPE, Municipal government departments, Ministry of Agriculture, Livestock and Food Supply

From whom: Christoph Reiber (c_reiber@uni-hohenheim.de), Karin Stock de Oliveira Souza (karinsos@yahoo.de), Anne Valle Zárate (valle@uni-hohenheim.de)

Problem: Drought and the consequent water and forage shortages lead to low livestock productivity along with high drought mortality rates (12–15 %). Stocking rates are often higher (3–5 goats per ha) than the carrying capacity of the Caatinga rangeland. The local resources (Caatinga rangeland, local goat breeds, manure) are often used in an inappropriate manner.

Key messages:

- Increase availability and access to water and forage.
- Use Caatinga rangeland in a sustainable way.
- Consider using site- and system-adapted livestock breeds.
- Make efficient use of animal manure.

Context: The majority of the dryland farmers manage their livestock, particularly goats, extensively. The free-roaming animals live exclusively from the Caatinga vegetation. Increasing goat and sheep numbers, coupled with long droughts, puts the Caatinga ecosystem under increasing grazing pressure (Reiber et al. 2016). From an ecological-sustainable livestock production perspective, it is crucial to avoid over-exploitation of the Caatinga rangeland. Farmers and experts likewise think that forage cultivation is the main strategy to adapt to these problems, as well as to improve livestock production in general (Siemann 2015). Innovations with high adoption potential are cultivation of forages, pasture rotation, the use of manure, and alternative methods to control parasites (worms). These innovative practices are easy to understand, bear low risks and are inexpensive. In our study, hay making presented a moderate potential due to the slightly higher associated costs (Costa 2015).

Goats in an enclosure. *Photo: M Siegmund-Schultze*

Manure is an accessible, valuable and cheap nutrient source and soil amendment. We revealed an under-exploitation of manure as fertilizer for crop fields, particularly by the dryland farmers (Stock de Oliveira Souza et al. 2014). Only 6 % of the dryland farmers and 41 % of farmers in the irrigation schemes actively used manure. Goat manure was shown to significantly increase water content of the sandy soil (Mertens et al. 2016).

Our study: We interviewed about 200 livestock farmers and 10 experts. Topics were the performance of livestock production systems, the factors influencing the sustainability of livestock systems, the innovation and adaptation strategies of farmers, and the suitability of different farmer innovations for further adoption. In addition to the

Small farmer with goats, sheep, and cattle.
Photo: M Siegmund-Schultze

qualitative (e.g., perceptions) and quantitative (number of animals, areas, etc.) data gathered through interviews, the weight and body condition score of goats were determined.

Our Recommendations:

Promote the availability and access to water and forage, and support the management and preservation of the natural resources, such as the Caatinga rangeland, by:

1. Promoting the production and conservation (e.g., hay making) of drought-tolerant forages by individual farmers, farmer organizations (collaboratively), and the government.

2. Regulating and monitoring livestock stocking rates in the Caatinga rangeland considering the carrying capacity of the system.

3. Establishing incentives for farmers to manage cultivated forage and the Caatinga in a sustainable way (e.g., pasture rotation).

4. Preventing deforestation and promoting reforestation.

5. Establishing Caatinga conservation areas.

6. Using the manure for crop and forage production.

7. Promoting efficient water harvesting, conservation and irrigation systems.

8. Implementing controlled breeding systems with local breeds.

Additionally, an emergency water and forage (hay bales) supply system should be implemented (governmental and/or private initiative).

Conventional and participatory research and extension programs—including group and individual demonstrations, farmer field schools, field days, training sessions, and experiments (with forage, manure, local breeds)—should be implemented to promote the promising innovations, increase awareness about their relevancy, and enhance the know-how to successfully apply the innovations.

Further reading:

Costa RS (2014) Farmers innovations in livestock production systems in Pernambuco, Brazil. Master Thesis, Universität Hohenheim, Germany.

Mertens J, Germer J, Araújo Filho JCd, Sauerborn J (2016—online first): Effect of biochar, clay substrate and manure application on water availability and tree-seedling performance in a sandy soil. Archives of Agronomy and Soil Science, 1-15. doi: 10.1080/03650340.2016.1249473.

Reiber C, Siemann M, Stock de Oliveira Souza K, Amorim Franchi G and Valle Zárate A (2016) Balancing extensive goat production and conservation interests in the Caatinga rangeland resource. Poster and abstract. Tropentag "Solidarity in a competing world—fair use of resources", September 18-21, 2016, Vienna, Austria.

Siemann M (2015) Contrasting farmer and expert knowledge for adaptation strategies to challenges in livestock production in Northeast Brazil. Master Thesis, Hohenheim Universität, Germany.

Stock de Oliveira Souza K, Reiber C, Siegmund-Schultze M, Valle Zárate A (2014) Resource use and resilience of goat production systems in Pernambuco, Northeast Brazil. Poster and abstract. Tropentag 'Bridging the gap between increasing knowledge and decreasing resources', September 17-19, 2014, Czech University of Life Sciences Prague, Prague, Czech Republic.

2.9 Fodder conservation techniques (leaflets)

For whom: Livestock keepers with cropland, Farmers' associations and cooperatives, Rural extension services, CODEVASF

From whom: Christoph Reiber (c_reiber@uni-hohenheim.de), Raphaela Santos da Costa von Gehlen, Mira Siemann

Problem: Scarcity of feeds during the dry season with negative impacts on animal reproduction, damage of the ecosystem through overuse of the local vegetation.

Solution: Forage conservation in the form of hay and silage.

Explanation: New strategies have to be implemented in order to provide enough feed to meet the needs of animals without degrading the ecosystem. Fodder production is a well-known strategy against feed shortage. Fodder conservation in the form of hay and silage is a promising strategy to increase fodder availability for the dry season, however, it is yet rarely practiced. Both technologies of hay and silage are presented in two leaflets in Portuguese, displaying advantages and disadvantages as well as helpful practical advice for their productions, which is explained in its different steps.

Feed shortages can be overcome through fodder conservation. *Photo: M Siegmund-Schultze*

The leaflets in Portuguese can be accessed here:

Hay: http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/text_files/flyer/LeafletHay_MS.pdf

Silage: http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/text_files/flyer/LeafletSilage_MS.pdf

2.10 Managing Caatinga sustainably: good for livestock, farmers, and the environment

For whom: Farmers' associations and cooperatives, Rural extension services, IPA, IF Sertão-PE, CODEVASF

From whom: Arne Cierjacks (arne.cierjacks@tu-berlin.de), Jarcilene Almeida-Cortez (jacortez@ufpe.br), Katharina Schulz (katschul@gmail.com), Déborah Oliveira (deborahalani@gmail.com), Maike Guschal (maike.guschal@gmail.com)

CONTEXT: Most of the Caatinga area is grazed by goats, sheep, and cattle. Especially during droughts, cacti and *"macambira"* are used as livestock fodder. In our study, we analyzed the effect of grazing on biodiversity (plants, amphibians, and reptiles) and biomass. As many areas of the Caatinga are already degraded, it is very important to adapt land management to prevent overgrazing and further decreases of the forest cover.

KEY MESSAGES:

- Reduce animal loads to about 1 goat per hectare.
- Use a rotating pasture system.
- If done at all, only cut small groups of *macambira* (< 6 x 5 m²).
- If possible, grow fodder plants or buy additional fodder by selling animals.
- Fence a third or half of water supply ponds (*açudes*).

RECOMMENDATIONS:

We recommend reducing the livestock numbers to about 1 goat or sheep per hectare. We also recommend a rotating pasture system. This will allow the Caatinga vegetation to recover and to produce new livestock fodder. Overall, forest cover has increased in the region between 2001 and 2012, but most of the forest areas are species-poor. Improved grazing management is an important requirement to foster the development of natural, diverse Caatinga dry forests in the long run.

Amphibians and reptiles are important for pest control as they are relevant predators of herbivorous insect groups which damage vegetation, e.g., the leaves of Caatinga trees. In our study, we found that large groups of *macambira* are especially important for amphibians and reptiles. Therefore, we recommend cutting only small groups of *macambira* (< 6 x 5 m²) and establishing patches with high connectivity among each other.

Usually, a high herbal biomass can be found surrounding water supply ponds (*"açudes"*), which is important as livestock fodder for the animals. Fencing a third or half of each açude leads to a more constant fodder supply throughout the year because one part can recover while the other part is grazed. At the same time, diversity of amphibian species is maintained as a diverse vegetation structure promotes a higher species number in this animal group. Still, especially during droughts, we recommend buying additional fodder by selling animals instead of cutting large numbers of cacti and *macambira* as these plants need a long time to regrow.

Further reading:

Access a leaflet in Portuguese on “Criação sustentável de rebanhos: manejo alimentar na Caatinga” on INNOVATE’s website page: http://www.innovate.tu-berlin.de/v_menue/materials_for_stakeholders/

or directly download the pdf file:

http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/text_files/flyer/cartilha_caprinocultura_INNOVATE_2016.pdf

Guschal M, Almeida-Cortez J, Ernst R (in preparation) Is water availability the most important factor for anuran diversity in the semiarid?

Guschal M, Almeida-Cortez J, Ernst R (in preparation) Natural key habitats increase the resilience of herpetofauna in a heavily impacted tropical dry forest (Caatinga) of northeastern Brazil.

Schulz C, Koch R, Cierjacks A, Kleinschmit B (2017) Land change and loss of landscape diversity at the Caatinga phytogeographical domain—Analysis of pattern-process relationships with MODIS land cover products (2001-2012). Journal of Arid Environments 136: 54-74. doi: 10.1016/j.jaridenv.2016.10.004.

Schulz K, Voigt K, Beusch C, Almeida-Cortez JS, Kowarik I, Walz A, Cierjacks A (2016) Grazing deteriorates the soil carbon stocks of Caatinga forest ecosystems in Brazil. Forest Ecology and Management 367: 62-70. doi: 10.1016/j.foreco.2016.02.011.

2.11 Effective nature conservation is needed to protect the Caatinga biome

For whom: Local residents, Schools, Municipal Departments of Education, Municipal Departments of the Environment, IF Sertão, NGOs, ICMBio, IBAMA, State Departments of the Environment

From whom: Arne Cierjacks (arne.cierjacks@tu-berlin.de); Jarcilene Almeida-Cortez (jacortez@ufpe.br); Katharina Schulz (katschul@gmail.com); Déborah Oliveira (deborahalani@gmail.com); Maike Guschal (maike.guschal@gmail.com)

Problem:

- Degradation of vast Caatinga areas.
- Species-rich areas are threatened by unsustainable land use.

Key messages:

- Respect protected areas: do not allow livestock into protected areas, do not remove plants.
- Plant trees (e.g., *umbuzeiro*).
- Do not cut *macambira*.
- Create a network of protected areas.
- Provide access to environmental education.
- Contract local people to patrol protected areas.

A mere signboard indicates a conservation area.
Photo: M Siegmund-Schultze

Caatinga protected by a fence.
Photo: M Siegmund-Schultze

- Cooperate with public institutions and national and international NGOs for funding.

Context: Many areas of the Caatinga are degraded through overgrazing and show low tree density and vegetation cover along with bad soils. Although forest cover has increased in the Caatinga region over the last decades, most forests are species-poor and contain only small numbers of the typical Caatinga species. Protected areas—these are where the typical species are conserved—are important because they represent source habitats for restoration of degraded or species-poor Caatinga.

Recommendations:
We recommend respecting protected areas, which means not allowing livestock to enter into protected areas, not cutting plants (e.g., *macambira*) and not hunting wild animals. Still, some trees, such as *umbuzeiro*, are not able to regenerate naturally. For these species, we recommend enrichment planting.

At the regional scale, it is important to create a network of protected areas which takes migration corridors of species into account. The zoning of protected areas with core, development, and usage zones should be implemented. Furthermore, protected areas should be patrolled by locally contracted people for biodiversity monitoring and control of illegal activities. To get funding for these activities, we suggest cooperations between public institutions and national and international NGOs. In the long run, environmental education of local people, especially young pupils and university students, is pivotal for effective nature conservation. Protected areas and their related institutions can play an important role in achieving a better awareness of the society for environmental issues.

Further reading:

A description of the flora and fauna of the protected area Serra da Canoa (conservation category “Estação Ecológica”) was prepared and provided to a local NGO (SOS Caatinga) in order to support the protection of the area in the future. You can access the manual in Portuguese here: http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/text_files/flyer/report_Serra_da_Canoa_INNOVATE.pdf

Pictures of the protected area can be found on the project’s Facebook at http://bit.ly/2fHBIdT.

A leaflet for practitioners in Portuguese language on “Conservação da natureza—áreas protegidas” can be downloaded from the INNOVATE website: http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/text_files/flyer/cartilha_reservas_INNOVATE_2016.pdf

Guschal M, Almeida-Cortez J, Ernst R (in preparation) Is water availability the most important factor for anuran diversity in the semiarid?

Guschal M, Almeida-Cortez J, Ernst R (in preparation) Natural key habitats increase the resilience of herpetofauna in a heavily impacted tropical dry forest (Caatinga) of northeastern Brazil.

Oliveira D et al (in preparation) How does the historical land use influence the population dynamics of *Spondias tuberosa* Arr. in Caatinga, Brazil.

Schulz C, Koch R, Cierjacks A, Kleinschmit B (2017) Land change and loss of landscape diversity at the Caatinga phytogeographical domain—Analysis of pattern-process relationships with MODIS land cover products (2001-2012). Journal of Arid Environments 136: 54-74. doi: 10.1016/j.jaridenv.2016.10.004.

Schulz K, Guschal M, Kowarik I, Almeida-Cortez J, Sampaio EVSB, Cierjacks A (submitted) Grazing, forest density, and carbon storage: towards a more sustainable land use in Caatinga dry forests of Brazil. Regional Environmental Change.

Schulz K, Guschal M, Kowarik I, Almeida-Cortez J, Sampaio EVSB, Cierjacks A (in preparation) Intense grazing reduces plant species diversity of Caatinga dry forests in northeastern Brazil.

2.12 Leaflet Caatinga: knowing, liking, conserving

For whom: Environmental institutions, Schools, Researchers, Municipal governments, Interested public

From whom: Jarcilene Almeida-Cortez (cortez_jarcy@yahoo.com), Fernanda Meira Tavares, Bárbara Laine Ribeiro da Silva, Maria Olívia Cano, Rita de Cassia Araújo Pereira, Arne Cierjacks

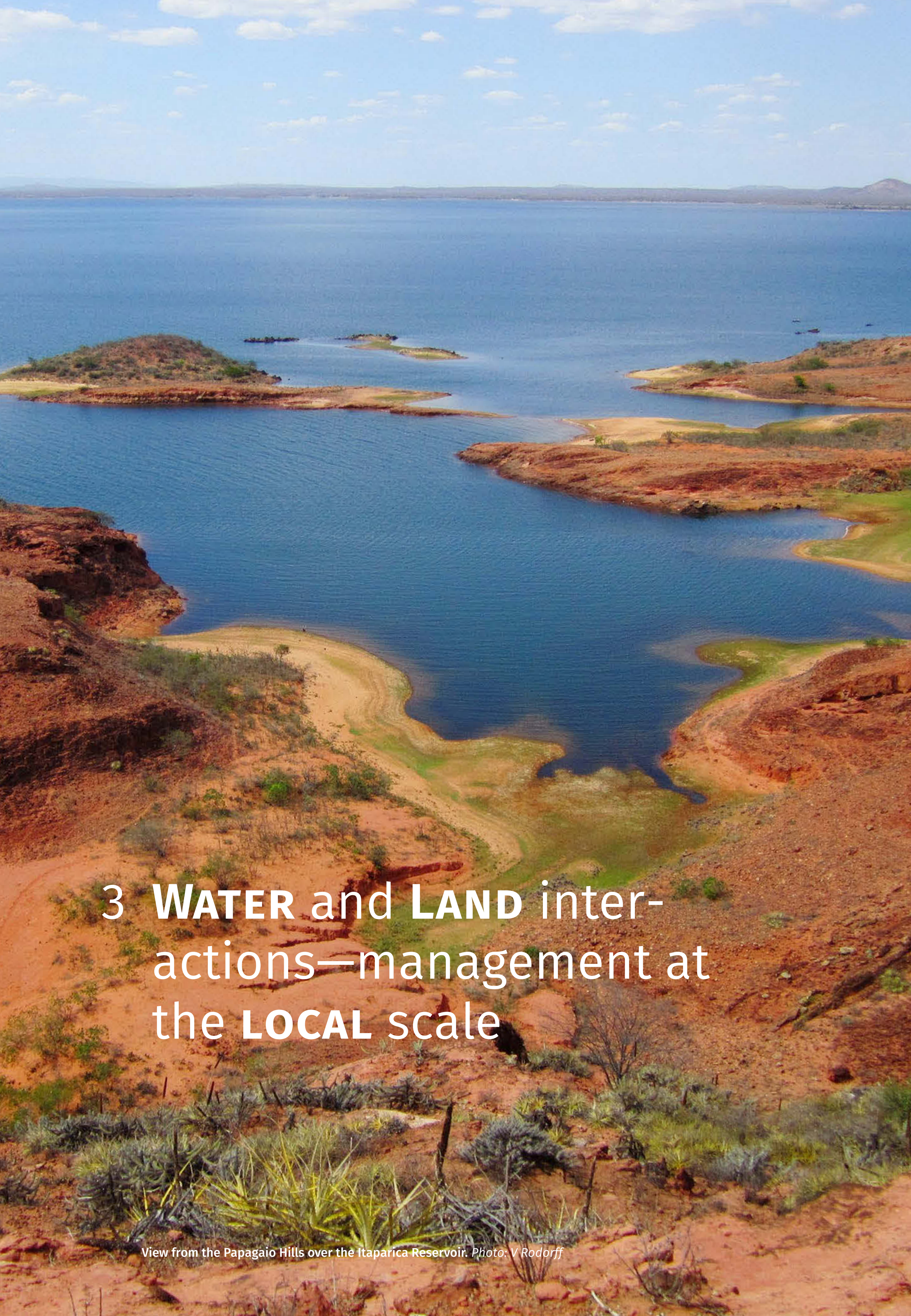
The leaflet: *"Caatinga—conhecer para preservar"* (knowing in order to preserve) explains general features and characteristic plants of the Caatinga biome as well as its role for the local population. While presenting the Caatinga's beauty in text and photos, which provide incentives to appreciate nature in general, the leaflet aims at promoting and discussing the necessity of sustainable use of tropical dry forest resources. The leaflet has been distributed during stakeholder education days in 2014 and workshops in 2016.

You can find a copy through the following link:

http://www.innovate.tu-berlin.de/v-menue/subprojects/sp4_biodiversity_and_ecosystem_services/sp4-rm1_plant_biodiversity/parameter/en/ (webpage in English, leaflet in Portuguese)

or download directly the pdf file: http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/text_files/flyer/cartilha_caatinga_1INNOVATE.pdf

A Caatinga herb: *Portulaca* sp. *Photo: C Beusch*



3 WATER and LAND interactions—management at the LOCAL scale

View from the Papagaio Hills over the Itaparica Reservoir. *Photo: V Rodorff*

3.1 Sediment retention dikes promote local storage of water

For whom: Rural communities, Rural land owners, Rural extension services, IPA, EMBRAPA, Institutions of higher education, Municipal government departments, CODEVASF, Watershed committees, NGOs

From whom: Pierson Barretto (pierson.barretto@gmail.com)

CONTEXT: Although the region around the Itacuruba Reservoir mostly has a relatively flat topography, soils are nonetheless very sensitive to erosion. The climate is semi-arid; most streams in the semi-arid region are intermittent or even ephemeral, only carrying water shortly after rainfall events. Rainfall averages are about 400 mm annually, though in drought years rainfall may not even reach 100 mm (Figure 2 on page 16), while 20 % to 50 % of total annual rainfall occurs in periods of a few hours, causing floods. In normal years the rainfall amount is substantial, though it remains little used.

KEY MESSAGES: Sediment retention dikes, whose construction only requires labor, reduce erosion after rainfall events. They contribute to water availability and lead to improved soil water conditions locally.

EXPLANATION: The dikes can accumulate up to 30 cm of sediment deposition in 2 years. The dikes reduce flood speed and erosion, increasing water infiltration into the soil, and reducing the amount of sediments that end up in lakes and reservoirs. This contributes to improving water quality, while also increasing the availability of water for the environment and economic uses. Under very conducive conditions, water stored underneath can be used for watering animals or irrigating crops through water pipes. The improved soil water conditions near dikes allow grass and trees to grow, which can be grazed and browsed by livestock and can sustain beekeeping.

The construction: People determine the location of crescent-shaped stone walls to be placed transverse to the stream flow. The stones are stacked without using cement. This can be organized as a community activity, to be realized within one day. A sediment marker is placed to monitor the development of sediment retention.

The dike is a permeable wall built in an ephemeral stream. *Photo: P Barretto*

Just stones and labor are needed to build one. *Photo: P Barretto*

Who pays? The activity is based on labor input only. The material—the stones—are collected as nearby as possible. The existence of stones is a prerequisite.

Origin: Arthur Padilha conceived the technique (mentioned in Brazilian Agenda 21, 1999) by observing how nature works in his farm in Afogados da Ingazeira (Pernambuco, Brazil). The pictures show an application of the technique in Itacuruba, a municipality in a drier part of the same state.

3.2 Land and water governance are suffering from a lack of cooperation between the local sectors

For whom: Municipal government departments, Local watershed committees, Forum of the Territory, Rural extension services, Farmers' Union, CODEVASF, State Government Departments, EMBRAPA, IPA

From whom: Verena Rodorff (verena.rodorff@tu-berlin.de), Marianna Siegmund-Schultze (m.siegmund-schultze@tu-berlin.de)

Problem: Little integration of the land and water sectors in planning processes.

Context: The Itaparica Region (here: Pernambucan municipalities on the north side of the Itaparica Reservoir) shows a discontinuity of actors, which frequently have overlapping roles or responsibilities. Often, there is a lack of consistent and continuous communication between the actors of institutions with the same or similar ranges of action, often not coordinating regular activities, that is to say, not allowing functional governance. Recurrently, the local population is not adequately informed and a format for environmental education does not exist. Furthermore, there are no follow-up measures for past and present large infrastructure projects, such as the Itaparica Dam and the affected uses and users of water and terrestrial resources. There is also a lack of regional and sectorial developmental planning, especially concerning irrigation and dry farming projects. Adding to this is an unequal distribution of the territory. The irrigation projects show problems of soil salinization and soil degradation in the irrigated agricultural areas. More than 25 years after the dam's construction,

Discussions at the local scale are a necessary element of governance.
Photo: L Steinmetz

Conflicts need governance: Caatinga wood is a highly valued fuel, however standing trees are also needed.
Photo: M Siegmund-Schultze

close dependencies still exist between the resettled farmers and the electric power operator, respectively the CODEVASF today, which hamper the access to markets and services for farmers. There are significant social differences between the irrigation schemes. Furthermore, water is distributed unequally due to a lack of maintenance and old infrastructure as well as unmonitored water withdrawal according to the demographic growth within—and immigration into—the projects due to lack of access to water outside the irrigation schemes.

Obstacles to sustainable development:

1. Some municipalities are weak in decision-making and in planning on the municipal and inter-municipal level. Poor enforcement of regulations. Lack of planning the in the urban space and the urban-rural interface, not taking population growth into account.

Examples: Incursions into permanent preservation areas ("APP") and legal reserves without consequences; informal spatial expansions of public irrigation schemes.

2. Different actors work in parallel, not using synergies, and communication among each other is rather limited. Lack of a joint strategy among responsible actors and the municipality, respectively the subcontractors. The subcontractors are often the direct contact persons for the resource users. These companies are intermittent players, although some of the personnel remain after a contract changes. The selection of the subcontractors follows economic reasons and does not strive for efficacy and quality of their services.

Example: The extension service is organized according to type of farmer (e.g., established farmer, farmer resettled by INCRA, farmer resettled by CHESF) with different responsible institutions.

3. Confusion about rights and responsibilities of open spaces and territories. The towns and the "islands" formed by the irrigation schemes can be considered highly vulnerable areas, especially due to immigration and their dynamic structures. Land titles are missing, and necessary to be eligible for credits.

Examples: The Apolônio Sales irrigation scheme is almost an urban district due to its proximity to the urban center. The irrigation schemes attract farmers beyond the initially calculated number of farmers with privileged access to water.

Recommendations:

1. Strategic planning of development; long-term and adaptive planning with follow-up studies.

2. Establishing plans for regional and local development, guaranteeing participation processes for stakeholders.

Explanation: It is recommended to develop a document integrating guidance and collective objectives, as well as prepare plans for agricultural and rural development and other planning instruments. These should take into account urban and rural growth and development. The Strategic Environmental Assessment (SEA) supports a sustainable and participatory planning during the planning phase.

Who gets the water? Drinking water distribution by truck is still a common—and costly—practice. *Photo: M Siegmund-Schultze*

3. Implementation of river basin committees of tributary rivers.

Explanation: There is need for decentralized and participatory institutions at the local scale, which network with the river basin committee of the main river—here the São Francisco River. The municipality has to become a more responsible organ, aligned with unions, associations and other relevant institutions in order to jointly develop strategies, plans and programs. In order to develop a culture of sustainable and adaptive regional management and governance, the municipality must address both successes and past mistakes.

4. Advance the independence of irrigation schemes through the issuance of land titles.

Explanation: It is recommended to incentivize the creation of cooperatives and associations to strengthen the agricultural sector. The lack of land ownership title has to be solved in order to, among others, allow the access to credits by the farmers.

5. Establish a social discourse about the development of the irrigation schemes.

Explanation: A social dialogue is necessary to know, negotiate and define the expectations and responsibilities of each involved group of actors. The objective would be to jointly draft a strategic document and define the task of each one, including significant milestones, monitoring and adjustment mechanisms.

6. Improve the access to information about municipal and regional processes, including farmers' access to research results; establish supporting networks (websites, trainings and workshops).

Explanation: Existing plans and programs are often not known or used. Similarly, information relevant for farmers barely reaches its target group. It is important to build up an online database and also to publish the information in other communication media, as well as reinforce the civil society's participation in the evaluation and construction of new plans and projects. The documentation (for example, minutes, resolutions, and contracts) and plans have to be distributed and stay available for all in an online platform (similar to the CBHSF's website).

Further reading:

Rodorff V, Araújo GJF, Gomes ETA, Köppel J, Siegmund-Schultze M, Sobral MC (2013) Driving forces and barriers for a sustainable management of the Itaparica reservoir region—basic milestones towards a constellation analysis. In: Gunkel G., Silva J.A.A. de, Sobral M. do C. (Eds) 2013—Sustainable Management of Water and Land in Semiarid Areas. Editora Universitária UFPE, Recife, pp 254-268.

Rodorff V, Siegmund-Schultze M, Gottwald S, Meckel U, Sobral MC (2014) Effektivität von Staudamm-„Follow-up“-Programmen—25 Jahre nach dem Bau des Itaparica-Reservoirs in Nordost-Brasilien. UVP-report 27(4+5): 216-223.

Rodorff V, Siegmund-Schultze M, Gottwald S, Sobral MC, Köppel J (2015) Eficácia de programas de acompanhamento (follow-up).—25 anos após a construção do reservatório de Itaparica no Nordeste brasileiro. In: Theodoro HD, Matos F (Eds.) 2015—Governança e recursos hídricos: experiências nacionais e internacionais de gestão. D'Plácido, Belo Horizonte, Brazil, pp 199-218.

Rodorff V, Siegmund-Schultze M, Köppel J, Gomes ETA (2015) Governança da bacia hidrográfica do Rio São Francisco: desafios de escala sob olhares inter e transdisciplinares. Revista Brasileira de Ciências Ambientais 36: 19-44. doi: 10.5327/Z2176-947820151003.

3.3 Cartographic material of Petrolândia

For whom: Municipal government departments (e.g., Agriculture, Fisheries, Planning, Tourism, Environment, Public Health), Local NGOs, Interested public

From whom: Sarah Gottwald (sarahgottwald@posteo.de), Marianna Siegmund-Schultze

Problem: Good cartographic material of the study region is still scarce.

Our contribution: We developed the municipal map of Petrolândia, which is meant to pave the way for a more detailed spatial assessment as a basis for participatory planning at the municipal scale. The map can be used to debate about and delimitate areas in planning processes. At a greater scale, the municipal map can contribute to a better understanding of a remote municipality within the state of Pernambuco, within the sub-basin G13, or within the large São Francisco watershed, respectively its Sub-Middle region.

Context: Our study in 2014 showed that few people were able to use maps without difficulty. Many were not familiar with maps and had difficulty locating many locations on them. Printed maps are still very relevant due to limited internet capacities. The CPRH (environmental agency of the state of Pernambuco) recently distributed maps with different themes to all municipalities of Pernambuco within an atlas. Likewise, CPRH recently launched an online GIS-system: http://sigcabure.cprh.pe.gov.br/. The system allows the visualization of a number of themes, such as indigenous and official settlement areas, agroecological and ecological-economic zoning, hydrology, conservation units and biodiversity conservation relevancy, and waste disposal.

The flattened map of Petrolândia can be downloaded from this web page: http://www.innovate.tu-berlin.de/v-menue/subprojetos/sp7_abordagem_para_apoio_em_decisoes/sp7-rm1_abordagem_de_apoio_a_decisao/

Further reading:

Gottwald S (2015) The potential of a public participation GIS (PPGIS) based Ecosystem Service Assessment—a Case Study in Petrolândia, Brazil. Master Thesis, Technische Universität Berlin, Germany.

3.4 Practicing and mainstreaming environmental education

For whom: Fishermen's communities, Farmers' associations and cooperatives, Municipal government departments, Local schools, NGOs, Rural extension services, CODEVASF, Institutions of higher education

From whom: Gérsica Nogueira da Silva (gersicamns@hotmail.com)

Problem:

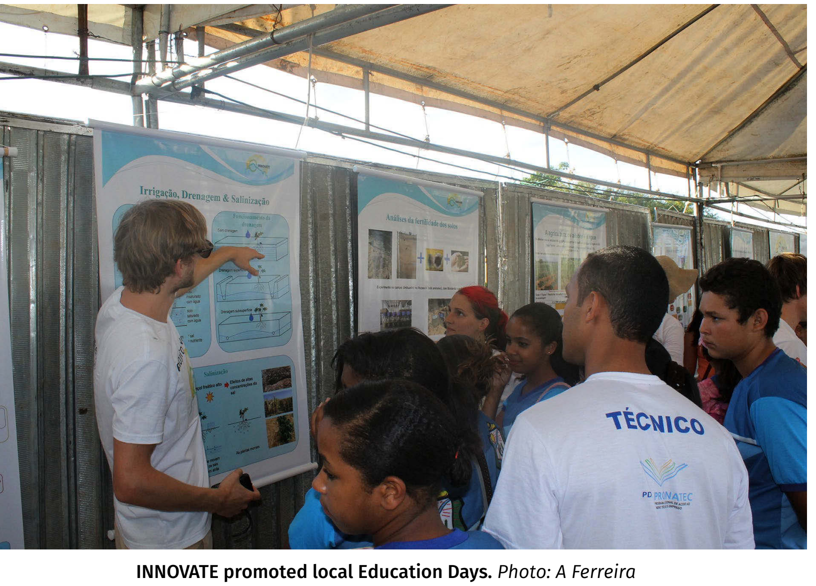
- Many local residents are not aware of the relationship between their actions and the environment.
- There is a lack of knowledge about the environment, and the environment undervalued.

Key messages: Socio-environmental awareness needs to be raised, including the ecological aspects of local production systems.

Explanation: All rural economic activities carried out in the region—principally agriculture, fishery and aquaculture—have externalities. These include the excessive use of water, fertilizers and feeds, and the inadequate disposal of solid waste.

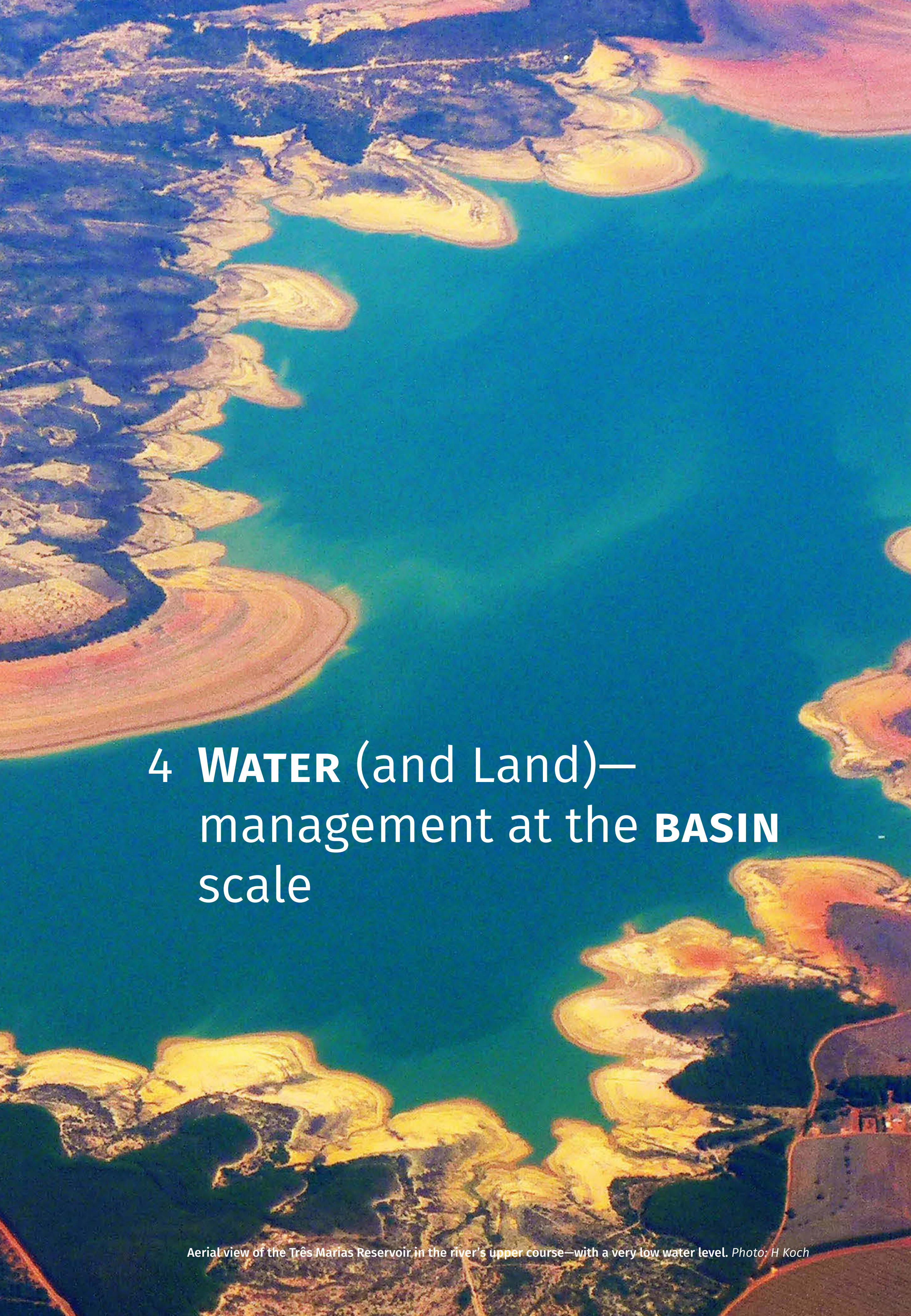
Further reading:

As an example, the booklet "Education Days" can be downloaded from the project's website: http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/text_files/Books/Cartilha_Dias_de_Educacao_INNOVATE.pdf



INNOVATE promoted local Education Days. *Photo: A Ferreira*

4 WATER (and Land)—management at the BASIN scale



Aerial view of the Três Marias Reservoir in the river's upper course—with a very low water level. *Photo: H Koch*

4.1 Adjust the closed fishing season

For whom: IBAMA, MPA, Fishermen's communities, CHESF, Municipal government departments, CPRH, ANA, SPU, CODEVASF, Institutions of higher education

From whom: Gérsica Nogueira da Silva (gersicamns@hotmail.com)

Key message: The closed fishing season, which safeguards fish reproduction, needs revision.

Context: Studies indicate that damming the São Francisco River and managing the cascade of reservoirs have caused changes in the reproduction cycles of fish, especially of migratory species, which swim upstream to reproduce.

Our study: An exploratory case study on native fish species in the Itaprica Reservoir confirmed the hypothesis of different reproduction peaks in different regions of the São Francisco River Basin. In the environmental survey undertaken together with artisanal fishermen, 69 % of interviewees confirmed in 2014 that, for the previous four years, the closed season did not match with the observed fish reproduction periods. This is probably due to the fluctuations in the rainy seasons and the control of the river's flow related to reservoir management.

An endemic fish species—migratory and today rare.
Photo: G Nogueira da Silva

Recommendations:

1. Reevaluation of the closed season, with a focus on endemic and migratory species. It is necessary to discuss the possibility of different time periods according to the physiographic regions, considering differences between the basin regions and the influence of environmental factors, such as reproduction triggers (rainy season and alterations in the water flow).

2. Test and determine mitigating measures for native species, such as: development of fish re-stocking programs in the São Francisco River Basin, delimitation of ecological water flow for migratory species and evaluation of flow reduction on fish reproduction during the closed season.

Further reading:

Nogueira da Silva GM, Carvalho RMC, El-Deir ACA, Sobral MC, Siegmund-Schultze M (submitted 2016) Artisanal fisheries of the Itaparica reservoir, São Francisco River, Brazil: socioeconomic profile, environmental dynamics, and management recommendations. Regional Environmental Change.

4.2 Towards an interlinked electricity mixture: complement hydropower by other renewables

For whom: Watershed committees (e.g., CBHSF), Executive agencies of watershed committees, Hydropower plant operators (e.g., CHESF, CEMIG), ANA, ONS, ANEEL, CODEVASF, State departments, Federal ministries, EPE, CNPE, Institutions of higher education

From whom: Hagen Koch (hagen.koch@pik-potsdam.de), Fred F. Hattermann, Johann Köppel (johann.koeppel@tu-berlin.de), José Roberto Gonçalves de Azevedo (robdosport@hotmail.com)

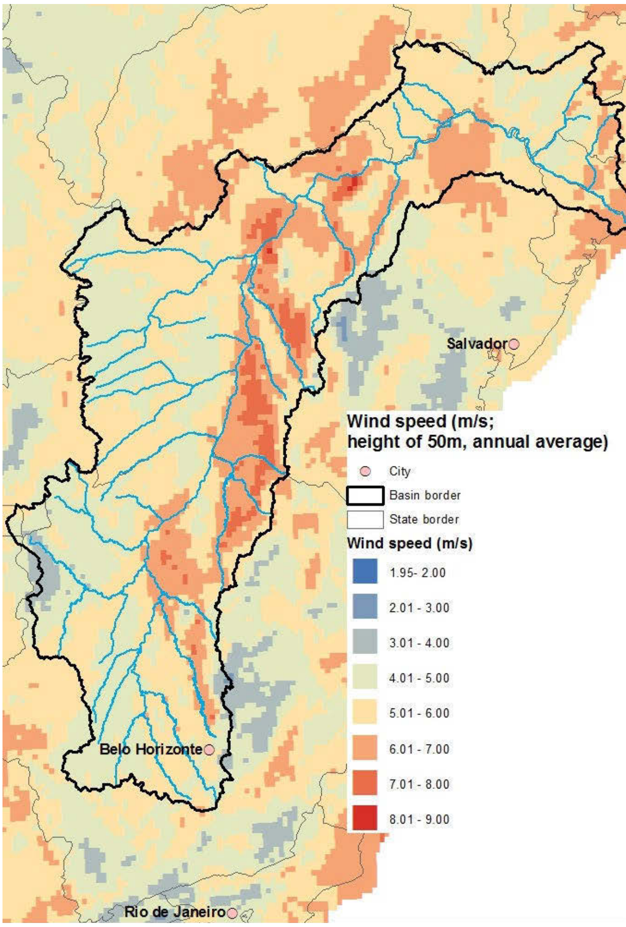
Problem: Climate change may substantially decrease the water available for hydropower; consequently, hydroelectricity generation will decrease.

Key messages:

- Balance water deficits and related losses in hydroelectricity generation by wind and solar energy.
- Planned hydropower plants (Pedra Branca and Riacho Seco) would increase annual generation by just 4 %.

Explanation: Hydropower generation is strongly affected by climate change. Under observed climatic conditions the annual hydropower generation in the São Francisco River Basin is between 40,000 and 50,000 GWh per year (mean value of about 45,000 GWh per year). Worldwide, researchers are trying to understand patterns of climate change and are developing and testing climate change scenarios for future changes. These scenarios differ; they show possible projections based on currently available information. In the so-called "dry future climate scenarios" hydropower generation will decrease (-13 %) to a mean annual value of approximately 39,900 GWh per year (time period 2021–2050 as a basis, an approximate value). In the so-called "wet future climate scenarios" hydropower generation will increase (+11 %) to a mean annual value of approximately 50,550 GWh per year.

In the wet scenarios higher flows in the rainy season cause higher hydropower generation, while in the dry season generation can decline slightly. Reservoir management could be adapted to these changing climate conditions by reducing discharges in the rainy season to store more water for the dry



Data source: CEPEL 2005 (http://www.cepel.br)
Prepared by H Koch
Mean annual wind speed at height of 50 m in the São Francisco River Basin

Blade for a wind turbine. *Photo: M Siegmund-Schultze*

season (Hattermann et al. submitted). In the dry scenarios reservoir management could be adapted by applying operational rules, as done during the current drought: minimum discharges from Três Marias Reservoir for the Upper São Francisco River Basin and the Sobradinho and Itaparica Reservoirs for the Sub-Middle and Lower São Francisco River Basin have been much lower compared to the standard operating rules. Also during wetter years, lower minimum discharges need to be accepted in order to fill the reservoirs and store water for potential following drought periods (Hattermann et al. submitted).

The loss of electricity generation due to lower discharges, especially in the "dry future climate scenarios", could be balanced by other renewable sources, e.g., wind energy. This diversification is already taking place, e.g., the installed wind power generation capacity in Brazil's Northeast has increased from zero to approximately 7,200 MW over the last ten years and a further increase to approximately 15,600 MW by 2020 is planned. However, it is necessary to interconnect hydropower and wind power generation (Koch et al. submitted), as up to now only water can be stored, while wind power generation depends entirely on current weather conditions.

The installation of new hydropower plants (we analyzed the planned reservoirs Pedra Branca with an installed capacity 320 MW and Riacho Seco with an installed capacity 240 MW) in the Sub-Middle São Francisco River Basin would increase annual hydropower generation by approximately 4 % (Koch et al. 2015). The new reservoirs, located in the semi-arid region of the São Francisco River Basin, would incur evaporation losses (although small when compared to those from the Sobradinho and Itaparica Reservoirs) and reduce water availability downstream. They also would imply a further fragmentation of the São Francisco main river. Regarding evaporation losses, it would instead be better to place new reservoirs in the Upper São Francisco River Basin, if new reservoirs are added at all.

Further reading:

Hattermann FF, Venohr M, Liersch S, Silva ALC, de Azevedo JRG, Matta E, Hinkelmann R, Fischer P, Koch H (submitted 2017) Climate and land use change impacts on the water-energy-food nexus in the semi-arid northeast of Brazil. Regional Environmental Change.

Koch H, Liersch S, Azevedo JRG, Silva ALC, Hattermann FF (2015) Modelagem da disponibilidade e do manejo da água na bacia hidrográfica do rio São Francisco. XXI Simpósio Brasileiro de Recursos Hídricos; 22-27 November 2015; Brasília/Brazil.

Koch H, Silva ALC, Azevedo JRG, Souza WM, Köppel J, Souza Júnior CB, Barros AML, Hattermann FF (submitted 2016) Integrated hydro- and wind power generation: a game changer towards environmental flow in the Sub-Middle and Lower São Francisco river basin? Regional Environmental Change.

4.3 Prepare for (temporarily) limited water supply

For whom: Watershed committees (e.g., CBHSF), Executive agencies of watershed committees, Hydropower plant operators (e.g., CHESF, CEMIG), ANA, ONS, CODEVASF, State departments, Federal ministries, Institutions of higher education

From whom: Hagen Koch (hagen.koch@pik-potsdam.de), José Roberto Gonçalves de Azevedo (robdosport@hotmail.com), Fred F. Hattermann, Gerald Souza da Silva (geraldsouzadasilva@gmail.com), Ana Lígia Chaves

Problem: If the climate becomes drier, then water supply will strongly decrease. Even if, on average, the total long-term precipitation does not decrease, there will still be longer drought periods in the future.

Key messages:

- Account for effects of climate change in the planning processes.
- Use more efficient irrigation systems and minimize losses from channels.
- Improve the integration of agricultural development projects with other water users.
- Restrict irrigated sugarcane production in semi-arid areas.
- Decrease water rights during drought periods and monitor the process.
- Reuse drainage water from irrigated agriculture and water from sanitation.

Explanation: Assuming a dry future climate, water supply will decrease markedly. Even in the wet future scenarios, during drought periods water supply will be low (Koch et al. 2015). Therefore, water supply will constrain expansion of irrigated areas, and, in the case of expansion, water shortages will decrease agricultural production. Especially irrigated sugarcane production is problematic as it requires huge amounts of water from surface bodies or groundwater. The use of more efficient irrigation systems, e.g., drip irrigation, and better integration of agricultural development projects with other water users is recommended, e.g., hydropower generation and the water diversion project.

Further reading:

Koch H, Liersch S, Azevedo JRG, Silva ALC, Hattermann FF (2015) Modelagem da disponibilidade e do manejo da água na bacia hidrográfica do rio São Francisco. XXI Simpósio Brasileiro de Recursos Hídricos; 22-27 November 2015; Brasília, Brazil.

4.4 Safeguarding nature and people: implement an environmental flow in reservoir management

For whom: Watershed committees (e.g., CBHSF), Executive agencies of watershed committees, Hydropower plant operators (e.g., CHESF, CEMIG), ANA, ONS, CODEVASF, State departments, Federal ministries, Institutions of higher education, IBAMA, MPA, fishermen's communities, CPRH, SPU

From whom: Hagen Koch (hagen.koch@pik-potsdam.de), José Roberto Gonçalves de Azevedo (robdosport@hotmail.com), Fred F. Hattermann, Florian Selge, Marianna Siegmund-Schultze (m.siegmund-schultze@tu-berlin.de), Gérsica Nogueira da Silva (gersicamns@hotmail.com)

PROBLEM:

- The natural annual cycle of the river's flow regime is flattened by reservoir management.
- The reservoir management focuses on hydropower generation first, not sufficiently accounting for the needs of the environment and the (traditional) riverside users.

KEY MESSAGES:

- Align hydropower generation with climatic conditions.
- Maintain natural flow rate patterns.
- Develop minimum discharges for all river stretches.
- The modified management should be monitored and sustained by research.

EXPLANATION: The short-term variations in flow rates negatively affect water availability, water quality (less dilution) and edge effects (macrophyte exposure and erosion). For biological processes, it is important to maintain peak flows in the rainy season, mimicking the natural environment.

A more environmentally-oriented reservoir management is possible, however, it will lead to reduced hydropower generation (Koch et al. 2015a,b). We exemplarily analyzed reservoir management rules for the Sobradinho and Itaparica Reservoirs, focusing on the following selected environmental aspects, which we compared to the standard management rules: i) environmental discharge (*"hidrogramas ambientais"*), ii) reduced reservoir capacity, and iii) reduced daily water level variation (maximum of 5 cm/day). The management rule for reduced daily water level variation in reservoirs (iii) turned out to be the most flexible, guaranteeing hydropower generation in the dry season, while also considering the ecology of the reservoirs and rivers, and slightly reducing evaporation sums. The study exemplarily used environmentally-oriented expectations of stakeholders and showed the

The dam and hydroelectric power station of the Sobradinho Reservoir.
Photo: H Koch

outcome of such decisions. Values derived in the study should not be mistaken as exact recommendations but rather trigger simulation-based decision-making. Aligning hydropower generation with climatic conditions (dry/wet season, dry/wet years) appears being mandatory. Maintaining natural flow rates is needed to secure fauna and flora in the river and the littoral zones.

Ecological flows (minimum discharges) are needed for all river stretches to guarantee water quantity and quality as well as the aquatic ecosystem services. Basing estimations of minimum discharges (*"hidrogramas ambientais"*) on past observations only will not be sufficient anymore under climate change. Ecological flows should be based on ecosystem functions but also consider water uses; they need to be very context-specific. Changes in water management or increasing water withdrawals upstream of or from reservoirs (e.g., for additional agricultural irrigation schemes according to CODEVASF plans or the water diversion project) can heavily decrease the inflow volumes to the studied reservoirs. The loss in hydropower generation could be balanced by, e.g., more wind energy (Koch et al. 2016, submitted).

Testing the modified reservoir management has to take into account a number of different and partly contradicting expectations and goals. The monitoring of changes in reservoir management has to consider these different aspirations. An adaptive participatory approach to reservoir management could flexibly respond to changing frame conditions. Inter- and transdisciplinary research should accompany the adaptation process.

Further reading:

Koch H, Selge F, Azevedo JRG, Silva GS, Siegmund-Schultze M, Hattermann FF (2015a) Incluindo aspectos ecológicos na gestão de reservatórios: opções de gestão no Submédio e Baixo do rio São Francisco. XXI Simpósio Brasileiro de Recursos Hídricos; 22–27 November 2015, Brasília, Brazil.

Koch H, Selge F, Azevedo JRG, Silva GS, Siegmund-Schultze M, Hattermann FF (2015b) Towards a more ecologically-oriented reservoir management: Testing release rules for the sub-middle and lower São Francisco river basin. INNOVATE Discussion-Paper. Available at the homepage of the Comitê da Bacia Hidrográfica do Rio São Francisco (CBHSF): http://cbhsaofrancisco.org.br/projeto-innovate-conclui-estudos-no-submedio-e-baixo-sao-francisco/ or download it from the INNOVATE website: http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/text_files/flyer/INNOVATE_DiscussionPaper_EcologicalAspectsReservoirManagement-1.pdf.

Koch H, Silva ALC, Azevedo JRG, Souza WM, Köppel J, Souza Júnior CB, Hattermann FF (2016) Geração integrada de eletricidade como alternativa para melhoria da vazão ecológica no Submédio e Baixo da bacia do Rio São Francisco. I Simpósio da Bacia Hidrográfica do Rio São Francisco, 05–09 June 2016, Juazeiro, Brazil.

Koch H, Silva ALC, Azevedo JRG, Souza WM, Köppel J, Souza Júnior CB, Barros AML, Hattermann FF (submitted 2016) Integrated hydro- and wind power generation: a game changer towards environmental flow in the Sub-Middle and Lower São Francisco river basin? Regional Environmental Change.

4.5 Consolidate the registry of water rights (*"outorgas"*)

For whom: State water agencies, ANA, Watershed committees (e.g., CBHSF), Executive agencies of watershed committees, Hydropower plant operators (e.g., CHESF, CEMIG), ONS, CODEVASF, State departments, Federal ministries, Institutions of higher education

From whom: Hagen Koch (hagen.koch@pik-potsdam.de), Gerald Souza da Silva (geraldsouzadasilva@gmail.com), José Roberto Gonçalves de Azevedo (robdosport@hotmail.com)

PROBLEM: The information on water rights (*"outorgas"*) is fragmented.

KEY MESSAGES:

- Consolidate the inventory of all water withdrawals.
- Set clear rules for withdrawal restrictions during drought and monitor effectively.

EXPLANATION: Registration of all users is aimed for but not realized at this point. An inventory of all water withdrawals is necessary (incl. small and up till now non-registered users), including water rights (*"outorgas"*) issued by ANA and those issued by the Brazilian states. The water rights should stipulate clear rules about restrictions during drought periods, and how restrictions are monitored (drought plan including prioritization and oversight mechanism).

Private water withdrawal from the Itaparica Reservoir.
Photo: M Siegmund-Schultze

FURTHER READING:

Silva GS, Moraes MMGA, Silva ACS (2014) Delimitação das áreas irrigadas no trecho do Submédio do rio São Francisco. In: XII Simpósio de Recursos Hidrícos do Nordeste. 4-7 November 2014, Natal-RN, Brazil.

4.6 Rethinking the controversial water diversion project *("transposição")*

For whom: Watershed committees (e.g., CBHSF), Executive agencies of watershed committees, NGOs, Hydropower plant operators (e.g., CHESF, CEMIG), CODEVASF, ANA, CNRH, ONS, State departments, Federal ministries, Institutions of higher education

From whom: Hagen Koch (hagen.koch@pik-potsdam.de), Gerald Souza da Silva, Gérsica Nogueira da Silva (gersicamns@hotmail.com), Marianna Siegmund-Schultze (m.siegmund-schultze@tu-berlin.de), Elena Matta (elena.matta@wahyd.tu-berlin.de), Fred F. Hattermann, José Roberto Gonçalves de Azevedo (robdosport@hotmail.com)

Problem: The water withdrawal for the diversion project will clearly reduce the water available to other water users.

Key messages:

- Water supply cannot be guaranteed all the time.
- The future management of the diversion project has to account for its different social and ecological side effects.

Explanation: The prospective effects of the changed flow conditions for the local residents, for instance artisanal fishermen, were not sufficiently evaluated (or at least communicated) in the planning phase of the diversion project. Many fishermen believe that there could be some negative impact on small-scale fishing. Fishing communities are present in the area of the water withdrawal for the eastern channel system, including in a settlement in the irrigation scheme Icó-Mandantes, with approximately 30 fishing families.

Depending on the water levels and availability—during several consecutive drought years severely reduced in the Itaparica Reservoir—the flow circulation in the Icó-Mandantes Bay can be altered. Increased velocity at the withdrawal point could be one change. It is also important to evaluate the water quality along with the resuspension of materials in the sediment, as well as the monitoring of fish and other aquatic organisms that can be transported to other reservoirs, possibly introducing new, and sometimes unwanted, species. First exploratory modeling of the hydrodynamics suggests that the future water withdrawal from the Icó-Mandantes Bay might affect the mixing of water at the local scale. This could be considered, however, as a positive side effect on water quality as pollution will get diluted faster. Further impacts on fish are however not yet known.

The withdrawals for both channels of the water diversion project were simulated (upstream of Itaparica and directly from

The first water withdrawal and pumping station of the water diversion project (eastern channel system, Itaparica Reservoir). *Photo: M Siegmund-Schultze*

The channel that brings water from the Itaparica Reservoir to the first pumping station of the water diversion project (eastern channel system).
Photo: M Siegmund-Schultze

all times (Koch et al. 2015). The changes in water level and volume at the local scale, i.e., Icó-Mandantes Bay, will be barely perceivable since the reservoir will quickly level out such variations, even for the planned maximum withdrawal under dry conditions. Flow velocities will increase near the intake, but momentum in the reservoir main stream is not influenced (Matta et al. 2016). Areas where abstraction pumps are located, e.g., Icó-Mandantes

Itaparica Reservoir in the Icó-Mandantes Bay) in models accounting for future land use and climate change scenarios. Assuming a dry future climate with low water supply, often the channels will only be able to withdraw the allowed minimum water quantities—or even less. Also in the wet future scenarios long drought periods will occur and the water supply cannot be guaranteed at

Bay, should be specifically considered for water-land conservation measures to reduce eutrophication processes to meet stakeholder demands, in particular to secure water quality for drinking water extraction. The results are first estimations, as the management regime of the two channel systems of the water diversion project is not yet disclosed.

Further reading:

Koch H, Liersch S, Azevedo JRG, Silva ALC, Hattermann FF (2015) Modelagem da disponibilidade e do manejo da água na bacia hidrográfica do rio São Francisco. XXI Simpósio Brasileiro de Recursos Hídricos; 22-27 November 2015, Brasília, Brazil.

Matta E, Koch H, Selge F, Simshäuser MN, Rossiter K, Nogueira da Silva GM, Gunkel G, Hinkelmann R (submitted 2016) High resolution two-dimensional modeling of flow and transport in Icó-Mandantes bay to support water management. Regional Environmental Change.

Siegmund-Schultze M, Köppel J, Sobral MC (submitted 2016) Unraveling the water and land nexus by inter- and transdisciplinary research: overall findings on sustainable land management in a semi-arid watershed in Brazil's Northeast. Regional Environmental Change.

4.7 Minimize the emissions of greenhouse gases (GHG)

For whom: Watershed committees (e.g., CBHSF), Executive agencies of watershed committees, Hydropower plant operators (e.g., CHESF, CEMIG), ANA, CODEVASF, ONS, State departments, Federal ministries, Institutions of higher education

From whom: Maricela Rodriguez (m.rodriguez@igb-berlin.de), Peter Casper (pc@igb-berlin.de), Hagen Koch (hagen.koch@pik-potsdam.de)

PROBLEM:

- GHG emissions from (tropical) reservoirs contribute to climate change.
- Eutrophication of reservoirs increases GHG emissions (mainly methane).

KEY MESSAGES: Reservoir management has strong effects on GHG emissions.

EXPLANATION: The main sources of GHG emissions (mainly of methane—CH_4 and carbon dioxide—CO_2) from reservoirs is the water body covering original riverbed and the flooded land; in hydroelectric reservoirs GHGs are also released through turbine passage of the water enriched with gases. In the Itaparica Reservoir, only a small share is related to the hydropower plant (turbine passage and spill water discharge). Within the water body, shallower areas (< 5 m depth) are important sources because here ebullition (bubble release) leads to increased methane release. With increasing nutrient supply (eutrophication) and temperature (climate change) rates of GHG emissions will increase. The Itaparica Reservoir emits in total $2.3 \times 10^5 \pm 7.45 \times 10^4$ t C/y in form of the gases CH_4 and CO_3 or $1.33 \times 10^6 \pm 4.5 \times 10^5$ t CO_2 eq/y, taken the different global warming potentials of these gases into account. In terms of emissions per unit of electricity, the reservoir would emit 0.02 t C/MWh or 0.10 t CO_2 eq/MWh, when operating at 100 % of its power capacity (1,475 MWh) the whole year (Rodriguez & Casper in revision).

Reservoir management can strongly affect GHG emissions. High electricity generation reduces the GHG emissions released per unit of electricity generated. However, during longer dry periods high electricity generation will deplete the reservoir volume rapidly, thus lowering capacity for electricity generation, and this imbalance between water level and energy production would lead to rises in GHG emissions—first by increasing shallow areas of the reservoir, and secondly by causing increased amounts of GHG emissions per unit of electricity generated (Rodriguez et al. in preparation).

In the Itaparica Reservoir constant and rapid flow of the mainstream prevents accumulation of nutrients, other substances as well as water stratification, while within bays, e.g., the studied Icó-Mandantes Bay, water stagnation leads to eutrophication and oxygen depletion due to higher respiration rates in both water and sediments. As a consequence, embayment has higher GHG productivity potential, mainly of CO_2 from respiration and CH_4 due to oxygen deficits near the sediments. On the contrary, water in the mainstream outside of the dam inlet is well oxygenated and contains only small amounts of GHGs. This results in low release of GHGs during turbine passage.

OUR RECOMMENDATIONS:
The main aim of Itaparica management to prevent increases in GHG release should be to minimize all activities leading to eutrophication, including impacts on water quality due to land use changes and unmonitored aquaculture, especially in hydrologically disconnected embayments. Water should be kept oxygenated to prevent the

production of CH_4 and to force the oxidation of most of the methane produced in anoxic sediments. Imbalances between water level and energy production need to be avoided. Management of the water level should also be a key factor for the evaluation of newly planned reservoirs. A balance of water level fluctuation of the Itaparica Reservoir is only possible under controlled management of the much larger Sobradinho Reservoir upstream. At the moment no data on GHG emissions from Sobradinho Reservoir are available.

Further reading:

Rodriguez M, Casper P (2013) Carbon cycle and greenhouse gas emissions. In: Gunkel G, Silva JA, Sobral MC (Eds) 2013—Sustainable Management of Water and Land in Semiarid Areas. Editora Universitária UFPE, Recife, pp 79-98.

Rodriguez M, Casper P (2015) Nicht alle tropischen Stauseen sind grosse “Klimasünder“. IGB Jahresbericht 2014, p 21.

Rodriguez M, Casper P, Gunkel G, Hartje V (2015) Eutrophication of reservoirs and its effect on greenhouse gas emissions. Extended abstract, 17th IWA International Conference on Diffuse Pollution and Eutrophication. September 14-18, 2015, Berlin, Germany.

Rodriguez M, Casper P (accepted with revisions) Greenhouse gas emissions from a semi-arid tropical reservoir in Northeast Brazil. Regional Environmental Change.

Rodriguez M, Koch H, Hartje V, Casper P (in preparation) Management and greenhouse gas emissions from a reservoir in a semi-arid tropical region.

4.8 The economic value of water: a concept to economize scarce water resources

For whom: Watershed committees (e.g., CBHSF), Executive agencies of watershed committees, ANA, CODEVASF, State departments, Federal ministries, Institutions of higher education

From whom: Anne Biewald (biewald@pik-potsdam.de), Márcia Alcoforado de Moraes (marcia.alcoforado.ma@gmail.com), Gerald Souza da Silva (geraldsouzadasilva@gmail.com)

Problem: Irrigation water in the public irrigation schemes is priced too low (if even priced at all).

Key message: The price of irrigation water should reflect its scarcity.

Context: Brazilian agriculture is strongly influenced by the global market. According to a global agro-economic land and water use model adapted to the São Francisco River Basin, a change in the land use pattern will occur. Sugarcane under irrigation is expected to expand at the expense of fruit crops. Sugarcane is very water-demanding and current water prices are too low considering its scarcity. Most of the irrigation schemes in the region are public and have, at least in part, been financed by the government and today still depend on water supplies developed and in many cases payed for by governmental funds. In general the Brazilian government subsidizes many of the water-associated costs in these public irrigation schemes, which makes it difficult to determine exactly which costs the farmers bear.

Recommendations:

Local water scarcity can be alleviated through imports of agricultural goods or aggravated through exports of crops with high water requirements, such as sugarcane or some types of fruit. In order to avoid enhanced water scarcity due to exportation, the price of irrigation water should reflect its scarcity. The potential integration of a global model with a local model for identifying the economic values of water can show the influence of global forces on the decisions concerning irrigation and the local use of land and water. This can support water policy design in order to foster sustainable development in the region and not intensify already existing conflicts. It is important to maintain a differentiated water pricing system, which still allows smallholders to thrive, although small-scale irrigated agriculture should also seek diverse options to improve water use efficiency and reduce water waste.

Our study: Economic values of water for the main public irrigation schemes in the Sub-Middle of the São Francisco River Basin were determined using Positive Mathematical Programming, a method from economics research. As the water values depend on

Drip irrigation of annual crops. *Photo: V Rodorff*

the crops grown in these irrigation schemes, we used a regionalized version of a global agro-economic land and water use model adapted to the river basin in order to simulate the crop land use, which can be determined by global demand and changes in trade barriers as well as climate change. The allocation of sugarcane and fruit crops projected with and without climate change by the global model, showed an impact on the average crop yields and on the water costs in the main public irrigation schemes resulting in changes in the water values. The economic values for all irrigation schemes in the baseline year were higher than the water prices established by the River Basin Committee (CBHSF). In the future these water values are even expected to increase.

Further reading:

Biewald A, Rolinski S, Lotze-Campen H, Schmitz S, Dietrich JP (2014) Valuing the impact of trade on local blue water. Ecological Economics 101: 43–53. doi: 10.1016/j.ecolecon.2014.02.003.

Kölling K (2004) Modelling the impact of climate change and altering socioeconomic drivers on the agricultural production in the catchment area of the Rio São Francisco in North-eastern Brazil, Master Thesis at the Humboldt University Berlin, Germany.

Moraes MMGA, Biewald A, Carneira A, Silva GNS, Popp A, Lotze-Campen H (submitted 2016) The impact of global changes on economic values of water for public irrigation schemes at São Francisco River Basin in Brazil. Regional Environmental Change.

Moraes MMGA, Ribeiro, MMR, Watkins DW, Viana JHN, Figueiredo LEN, Silva GS, Carneiro ACG (2016) Integrated economic models to support decisions on water pricing in biofuel production river basins: three case studies from Brazil. Biofuels, Bioproducts & Biorefining 10(3): 255–269. doi: 10.1002/bbb.1581.

4.9 Integrated hydro-economic models can explain the economic consequences of water allocation

For whom: Watershed committees (e.g., CBHSF), Executive agencies of watershed committees, ANA, CODEVASF, State departments, Federal ministries, Institutions of higher education, Hydropower plant operators (e.g., CHESF, CEMIG), ONS

From whom: Gerald Souza da Silva (geraldsouzadasilva@gmail.com), Márcia Alcoforado de Moraes (marcia.alcoforado.ma@gmail.com), Anne Biewald (biewald@pik-potsdam.de)

Problem: Current water allocation barely accounts for the scarcity of related resources.

Key messages:

- The scarcity costs of ecosystem services and environmental constraints are high, primarily affecting irrigation users.
- Scarcity costs are expected to further increase in the future.

Context: Human water consumption is the priority of (scarce) water by law. Upstream water withdrawals and release from the reservoirs determine and limit the water available for further consumptive uses in the Sub-Middle portion of the river basin, including the water diversion project as well as environmental demands. The projected changes in climate and land use suggest an increasing demand for irrigation water, along with higher scarcity costs. There is little coordination among the different uses. The traditional fragmented approach to water resources management must be replaced with a more holistic approach.

Recommendations:

Integrated models such as hydro-economic models can prescribe water allocation strategies from an economic perspective, while incorporating environmental, institutional, and policy constraints. The use of these economic models can identify trade-offs properly among different uses and help inform policy for the allocation of water resources.

Estimating economic values of the user's marginal water benefits and willingness to pay for actual and projected public irrigation schemes in the São Francisco River Basin could support their management, as it replaces the concept of a fixed water "requirement" with one that captures user behavior and the economic meaning of scarcity. This information and corresponding policies can foster enhanced economic welfare and sustainable water use, as well as help to resolve water use conflicts.

Our study: A seven-year period (2000-2006) in the past was selected to represent the hydro-climatologic conditions and land/water use in the study area, for which the optimal economic allocation was obtained. The constraints used were technical, socio-economic and environmental. Data from this period was used to analyze diverse changes: in operating rules, constraints, climate change, water availability and land use changes. Economic impacts of different water allocation strategies were analyzed by changing the constraints in the model. The global model results showed that the agricultural land area might double in the time span from 2005 to 2035. Water demand curves (rather than fixed values) were generated by irrigation scheme (Moraes et al. 2016) and implemented in the hydro-economic model.

Further reading:

Moraes MMGA, Carneiro ACG, Silva MPR, Marques GF (2015) Technical coefficients of direct use of water in monetary terms for agriculture and urban water use. Water Science & Technology: Water Supply 15(5): 1123-1132. doi: 10.2166/ws.2015.075.

Moraes MMGA, Ribeiro, MMR, Watkins DW, Viana JHN, Figueiredo LEN, Silva GS, Carneiro ACG (2016) Integrated economic models to support decisions on water pricing in biofuel production river basins: three case studies from Brazil. Biofuels, Bioproducts & Biorefining 10(3): 255–269. doi: 10.1002/bbb.1581.

Silva GS, Figueiredo LE, Moraes MMG (2015) Curvas de demanda pelos recursos hídricos dos principais usos consuntivos no submédio da bacia do São Francisco. (Demand curves for water resources of the main water users in Sub-Middle São Francisco River Basin). Revista Brasileira de Ciências Ambientais 36: 45-59. doi: 10.5327/Z2176-947820151004.

Silva GS, Moraes MMGA (submitted 2016) Economic water management decisions: the conflict of energy and agricultural production in addition to environmental demands in the Sub-Middle region of the São Francisco watershed. Regional Environmental Change.

4.10 Multi-level governance: an integrative and strategic approach is necessary

For whom: Watershed committees (e.g., CBHSF), Executive agencies of watershed committees, ANA, CNRH, CODEVASF, IBAMA, Water supply and sanitation organizations, Municipal government departments, State departments, Federal ministries, CPRH, INCRA, NGOs, Water users, Institutions of higher education

From whom: Marianna Siegmund-Schultze (m.siegmund-schultze@tu-berlin.de), Clécio Barbosa Souza Júnior (junior@campus.tu-berlin.de), Verena Rodorff (verena.rodorff@tu-berlin.de)

Problem:

- Coordination between different governance levels hardly occurs.
- Access to consolidated datasets and documents is limited.
- Tributary watershed committees are widely lacking.

Context: The Federal System for Water Resources Management ("SINGREH") is composed of the four following organizations in the case of the São Francisco River Basin: CNRH, ANA, and CBHSF with its executive agency. The CBHSF is the so-called water parliament, while its agency is the executory body. ANA issues water use licenses and receives payments for water usage. The CNRH functions as a mediator in case of disagreement.

Coordinative meeting of local fishermen. *Photo: M Siegmund-Schultze*

The participation of women and men, younger and older people is paramount for good decision-making. *Photo: M Siegmund-Schultze*

The CNRH and the CBHSF are organizations which widely rely on voluntary work where the members join-in at specific points in time. ANA and the executive agency of the committee are organizations with remunerated staff.

About 15 years after the creation of ANA and the CBHSF, their relationships still appear to be in a process of negotiation, as are the interrelations with further major actors influencing water management, allocation, and access to water at the federal scale. The positions of the CBHSF in the water discourse are often insufficiently concrete to effectively serve the population and other users of the whole basin. For example, in the region of the Itaparica Reservoir, which is part of the CBHSF's area of action as it belongs to the basin, the CBHSF is barely known by the local population and only minorly linked to the local water management institutions.

The Regional Advisory Boards ("CCR") of the CBHSF and the existing tributary committees should facilitate the responsible inclusion of the municipalities and local water users and become an equitable organ for participation at the local scale, which integrates relevant topics and discussions. So far, few tributary committees exist in the Sub-Middle and Lower sections of the São Francisco River Basin. The tributary committees are widely a missing link for local management; they could promote concrete decisions and involve local actors effectively.

The fragmentation of the water management can also be seen in the fragmentation of information relevant for decision-making. The organizations are obliged to make data and documents available. However, many documents are barely known or difficult to obtain as access is not easily provided, for example, on the local level *(compare chapter 3.2 on page 70)*. Data about the utilized water quantities and timing, and its users are also incomplete. Inconsistencies also exist within and between different databases.

Recommendations

1. Take advantage of the integrative character of the water policy (water and land) and related power relations by using the CBHSF (and its executive agency) as a broker. The river basin committees can further profit from the Federal Council for Water Resources (CNRH) to resolve conflicts.

2. Create mechanisms for participation within the organizations and with civil society through decentralized and participatory governance. Discussing and positioning on how to deal with a decentralized and participatory governance system are needed within the organizations *(compare chapter 6.5 on page 105)*.

3. Promote the presence, i.e., representation, of federal institutions at the local scale. The functions of the federal institutions like ANA, IBAMA, and sectorial ministries should be clearly defined for lower scales.

4. Promote the establishment of tributary committees of the São Francisco River *(compare chapter 3.2 on page 70)*, which is normally the state's competence, and facilitate local participation. Develop local plans and programs. Incentivize public participation at different scales and in different sectors in the Regional Advisory Boards (CCR) and in tributary committees.

5. Establish strategic and preventive planning in a participatory manner at all levels.

6. Consolidate databases and make documents available, which are necessary for decision-making.

Further reading:

Find a summary of a survey on the functioning of the mentioned watershed committee realized in 2014 here (in Portuguese): http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/images/RM_pics/Questionario_INNOVATE_retorno_2014.pdf.

Rodorff V, Araújo G, Gomes ETA, Köppel J, Siegmund-Schultze M, Sobral MC (2013) 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 MC (Eds), Sustainable Management of Water and Land in Semiarid Areas. Federal University of Pernambuco, Editora Universitária, Recife, pp. 254–268.

Rodorff V, Siegmund-Schultze M, Köppel J, Gomes ETA (2015) Governança da bacia hidrográfica do rio São Francisco: Desafios de escala sob olhares inter e transdisciplinares. Revista Brasileira de Ciências Ambientais 36: 19-44. doi: 10.5327/Z2176-947820151003.

Siegmund-Schultze M, Rodorff V, Köppel J, Sobral MC (2015) Paternalism or participatory governance? Efforts and obstacles in implementing the Brazilian water policy in a large watershed. Land Use Policy 48: 120-130. doi: 10.1016/j.landusepol.2015.05.024.

Souza Júnior CB, Siegmund-Schultze M, Köppel J, Sobral MC (submitted 2016) Sinais de um problema crônico: a governança hídrica carece promover os comitês de bacias, coordenar planos e gerir informações. Ambiente & Água.

5 Land—related to management at the basin scale

View of the landscape. *Photo: M Venohr*

5.1 The Caatinga biome as a whole needs more attention and protection

For whom: ICMBio, IBAMA, Ministry of the Environment (MMA), SEAD, MI, State Department of the Environment and Sustainable Development, CONSEMA, NGOs, Institutions of higher education

From whom: Birgit Kleinschmit (birgit.kleinschmit@tu-berlin.de), Robert Koch

Problem:

- Less than 1% of the Caatinga biome area is under legal protection.
- There are knowledge gaps for spatial coverage of plant species, richness and endangered plant species for the whole biome.
- Despite an overall increase in forest cover, open areas along the São Francisco River indicate degradation and risk of desertification.

Key messages:

- Recent studies revealed both woody vegetation loss and (re)gain.
- Land use and land cover change analysis of the past decades indicate overall forest gain.
- Modeling can identify major areas of conservation interest.

Recommendations:

1. The use of a complementary "stacked species distribution modeling" approach, which is cost-effective and rapidly applicable for assessing biodiversity patterns on a macro scale.

2. Using our results for the identification of potential candidate areas for conservation actions. Our predictions highlight key richness hotspots and threat patterns.

3. Lowering grazing pressure in the areas currently classified as vegetated shrublands and grasslands in order to enhance natural transformation back into woody savanna. Under managed conditions—and in most cases with supplemental watering in the beginning—reforestation with native species can support this natural process.

Explanation: According to Koch et al. (2017) a stacked species distribution modeling (S-SDM) approach is a sufficiently reliable tool for providing basic information to decision makers, and can be combined with additional local studies from our project to quantify pressures on, and threats to biodiversity. Our approach is easily transferable to other taxa and is not limited to plant species.

Stacked species distribution models reveal information on the constituent species within an area. We applied a complementary approach by combining our species richness hotspots with the spatial distributions of endangered plant species; both of which are important for estimating biodiversity. We stacked (overlaid) 1062 individual plant species and 27 individual endangered species models and revealed areas of high nature conservation importance.

Blossoming in the Caatinga. *Photo: C Beusch* the soil cover with trees, shrubs and grass. In addition, access of livestock to the Caatinga areas should be well managed in order to limit grazing pressure in a way that is sustainable for nature and people *(compare chapter 2.10 on page 64)*.

A small xique-xique cactus *(Pilosocereus gounellei)*.
Photo: M Siegmund-Schultze

OUR STUDY: We surveyed pattern-process relationships for the Caatinga phytogeographical domain on different spatial levels for the years 2001-2012 from MODIS land cover data. Using a landscape pattern analysis, a set of five landscape metrics was calculated using FRAGSTATS (*Schulz et al. 2017*). A spatially explicit overview of plant diversity and their statuses for the entire Caatinga has been modeled (*Koch et al. 2017*).

In the world databases, the land use of the São Francisco River Basin is more and more classified as "low vegetated shrublands" and "grasslands". These two classes imply a higher risk of land degradation and desertification. Therefore, the plea is to increase

FURTHER READING:

Koch R, Almeida-Cortez J, Kleinschmit B (2017) Revealing areas of high nature conservation importance in a seasonally dry tropical forest in Brazil: Combination of modelled plant diversity hot spots and threat patterns. Journal for Nature Conservation 35: 24-39. doi: 10.1016/j.jnc.2016.11.004.

Schulz C, Koch R, Cierjacks A, Kleinschmit B (2017)Land change and loss of landscape diversity at the Caatinga phytogeographical domain—Analysis of pattern-process relationships with MODIS land cover products (2001-2012) Journal of Arid Environments 136: 54-74. doi: 10.1016/j.jaridenv.2016.10.004.

5.2 Managing nutrient emissions from urban systems and agriculture

For whom: ANA, EMBRAPA, EPAMIG, SNIS, Water supply and sanitation organizations (e.g., COMPESA, COPASA, EMBASA), Watershed committees (e.g., CBHSF), Municipal government departments

From whom: Markus Venohr (m.venohr@igb-berlin.de), Peter Fischer (peter_fischer@online.de)

PROBLEM:

- Deterioration of surface water quality due to untreated wastewater and nutrient emissions from agriculture.
- Elevated risks of eutrophication processes due to highly phosphorus-saturated agricultural areas.

KEY MESSAGES:

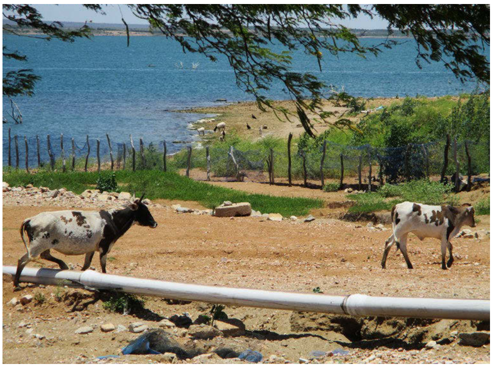
- Evaluation of future phosphorus (P) and nitrogen (N) emissions from planned irrigation schemes.
- Evaluation of future P and N emissions from urban areas considering population growth and existing wastewater treatment facilities.
- Integration of Mehlich-1 P monitoring data in nutrient emission models through translation to degree of P saturation and water-soluble phosphorus.

EXPLANATION: High nutrient concentrations in surface waters exceeding environmental standards were mainly observed downstream of larger cities. In particular, this was the case when wastewater was released untreated into surface waters. In rural areas, where septic tanks are the predominant way of treating wastewater from individual households, the effect on surface water was generally identified as minor. This is in general due to high nutrient retention of soils and groundwater, meaning that only a small fraction of nutrients discharged from septic tanks ultimately reaches surface waters.

The agricultural sector is increasingly gaining economic importance and causing potential ecological problems. Currently, agriculture contributes about 19 % of total phosphorus (TP) and 38 % of total nitrogen (TN) emissions in the river basin. These are basically emitted through the pathways of surface runoff and erosion (TP: 17 %, TN: 6 %), ground water (TP: 1 %, TN: 15 %), and tile drainage (TP: 1 %, TN: 6 %). Sparse vegetation and heavy seasonal rainfall are the main reasons for the elevated share of particulate and dissolved nutrient emissions from surface runoff and erosion.

During the past decades fertilizer input has increased, along with both total agricultural area and irrigated agricultural area. In the future, a further increase of all three components is assumed, increasing total emissions from fertilizer surplus, agricultural areas, and irrigated agriculture in particular. Combined, the changes in all three parameters will potentially aggravate water quality problems if not managed properly or balanced out by accompanying preventative measures.

Even small nutrient emissions from settlements and agriculture have cumulative impacts on water bodies.
Photo: F Selge



Nutrient emission pathways are manifold: e.g., from aquaculture, crops, livestock, and domestic and industrial wastewater. *Photo: M Siegmund-Schultze*

OUR STUDY: We used the following as input for modeling nutrient emissions from agricultural areas:

- Statistical data of the sanitation sector on a municipality level,
- Agricultural statistical data of arable land and grassland,
- Agricultural statistical data on fertilizer use per crop,
- Surface water quality data (for a proper assessment, however, higher temporal resolution and continuous measurements are required).

RECOMMENDATIONS:

Urban wastewater treatment

1. Direct release of untreated wastewater into surface waters should be avoided where possible.

2. Construction of state of the art treatment plants for all collected (but currently untreated) wastewater could substantially reduce total annual nutrient emissions into the São Francisco River Basin. Replacing existing treatment plants with modern ones would lead to a further reduction of nutrient emissions. In rural areas where wastewater is treated in septic tanks with a subsequent soil-groundwater passage, collection and treatment of water in centralized modern treatment plants will not lead to a significant change in total nutrient emissions. Furthermore, the centralized collection of wastewater in sparsely populated areas is very cost intensive and difficult to realize. However, the continuous leakage of poorly treated wastewater into soils and groundwater represents a risk of elevated concentrations of nutrients, pathogens, and other substances and may on a mid-term perspective lead to limitations for drinking water production.

Agriculture

3. Better and area-covering monitoring data of fertilizer application in order to quantify fertilizer surpluses and their spatial distribution on the municipality level. Using monitored plant available phosphorus (Mehlich-1 phosphorus) in the risk assessment of P losses from agricultural areas is recommended. These should be fed into nutrient emission models for a reliable quantification of nutrient emissions.

4. A set of measures should be tested to reduce emissions into surface waters through surface transport, e.g., soil conservation measures, intercropping, contour plowing or buffer strips alongside surface waters. Agriculture on hillsides should be avoided where possible. Intensive meat or dairy production in vulnerable regions with sparse vegetation should be avoided.

5. Fertilizer surpluses should be held at a low level. The use of legumes for intercropping can reduce the mineral nitrogen fertilizer application and help to reduce losses of soil and nutrients through surface transport. Training farmers on how to use fertilizer efficiently and reduce unnecessary nutrient losses (e.g., by surface transport or leaching), and water-saving irrigation methods had good results in Germany.

Further reading:

Venohr M, Hirt U, Hofmann J, Opitz D, Gericke A, Wetzig A, Natho S, Neumann F, Hurdler J, Matranga M, Mahnkopf J, Gadegast M, Behrendt H (2011) Modelling of nutrient emissions in river systems—MONERIS—methods and background. International Review of Hydrobiology 96: 435-483.

5.3 Reducing the risks of P losses from soils

For whom: ANA, EMBRAPA, EPAMIG, SNIS, O & M (operation and management units of irrigation schemes), Local farmers' associations, Watershed committees (e.g., CBHSF), Municipal government departments

From whom: Peter Fischer (peter_fischer@online.de), Markus Venohr (m.venohr@igb-berlin.de)

Problem: Elevated risks of eutrophication processes due to superficial fertilizer application and high P levels in agricultural soils.

Key message: Incorporate any superficially applied fertilizer into the soil.

Explanation: Phosphorus (P) is applied as fertilizer to soils. Whereas a certain level of soil P is necessary to secure optimum agricultural production, excessively applied P leads to increased loss risks and contributes to eutrophication processes in rivers and lakes. The most important transport processes of nutrients are surface runoff created by rainfall events and leaching of phosphorus through the soil layer into tile drainage and groundwater.

For risk estimation of diffuse P losses from agricultural areas, the degree of P saturation is investigated in many parts of the world. Although different approaches are used, the common principle is the definition of a critical Degree of P Saturation (DPS) value above which the risk of P loss from soil to water becomes critical. Mostly the DPS is investigated by methods that consider only a portion of the P sorption sites of a soil, e.g., Ca and Mg on calcareous soils and Fe and Al on acidic soils. Consequently, the DPS approaches are restricted to certain soil types. Consideration of all sorption sites of a soil is only possible by sorption isotherms, which are time-consuming and therefore expensive to measure.

Our study: A soil-independent approach to estimate the DPS by the fast and easy to measure parameter water soluble phosphorus (WSP) was shown to be applicable on tropical soils of Brazil (Pöthig et al. 2010,

Intercropping and soil coverage are measures that reduce soil erosion.
Photo: M Siegmund-Schultze

Fischer et al. in preparation). The calculation of DPS by water soluble P (WSP) allows for an identification of soils with degrees of P saturation that indicate elevated (DPS > 70 %) and high risks (DPS > 80 %) of dissolved P losses from agricultural areas. However, WSP monitoring data is not generally available for Brazilian agricultural areas. The only available data with high spatial and temporal resolution is phosphorus determined by the Mehlich-1 (M1P) methodology, which is used for estimation of plant-available P in soils (e.g., by EMBRAPA). M1P showed to be highly correlated with WSP for soil samples collected in the Upper and Sub-Middle part of the São Francisco River Basin dominated by Oxisols and Entisols. Consequently, WSP can be substituted by the WSP-M1P correlation for calculating DPS values of soils.

Superficial fertilizer application in an irrigation scheme near the Itaparica Reservoir, Pernambuco. *Photo: P Fischer*

However, our samples did not contain significant amounts of $CaCO_3$. Buffering of the Mehlich-1 acid extractor solution by $CaCO_3$ can be expected and would lead to an underestimation of WSP values by our approach. Consequently, we recommend further analyses of the WSP-M1P correlation on $CaCO_3$-containing soils.

The data evaluation of M1P monitoring data provided by EPAMIG resulted in relatively low DPS values (Fischer et al. 2016). This indicates an overall low risk of P losses for various municipalities in Minas Gerais and Bahia. However, the data showed high variation between and within municipalities and pointed at high risks of dissolved P losses (DPS > 80 %) at single locations. Consequently, a high spatial resolution of input data would be necessary to identify a regions with DPS values that indicate high risk of P losses from soil to water.

Recommendations

1. We recommend an evaluation of target M1P values in Brazilian soils with regard to the risk of P losses by translating M1P values into DPS. Fertilizer recommendations from agricultural institutions and laboratories should be adapted accordingly. This could help to prevent the establishment of unnecessarily high P levels in Brazilian soils in the future, which would threaten water bodies through eutrophication processes.

2. In order to reduce P losses from agricultural areas, incorporation of superficially applied fertilizer into the soils is recommended. The incorporation of fertilizer into the soils is also considered to have a positive effect on plant growth when fertilizer grains are near the seeds and roots of the plants. Consequently, a higher P use efficiency could be achieved along with concomitant reduction of risks of P losses and eutrophication processes in surface water bodies.

3. A broad discussion among experts in the area of soil and water chemistry, ecology, plant physiology and agriculture is recommended in order to verify how to optimize P fertilization with regard to plant production and reduction of P losses from agricultural areas in the São Francisco River Basin and Brazil as a whole.

4. In addition to the incorporation of superficially applied fertilizer, the prevention of erosion processes is also recommended for reducing P emissions into water bodies. In this context measures like intercropping to avoid erosion processes and buffer strips to hinder transported sediment from entering water bodies are recommended.

5. To identify agricultural areas with a high risk for eutrophication of water bodies, so-called critical source areas have to be defined. Critical source areas (CSA) of diffuse P losses are determined by parameters describing potential P loss from agricultural areas and hydraulic connectivity to water bodies. Nutrient emission models (e.g., Venohr et al. 2011) are useful tools to determine the risk of eutrophication by connecting soil P data with hydrological data to identify hotspots of diffuse P emissions. We recommend the integration of M1P monitoring data and its associated risk parameters (WSP and DPS) in nutrient emission models to improve the prediction accuracy of the models and effectively identify CSAs in the São Francisco River Basin. A prerequisite for the identification of critical source areas is the provision of M1P monitoring data at high spatial resolution. The effects of superficial fertilizer application should be included in the models.

Further reading:

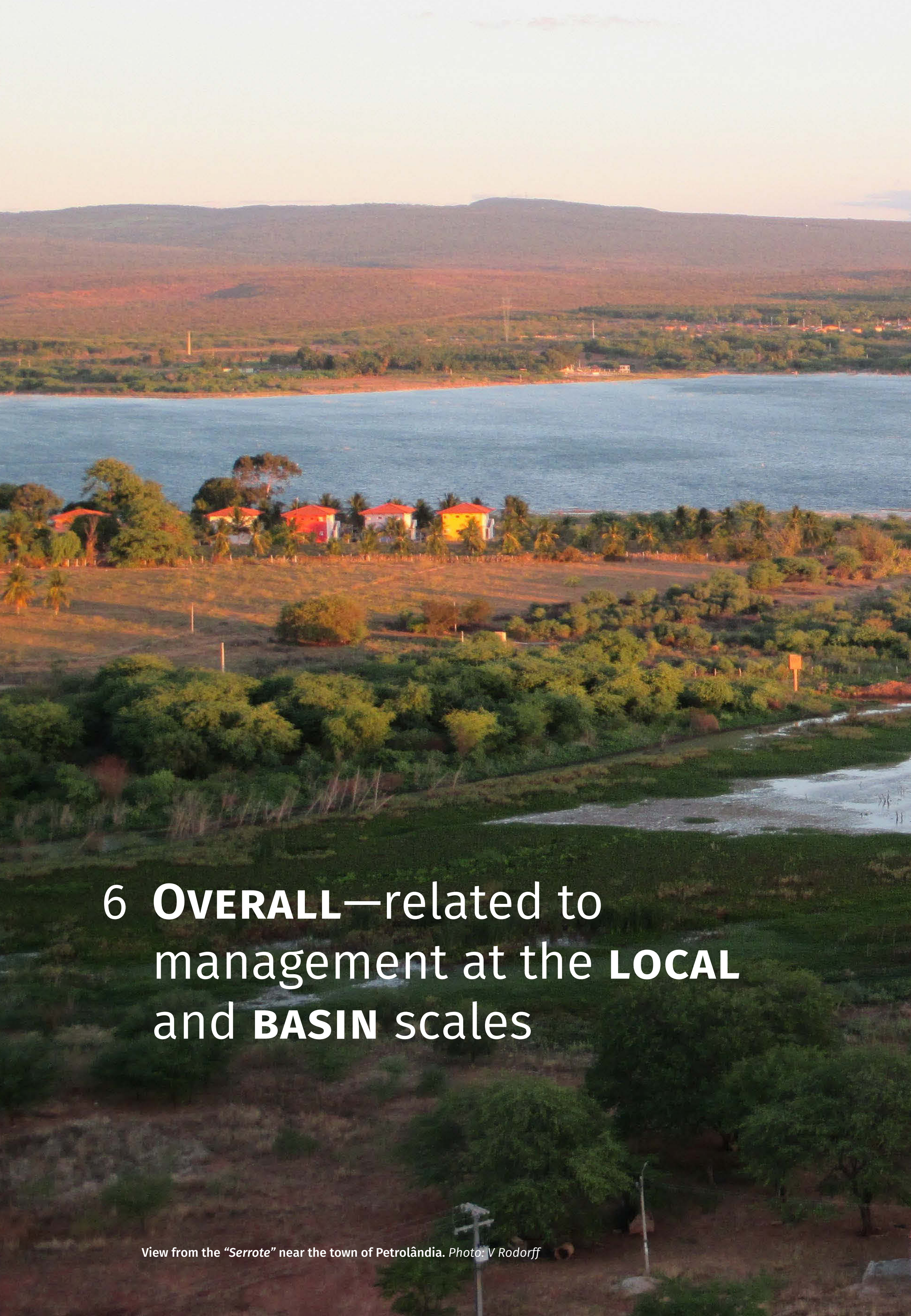
Fischer P, Pöthig R, Gücker B, Venohr M (2016) Estimation of the degree of soil P saturation from Brazilian Mehlich 1 P data and investigations on P losses from agricultural sites in Minas Gerais. Water Science and Technology. doi: 10.2166/wst.2016.169.

Fischer P, Pöthig R, Gücker B, Venohr M (in preparation) The risk of P losses from agricultural soils in the São Francisco catchment, Brazil: Degree of P saturation and superficial fertilizer application.

Fischer P, Pöthig R, Venohr M (in press) The degree of phosphorus saturation of agricultural soils in Germany: Current and future risk of diffuse P loss and implications for soil P management in Europe. Science of the Total Environment. doi:10.1016/j.scitotenv.2017.03.143.

Pöthig R, Behrendt H, Opitz D, Furrer G (2010) A universal method to assess the potential of phosphorus loss from soil to aquatic ecosystems. Environmental Science and Pollution Research 17: 497-504.

Venohr M, Hirt U, Hofmann J, Opitz D, Gericke A, Wetzig A, Natho S, Neumann F, Hurdler J, Matranga M, Mahnkopf J, Gadegast M, Behrendt H (2011) Modelling of nutrient emissions in river systems—MONERIS—methods and background. International Review of Hydrobiology 96: 435-483.



6 **Overall**—related to management at the **local** and **basin** scales

View from the *"Serrote"* near the town of Petrolândia. *Photo: V Rodorff*

6.1 Improving climate databases for better planning of the adaptation measures

For whom: State water agencies (e.g., APAC, IGAM, INEMA, SEMARH), ANA, INMET, CPRM, INPE, DNOCS, EMBRAPA, Institutions of higher education, Watershed committees

From whom: Janaina Assis (jmoassis@gmail.com), Werônica Souza (weronicameira@gmail.com)

Problem:

- Water scarcity with high demand.
- Difficulties in making climate data available.
- In general, limited availability and quality of climate data for the São Francisco River Basin.

Key messages:

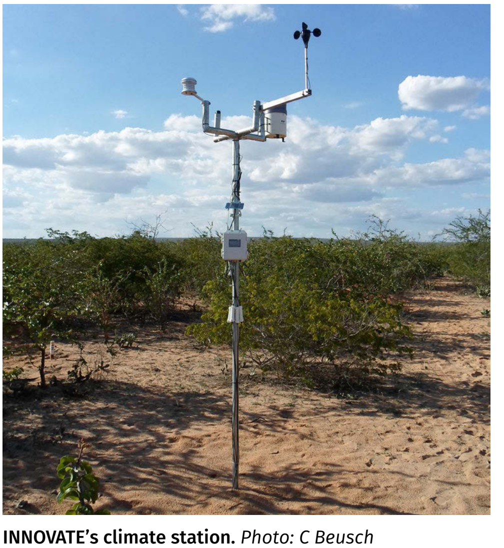
- Monitor and study the river flow in extreme drought periods to propose water fees that take into account the multiple uses of water.
- Invest in technologies for forecasting and monitoring droughts in order to better plan agricultural production processes.
- Intensify climate research for the Upper and Middle sections of the São Francisco River Basin.
- Create a central point for the compilation and distribution of climate and hydrological data.

The study: We analyzed climate variability and future scenarios of climate change for the Sub-Middle of the São Francisco River Basin. We collected data from 36 regional climate stations, analyzed the data for consistency, and applied the Rainfall Anomaly Index to the total annual rainfall data from the stations, covering the years 1964–2014.

Explanation: The scenario of environmental vulnerability in the semi-arid region of Brazil's Northeast and possible consequences resulting from climate change call for action by both the government and non-governmental actors. Commitment is needed to promote activities that enhance the drought resilience capacity of the population. Climate research can play an important role when well adapted to the specific challenges, which are introduced below.

1. Water scarcity with high demand: Low rainfall, which is associated with a rise in temperature and evapotranspiration, aside from temporary sources of water storage, calls for research and monitoring of water consumption and demand.

2. Difficulties in making climate data available: To improve access to climate data, a major monitoring and data-collecting incentive is necessary, also the granting of access to data. Given that these data are used for research with relevant societal impacts,



INNOVATE's climate station. *Photo: C Beusch* better availability also facilitates research on local development, especially in areas with large irrigation schemes.

3. Limited quality and availability of climate data for the São Francisco River Basin: Since the regional development of the large river basin is a function of the water originating in the Upper and Middle courses of the basin, it is necessary to undertake studies on the probable impacts of climate change on the Upper and Middle sections of the São Francisco River Basin.

Further reading:

Assis JMO, Sobral MC, Souza WM (2012) Análise de detecção de variabilidades climáticas com base na precipitação nas bacias hidrográficas do sertão de Pernambuco. Revista Brasileira de Geografía Física 3: 630-645.

Assis JMO, Souza WM (2015) Análise climática da precipitação no submédio da bacia do Rio São Francisco a partir do índice de anomalia de chuva. Revista Brasileira de Ciências Ambientais 36: 115-127. doi: 10.5327/Z2176-947820151012

6.2 INNOVATE’s metadatabase: which data was collected and used, where is it available?

For whom: People interested in studying topics related to the São Francisco River Basin and Itaparica region: scientists from diverse universities and research corporations, civil society, members of the CBHSF and tributary committees.

From whom: Célia Afonso (celiafonso@mailbox.tu-berlin.de), Marianna Siegmund-Schultze (m.siegmund-schultze@tu-berlin.de) & many project members

The metadatabase describes all datasets generated or used by members of the INNOVATE project. It helps in tracing which type of data was collected and where the datasets can be found. It serves to facilitate follow-up studies and enables researchers to find relevant datasets.

Primary data is what scientists have collected on their own (via measurements in the field or in experiments, surveys, key person interviews) and secondary data is what they found on webpages or received from organizations or other scientists. Generally, secondary data has first to be checked for consistency and completeness and is partly subject to reorganization in order to fit one’s needs. The metadatabase describes these datasets. Data itself is not uploaded but can be accessed upon request and use agreement.

Further reading:

The metadatabase of INNOVATE is within the so-called GLUES Catalog. Go to the geoportal website (http://geoportal-glues.ufz.de/index.php) and click on “Data” in the yellow box, or directly access at:

https://catalog-glues.ufz.de/terraCatalog/Start.do;jsessionid=DA0FAF4FE650F550E480AD73D2B11736 Enter what you are looking for in the search line, for instance, start by entering INNOVATE.

6.3 Clarification of complex situations: Constellation Analysis explained in WOCAT style

For whom: Associations and cooperatives, NGOs, Municipal and state government departments, Federal ministries, Institutions of higher education, Committees, Councils, Agencies

From whom: Verena Rodorff (verena.rodorff@tu-berlin.de), Liron Steinmetz, Marianna Siegmund-Schultze (m.siegmund-schultze@tu-berlin.de)

CONSTELLATION: Analysis is a flexible tool, which enables a mutual understanding of divergent positions of different stakeholders, paving the way for more informed decision-making. It can be utilized by any group, preferentially mixed stakeholder groups. The method aims at a transparent, mutually accepted visualization of elements that are systematically assigned to four categories (actors; rules and concepts; natural elements; technical elements), and shows the quality and direction of their relationships. The method is suitable for clarifying many different questions or situations. It has been applied in the frame of the INNOVATE project at the local reservoir scale and the national, respectively river basin scale.

We prepared a leaflet using a form from WOCAT (World Overview of Conservation Approaches and Technologies; https://www.wocat.net/). The leaflet introduces the method briefly, and describes challenges, impacts, strengths and weaknesses. We also prepared a video together with WOCAT members. The video explains all steps of Constellation Analysis and shows applications of the method; participants comment on their experience.

FURTHER READING AND WATCHING:

Access the WOCAT leaflet, which explains the Constellation Analysis approach: http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/text_files/flyer/App_Wocat_Constellation_Analysis_EN_INNOVATE.pdf (English) or find it directly in the WOCAT approaches database: https://qcat.wocat.net/en/wocat/list/?type=approaches

A video on constellation analysis: A link to the video is available at www.wocat.net and http://www.innovate.tu-berlin.de/v_menue/materials_for_stakeholders/parameter/en/. The direct path is https://vimeo.com/208126454.

A discussion between local farmers is triggered by constellation analysis.
Photo: M Siegmund-Schultze

6.4 Probabilities of adopting an innovation: Bayesian Networks explained in WOCAT style

For whom: EMBRAPA, IPA, CODEVASF, NGOs, Rural extension services, Government departments, Institutions of higher education

From whom: Verena Rodorff (verena.rodorff@tu-berlin.de), Liron Steinmetz (liron@web.de), Marianna Siegmund-Schultze (m.siegmund-schultze@tu-berlin.de)

The aim of Bayesian Network modelling is the integration of multiple issues and system components, using information from different sources, while handling missing data and uncertainty. The outcome can be used to draw recommendations that support local management decision-making.

The steps in creating a Bayesian Network model are: Developing a hierarchical qualitative model of elements, which determine the topic under question. Each of the so-called nodes possesses two or more defined states. Literature, experts or surveys are then used to determine the relationships between the elements in a quantitative way, usually by filling out a questionnaire or table. The latter is then transferred to the Bayesian Network software (for instance, Netica, which is free of charge for up to 15 nodes). Once the model is built, different scenarios can be applied and estimated by modifying the states of the elements. The major influencing factors can be identified. Bayesian Network modeling has been applied in the frame of the INNOVATE project at local scale *(compare chapter 2.7 on page 59)*.

Expert interviews are crucial for revealing local parameters. *Photo: G Novaes*

We prepared a leaflet using a form from WOCAT (World Overview of Conservation Approaches and Technologies; https://www.wocat.net/). The leaflet introduces the method briefly, and describes challenges, impacts, strengths and weaknesses.

Further reading:

Access the WOCAT leaflet, which explains the Bayesian Network approach: http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/text_files/flyer/App_Wocat_Bayesian_Network_EN_INNOVATE.pdf (English) or find it directly in the WOCAT approaches database: https://qcat.wocat.net/en/wocat/list/?type=approaches

6.5 Encourage, strengthen, and monitor public participation

For whom: Watershed committees, Executive agencies of watershed committees, ANA, CNRH, CONAMA, CODEVASF, IBAMA, Water supply and sanitation organizations, Forum of the Territory, Farmers' Union, Municipal and state government departments, Federal ministries, Water and land users' associations and cooperatives, NGOs

From whom: Marianna Siegmund-Schultze (m.siegmund-schultze@tu-berlin.de)

Proposition 1: Introducing a participatory committee challenges the overall governance culture.

The river basin committees have been institutionalized through the National Water Law in 1997. Specific laws initiate the establishment of single river basin committees at state and federal levels. While many existing governmental organizations are represented in these committees, no clear shift within these organizations is visible in regard to adapting their working culture and procedures to the new paradigms of decentralization and participation. The federal government emitted guidelines to facilitate the "national commitment for social participation" in 2014. Additional incentives and facilitation of the processes are recommended to support existing organizations in reflecting and responding to the new paradigms. Finally, a social discourse is necessary to debate which type of government and governance is wanted and what this implies for everybody.

Proposition 2: Power transfer from line to participatory institution is crucial but contested.

The CBHSF is a relatively new player in the power arena of water governance. The established organizations, with their full-time and professional staff, might sometimes be quicker and more efficient in making decisions because their experience facilitates decision-making. Transparency of decision-making renders the "deciders" vulnerable to critique. Critique can be positive when leading to improved procedures, though, what is good (improved) and what is not is often not perceived in the same way by different actors. Likewise, the process of adapting procedures is not welcomed by all actors in the same way. Change can be felt as promoter of insecurity, making processes uncomfortable. A fading of power can be perceived negatively by individuals or whole organizations. The players need to negotiate their functioning under new rules in a concerted way—this means additional workload, partly experienced as pressure or stress, until clarity of roles and competence is established anew. Transformation processes are generally strenuous and often lengthy; however, they are

A discussion between different stakeholders unfolds.
Photo: M Siegmund-Schultze

also chances for renovation. Patience and strategy are key factors.

Proposition 3: Social issues need special attention.

Participatory (water) governance involves very diverse topics and expectations. When alliances about a topic are reached, for example, about environmental conservation, which, in the case of the CBHSF, all members considered necessary in a certain way, this does not mean that other issues can be resolved in the same way. Often, social topics are especially contested, as they are connected to differing individual values and judging standards, or comprise a loss of advantages. Marginalized groups often lack a voice and assertiveness.

Proposition 4: Identity and trust building are particularly challenging in a very diverse watershed.

The larger a region or a river basin is, the higher its heterogeneity in ecological, social, political, cultural, and economic terms. It is important to appreciate these differences. The related challenges provide opportunities but also barriers. The interaction between different persons can promote an understanding between them. However, developing confidence needs time and opportunities. The transition from a simple cooperation between unconnected individuals to a commitment with dedication and responsibility to reach a common objective is necessary for complex tasks, and is not free of contradictions. The fair treatment among members needs attention and support.

Map making can promote the exchange of information and be a basis for citizens' participation.
Photo: M Siegmund-Schultze

Proposition 5: Championing participatory governance and the committee's work locally is a task ahead for the active members.

The majority of members of a river basin committee (or any other committee or council) are volunteers who meet regularly despite of their continuing daily work, which remains their main occupation and major focus of dedication and identification. We observed this distance in relation to the committee's work, leading to the outspoken perception of few members that it is the director's function alone to inform about the discussed topics of the committee and not everyone's responsibility. However, first-hand information would be useful and significant for the local communities.

Further reading:

Siegmund-Schultze M, Gomes ETA, Gottwald S, Rodorff V (submitted 2017) O que é uma boa participação pública? Conceitos, desafios e guias para reflexão. Revista Iberoamericana del Agua.

Siegmund-Schultze M, Gomes ETA, Gottwald S, Köppel J, Rodorff V, Sobral MC (2015) Participação na gestão dos recursos hídricos: lidando com as divergências nas definições, objetivos e prática. 12th SILUSBA Conference, 22-27 Nov 2015, Brasília. 8 pages.

Siegmund-Schultze M, Rodorff V, Köppel J, Sobral MC (2015) Paternalism or participatory governance? Efforts and obstacles in implementing the Brazilian water policy in a large watershed. Land Use Policy 48:120-130. doi: 10.1016/j.landusepol.2015.05.024.

6.6 Good governance: guidelines to reflect and adjust who steers what and how

For whom: All those involved in governance processes: Associations, Cooperatives, Municipal and state government departments, State and federal agencies, Federal ministries, NGOs, Rural extension services, Institutions of higher education

From whom: Verena Rodorff (verena.rodorff@tu-berlin.de), Marianna Siegmund-Schultze (m.siegmund-schultze@tu-berlin.de), Sonja Hölzl (sonja_e.hoelzl@gmx.de), Johann Köppel (johann.koeppel@tu-berlin.de)

Problem: Sustainable implementation requires a clear and fair governance process.

Context: Environmental and societal changes call for the recurrent adaptation of land management practices. This requires functional governance systems, which assure the quality and quantity of natural resources in a sustainable way. Good governance has been discussed in literature; a straightforward approach to operationalizing it in practice is still lacking.

Recommendation: Apply a transparent and fair process and monitor it regularly. Governance attributes to be clarified are: (i) is there a functional enabling framework, (ii) is legitimacy and accountability of actors given, (iii) are decision-making processes fair and transparent, and (iv) how are quality control and adaptiveness assured? We developed a template of guiding questions for reflecting and promoting good governance (Table 5). The prototyped template of good governance questions offers systematization for planning and steering the implementation of sustainable land management practices.

Exemplary application: The use of water plays a salient role in irrigated agriculture, just as well as the pesticide and fertilizer use. The handling of these inputs has consequences for biodiversity, the soil and the availability of water resources. Alternatives to conventional management exist, but so far are barely applied. Biological pest control is one of these alternatives, which can have economic as well as ecological benefits. For more details about the application of criteria for governance to the example of biological pest control *(compare chapter 2.6 on page 57)*.

Table 5 **Guiding questions to develop the dimensions of good governance in the process of implementing an innovation**

Indicator questions by dimension
Comprehensive Scrutiny of the Innovation—Best Practices of Sustainable Land Management
What resource and ecosystem is affected? What is the purpose of the innovation?
Which functions and ecosystem services are involved?
What are possible external effects and their magnitudes?
(i) Enabling Framework and (ii) Accountability
Conduciveness of the due process
What are the regulatory frameworks and the formal and informal rules? Do people comply with them?
Are the rules appropriate for the different scales? (local, regional, state, federal)
How are the different scales interlinked?
Is the structure of the decision-making process horizontal or vertical? Does subsidiarity apply?

Indicator questions by dimension

Comprehensive Scrutiny of the Innovation—Best Practices of Sustainable Land Management

Who is (to be) involved in the decision-making process?

- Public sector
- Private sector
- Civil society
- Agents (individuals, organized groups)

Organizational justice

Why (selection process, legitimacy) and in what role are the actors involved?

Who is for or against the innovation under question?

Are the existing capacities in the area / sector / institution sufficient?

Who provides training and who has access to it? What is the information flow?

Are the actors committed? To whom do they answer and what are potential consequences?

Are there any discrepancies with personal agendas?

How are differences in values and belief systems (personal and institutional) taken into account?

What are the mechanisms for controlling corruption?

(iii) Fairness and Transparency

Justice in the decision-making process

Interactional justice:

- How do people treat each other and how are they treated by the authorities?

Procedural justice:

- Is the process and its rules made transparent?
- Are people enabled to participate; do they receive information, have questions answered?
- Is the participation of women, traditional groups and indigenous tribes secured?
- How is the mobilization of the civil society?

Informational justice:

- How and when is information shared among participants, and by whom?
- Is the information comprehensive, readable and complete?
- Is there access to scientific research results?

Justice of the outcome

Distributive justice:

- Is the result of the allocation or the access to scarce resources fair?
- In which way is equitability of allocation and access solved?

(iv) Adaptiveness and Quality Control

Which instruments of control have been established?

How does the monitoring function, and where does it enter into the system?

What are the assessment and adaptation processes and responsibilities in the short and long term?

Are the following considered? Vulnerabilities, resilience, adaptation, adaptability, robustness, social learning.

Source: Rodorff et al. (submitted 2016)

Further reading:

Rodorff V, Siegmund-Schultze M, Köppel J, Hölzl S (2016) Dimensões da boa governança dos recursos naturais para a implementação de boas práticas na gestão sustentável da bacia hidrográfica do rio São Francisco. Poster Presentation. I Simpósio da Bacia Hidrográfica do Rio São Francisco—SBHSF: Integrando conhecimentos científicos em defesa do Velho Chico. June 5-9, 2016, Juazeiro, Brazil.

Rodorff V, Siegmund-Schultze M, Guschal M, Hölzl S, Köppel J (submitted 2016) What makes governance fair in the implementation of sustainable land management? The scenario of biological pest control in Brazil's Northeast. Regional Environmental Change.

6.7 A follow-up concept is an integral part of good governance

For whom: CODEVASF, Municipal and state departments, State and federal agencies, Federal ministries, ANA, Hydropower plant operators, IBAMA, ONS, Watershed committees, NGOs, Associations, Cooperatives, Rural extension services, Institutions of higher education

From whom: Verena Rodorff (verena.rodorff@tu-berlin.de), Marianna Siegmund-Schultze (m.siegmund-schultze@tu-berlin.de), Johann Köppel (johann.koeppel@tu-berlin.de), Maria do Carmo Sobral (msobral@ufpe.br)

Problem: Comprehensive laws and plans exist; however, their implementation is incomplete. Extracted lessons rarely inform future plans.

Key message: It is necessary and very useful to have follow-up, which informs implementation of future plans.

Explanation: Good governance *(compare chapter 6.6 on page 107)* involves participatory, just and transparent approaches. Gaps in accountability and transparency are still widespread, as is access to data and information, which are all relevant for decision-making processes. Follow-up of plans and programs serves to draw lessons from implementation processes and their decision-making in order to inform the elaboration of new plans. This is rarely realized. Monitoring serves to evaluate the efficacy and efficiency of plans and helps to adjust future plans—and in this form is a mechanism of quality control.

Especially, large infrastructure projects (which require the efficient and sustainable use of natural and financial resources) need to be examined prior to their realization

Large (and small) engineering works need to be well-monitored. This helps in tailoring adaptation measures and can inform new projects. *Photo: L Steinmetz* in regard to their probable and potential effects on people and the environment. It is highly relevant to establish a monitoring system after construction in order to assess the further development of the construction and the reliability of the plans.

We analyzed the example of the Itaparica Dam and found a series of programs and plans on different scales. Apparently, there was little connection between the plans. In order to learn about what worked well and what were past errors, it is essential to evaluate actions, interactions and cumulative effects and thus develop an understanding of a past project's impacts. In this way, one takes advantage of earlier activities. Future plans can then incorporate processes that are more just and efficient and measures to avoid, reduce or compensate negative impacts can be more comprehensible.

FURTHER READING:

Rodorff V, Siegmund-Schultze M, Gottwald S, Meckel U, Sobral MC (2013) Effektivität von Staudamm-„Follow-up"-Programmen—25 Jahre nach dem Bau des Itaparica-Reservoirs in Nordost-Brasilien. UVP-report 27 (4+5): 216–223.

Rodorff V, Siegmund-Schultze M, Gottwald S, Sobral MC, Köppel J (2015) Eficácia de Programas de Acompanhamento (Follow-up)—25 anos após a construção do reservatório de Itaparica no Nordeste brasileiro. In: Theodoro HD, Matos F (Eds), Governança e recursos hídricos: Experiências nacionais e internacionais de gestão. D'Plácido, Belo Horizonte, pp. 199–218.

6.8 The implementation of sustainable innovations affects the whole arena of actors and their relationships

For whom: This is a general topic, which has relevance for all stakeholders.

From whom: Verena Rodorff (verena.rodorff@tu-berlin.de), Marianna Siegmund-Schultze (m.siegmund-schultze@tu-berlin.de), Johann Köppel (johann.koeppel@tu-berlin.de)

PROPOSITIONS:

- The analytical view into partial elements often blurs the overall picture.
- Innovations need to match with the local situations, which will be affected by them.
- Constellation Analysis helps to perceive the current as well as the potential future situations (i.e., "constellations").

CONTEXT: INNOVATE members worked on different topics of sustainable land and water management in the São Francisco River Basin and the Itaparica Reservoir region. Each member ultimately aimed at implementing innovations that advance

Concrete actions happen on the ground; the inclusion of all affected groups (here a relocated resident) is necessary. *Photo: M Siegmund-Schultze* the sustainability of the use, conservation, and governance of the natural resources. The implementation of innovations depends on the wider environment, including its actors and their support or interferences. Anticipating these processes builds a basis for preventive measures when preparing for the implementation of innovations.

A portion of the committee members that attended a plenary meeting.
Photo: M Siegmund-Schultze

Constellation of good practices and good governance for sustainable land management: The Itaparica region and the São Francisco River Basin are characterized by natural conditions such as rain or drought, but also by the multiple uses of water and the major technical changes of the last decades, which have had significant social, economic and environmental impacts: the construction of dams for hydroelectric power generation, the increase of irrigated agriculture and aquaculture activities, among others. The constellation unites the scientific results (good practices and models) of the researchers and shows implications for stakeholders.

The goal is to implement good practices in technology, management and governance in the region in order to promote sustainable management. To this end, relationships must be deepened, improved, or established. Crucial elements (especially actors) were collected from previous constellations (Rodorff et al. 2013, 2015) and expanded for the future. The main document of the INNOVATE project for implementing the scientific results is the Guidance Manual, which explains results and recommendations of good practices—all derived from research. Connections with double arrows have been integrated, which indicate actions essential to achieving good governance and sustainable practices through comprehensive and constructive interaction between the actors (see Figure 12). For example, universities and research institutions are powerful players in developing models and practices. Key stakeholders such as farmers' associations or hydropower operators should be involved in the development of new technologies, for example in order to shape them in an accessible, feasible and efficient way.

Governance aspects need to be improved in the region in order to sustain the implementation process. A prerequisite is to invest in education and training in order to increase the power and responsibility of actors and institutions, especially at the municipal level, which possibly need some structural changes. Transparency of data and information is the basis for decision-making. While often short-term planning is viewed as a priority, it is important to plan both in the short- and the long-term. In planning, more transparency is needed in the institutional configurations that exert a privileged influence in the formulation of public policies, for example. The fair and equitable participation of civil society and the private sector in decision-making is paramount. It is important to monitor and, where necessary, improve communication between actors.

Clarifying the roles and responsibilities of the institutions involved facilitates the collaborative process. Mechanisms of quality control and adjustment are needed. To this end, adaptive management is a good choice, certainly with control measures to avoid taking individual advantages to the detriment of others.

Dependencies form barriers to development. At the local level it is necessary to issue land titles—associated with better use of water and land—to the current land owners, and undertake community-based development planning in irrigation schemes as well as other settlement structures. This fosters a common awareness and accountability framework and facilitates access to credit. Monitoring and evaluating the impact of past decisions is crucial for evidence-based decision-making. Similarly, it is important to anticipate potential impacts of decisions made under new conditions.

Further reading:

Rodorff V, Araújo G, Gomes ETA, Köppel J, Siegmund-Schultze M, Sobral MC (2013) 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, MC (Eds) Sustainable Management of Water and Land in Semiarid Areas. Federal University of Pernambuco, Editora Universitária, Recife, pp. 254–268.

Rodorff V, Siegmund-Schultze M, Köppel J, Gomes ETA (2015) Governança da bacia hidrográfica do rio São Francisco: Desafios de escala sob olhares inter e transdisciplinares. Revista Brasileira de Ciências Ambientais 36: 19-44. doi: 10.5327/Z2176-947820151003.

Siegmund-Schultze M, Köppel J, Sobral MC (2015) Balancing ecosystem services and societal demands in a highly managed watershed: setup and progress of a comprehensive research project. Revista Brasileira de Ciências Ambientais, 36: 3-18. doi: 10.5327/Z2176-947820151001.

Siegmund-Schultze M, Köppel J, Sobral MC (submitted 2016) Unraveling the water and land nexus by inter- and transdisciplinary research: overall findings on sustainable land management in a semi-arid watershed in Brazil’s Northeast. Regional Environmental Change.

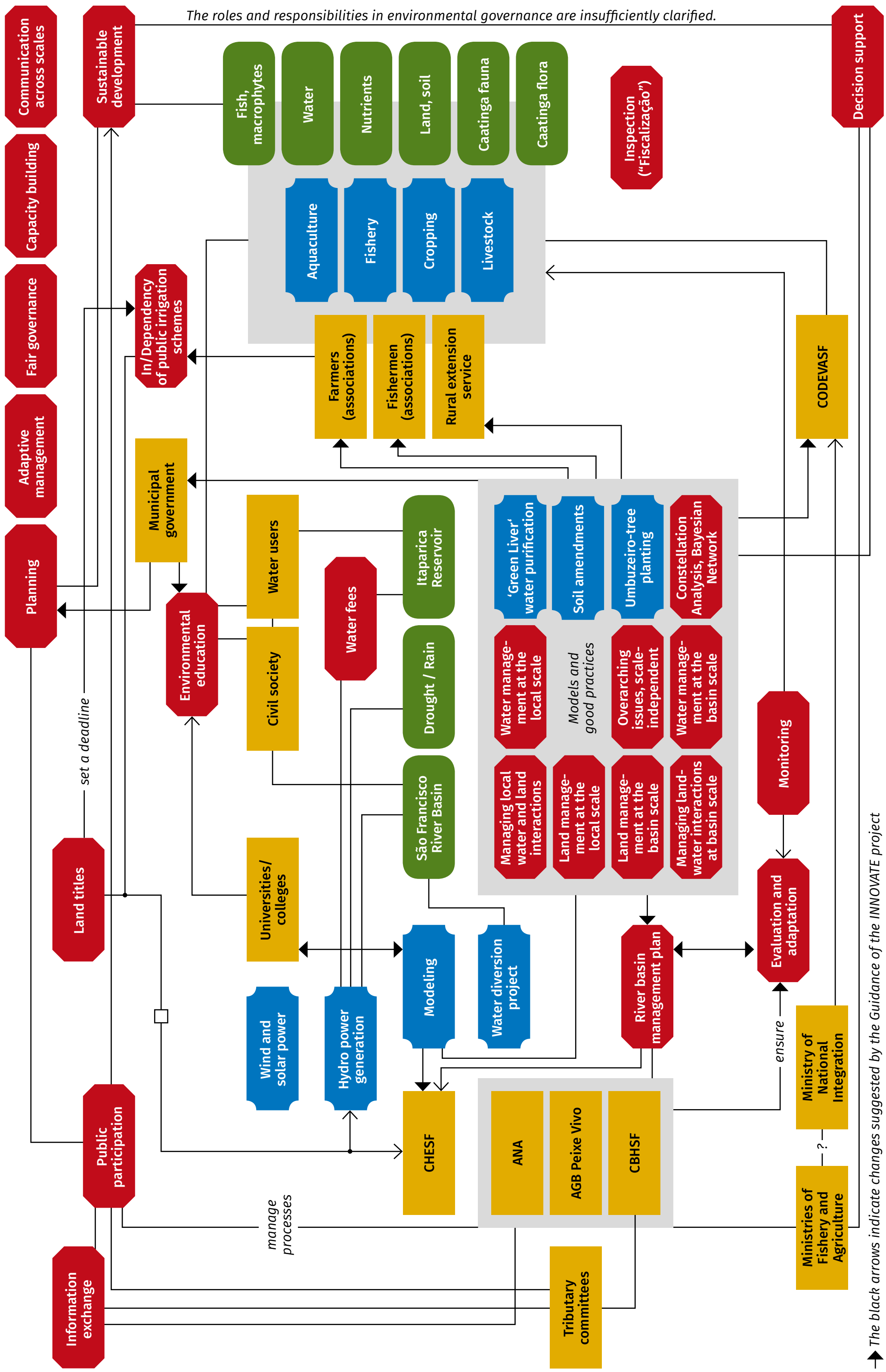


Figure 12 **Constellation of good practices and good governance for sustainable land management of the São Francisco River Basin and the Itaparica Reservoir region**

List of supplementary materials

INNOVATE online

The INNOVATE project websites:

http://www.innovate.tu-berlin.de/v_menue/home/ (English)
http://www.innovate.tu-berlin.de/v_menue/home/parameter/de/ (Portuguese)

The websites will remain online for the time being after the project's end.

You can find the project's scientific publication list on the website:
http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/text_files/Publikationen/INNOVATE_Publication_List.pdf

A list of theses completed in the frame of INNOVATE can be found here:
http://www.innovate.tu-berlin.de/v_menue/theses/

INNOVATE on social media:

https://www.facebook.com/innovate2012/

Written materials for download

Material cross-cutting issues

Booklet "Education Days": In 2014, we did two series of so-called Education Days. The booklet contains short texts and several of the posters presented in the municipalities of Itacuruba, Floresta and Petrolândia. http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/text_files/Books/Cartilha_Dias_de_Educacao_INNOVATE.pdf *(compare chapter 3.4 on page 74)*

Survey summary: the functioning of the CBHSF: The analysis of the Itaparica region has been complemented by studying the governance of the entire watershed of the São Francisco River. The River Basin Committee of the São Francisco River (CBHSF) is considered a major stakeholder for implementing project measures. Find the summary (Portuguese) of a survey realized in 2014 on the functioning of the committee. http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/images/RM_pics/Questionario_INNOVATE_retorno_2014.pdf *(compare chapter 4.10 on page 89) (compare chapter 6.5 on page 105)*

Map of Petrolândia: The quality of maps to be found in the study region is low, but by evaluating the application potential of Public Participation GIS (PPGIS) as an instrument for including social values into ecosystem service (ESS) in a map of the Petrolândia municipality, Sarah Gottwald, in her master thesis, aimed at enhancing the existing cartographic database. http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/images/RM_pics/mapa_Petrolandia_INNOVATE_2015.pdf *(compare chapter 3.3 on page 73)*

Leaflet Constellation Analysis: Constellation Analysis is a bridging concept. It structures the collection of information and organizes it visually in order to derive shared understanding. http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/text_files/flyer/App_Wocat_Constellation_Analysis_EN_INNOVATE.pdf *(compare chapter 6.3 on page 103)*

Leaflet Bayesian Networks: The principle of Bayesian Network modelling is the integration of multiple issues and system components, integrating information from different sources and handling missing data and uncertainty. The outcome may be recommendations that support local management decision-making. http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/text_files/flyer/App_Wocat_Bayesian_Network_EN_INNOVATE.pdf *(compare chapter 6.4 on page 104)*

Biodiversity

Leaflet Caatinga: The leaflet -Caatinga—conhecer para preservar- (knowing in order to preserve) from 2014 explains general features and characteristic plants of the Caatinga biome as well as its important role for the population. While presenting the Caatinga's beauty in text and photos, therefore giving incentives to appreciate nature in general, it aims at promoting and discussing the necessity of sustainable use of tropical dry forests' resources. http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/text_files/flyer/cartilha_caatinga_1INNOVATE.pdf *(compare chapter 2.12 on page 67)*

Leaflet protected areas: Many areas of the Caatinga are degraded through overgrazing and show low tree density and vegetation cover along with bad soils. Protected areas, where the typical species are conserved, are important because they represent source habitats for restoration of degraded or species-poor Caatinga. The leaflet (in Portuguese) gives a practical understanding on how to implement and manage such areas. http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/text_files/flyer/cartilha_reservas_INNOVATE_2016.pdf *(compare chapter 2.11 on page 65)*

Comic *Zé da Jia*: In the leaflet of "*cordel* literature" Zé da Jia explores the benefits of amphibians in combating crop pests. Farmers can take advantage of biodiversity in their cropping areas by maintaining amphibian habitat instead of applying pesticides. https://drive.google.com/file/d/0B0tWL8jSAQQFaEVLcjNFWlEyaGs/view?pref=2&pli=1 *(compare chapter 2.5 on page 56)*

Leaflet biological pest control: The technology described here aims to support and utilize the potential of amphibians (such as frogs and toads) as biocontrol agents—as an alternative to agrochemicals in crops. http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/text_files/flyer/Tech_Wocat_Biological_Pest_Control_EN_INNOVATE.pdf *(compare chapter 2.6 on page 57)(compare chapter 2.4 on page 53)*

Report Serra da Canoa: The Serra da Canoa has been a conservation area since 2012; it has also been suggested that it becomes a priority conservation area. Our project used the Serra da Canoa as a reference for low anthropogenic impacts to compare the diversity of plants, amphibians, and reptiles with other areas of the region (Floresta, Itacuruba, and Petrolândia). The report summarizes the main results of the biodiversity evaluation. http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/text_files/flyer/report_Serra_da_Canoa_INNOVATE.pdf *(compare chapter 2.11 on page 65)*

Sustainable management—Land

Leaflet irrigated agriculture: Irrigation farming often goes along with the intensive use of herbicides and pesticides as well as poor irrigation systems, which may lead to soil salinization. The leaflet (Portuguese) presents sustainable practices which also have the potential to increase production. http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/text_files/flyer/Cartilha_Agricultura_INNOVATE_2016.pdf *(compare chapter 2.4 on page 53)*

Leaflet livestock feed management: Most of the Caatinga area is grazed by goats, sheep, and cattle. Especially during droughts, cacti and *macambira* are used as livestock fodder. The leaflet (Portuguese) gives recommendations of sustainable practices regarding quantities, timing, and methods of animal feed management in the Caatinga. http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/text_files/flyer/cartilha_caprinocultura_INNOVATE_2016.pdf *(compare chapter 2.10 on page 64)*

Leaflets about hay and silage: Feed shortage in the dry season and in drought years is a major challenge and limiting factor for livestock production. With the leaflets on hay and silage (both in Portuguese) we aimed at spreading knowledge about forage conservation as a promising strategy that is still not common among farmers. http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/text_files/flyer/LeafletHay_MS.pdf; http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/text_files/flyer/LeafletSilage_MS.pdf *(compare chapter 2.9 on page 63)*

Sustainable management—Water

Discussion paper on reservoir management: The construction and operation of large dams triggered discussions about the environmental and social benefits and costs. The discussion paper "Towards a more ecologically-oriented reservoir management" analyzed different options for ecological reservoir management by testing release rules for the Sub-Middle and Lower São Francisco River Basin. http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/text_files/flyer/INNOVATE_DiscussionPaper_EcologicalAspectsReservoirManagement-1.pdf *(compare chapter 4.4 on page 80)*

Leaflet green liver water purification: The recent development of commercial aquaculture is threatening water quality in the reservoir through surplus fish feed, droppings, fish pharmaceuticals or when fish pond effluents enter the reservoir without cleaning. The "Green Liver System" uses aquatic plants, established in artificial wetlands, to remove, transfer, stabilize or eliminate pollutants in wastewater from fish farms. http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/text_files/flyer/Tech_Wocat_Green_Liver_EN_INNOVATE.pdf *(compare chapter 1.9 on page 39)*

Aquaponics manual: The aquaponics model is an integrated aquaculture and plant production system allowing for nutrient recycling. We developed a manual with technical instructions and potential research questions. http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/images/RM_pics/RM-Guidance/Aquaponic_Model_System_INNOVATE.pdf *(compare chapter 1.10 on page 43)*

Map of conflicts: artisanal and commercial fisheries: We have mapped present fish farming enterprises in the Itaparica Reservoir. The map indicates areas of conflict with traditional fishery. http://www.innovate.tu-berlin.de/fileadmin/fg123_innovate/images/RM_pics/RM-Guidance/Innovate_Mapa_conflitos_pesca_PT.tif *(compare chapter 1.11 on page 45)*

Videos

INNOVATE members prepared two videos in cooperation with the WOCAT team:

Biological pest control (a technology-explaining video)

Constellation Analysis (an approach-explaining video)

Links to the videos are available at www.wocat.net and http://www.innovate.tu-berlin.de/v_menue/materials_for_stakeholders/parameter/en/. They can directly be watched at: https://vimeo.com/208127666 (Biological Pest Control) and https://vimeo.com/208126454 (Constellation Analysis).

NEXUS, the society and nature working group of UFPE, prepared a video:

Land and water: semi-arid business

It can be watched at: https://www.youtube.com/watch?v=bategCWiIBQ&t=6s.

The WOCAT book: making sense of research

WOCAT is the acronym for World Overview of Conservation Approaches and Technologies (https://www.wocat.net/). We jointly developed a synthesis book for stakeholders based on scientific results of the twelve regional projects within the Sustainable Land Management program (Module A) of the German BMBF (compare: http://www.innovate.tu-berlin.de/v_menue/project_placement/). The book, "Making sense of research for sustainable land management", is in English.

Download the book at: http://www.ufz.de/index.php?en=42205. INNOVATE content is spread throughout the book; check out the topics of your interest.

The metadatabase of INNOVATE

The metadatabase of INNOVATE (the description of data used by the project members); *(compare chapter 6.1 on page 101)* is within the so-called GLUES Catalog. Go to the geoportal website (http://geoportal-glues.ufz.de/index.php) and click on "Data" in the yellow box, or directly enter:

https://catalog-glues.ufz.de/terraCatalog/Start.do;jsessionid=DA0FAF4FE650F550E480AD73D2B11736
Enter in the search line what you are looking for, for instance, start by entering "INNOVATE".

Data and databases on external websites

The following collection of web links facilitates access to some of the data and databases used by INNOVATE. Address validity was last checked in December 2016.

Socio-economics, governance

https://sidra.***ibge***.gov.br/
Statistical data on living conditions, agriculture, and more, up to the municipality scale.

http://***cbhsaofrancisco***.org.br/documentacao/
Documents of the river basin committee.

http://www.***codevasf***.gov.br/principal/perimetros-irrigados/elenco-de-projetos
Characterization of public irrigation schemes run by CODEVASF.

https://www.***embrapa***.br/agropensa/bases-de-dados
Data on agriculture—EMBRAPA.

https://www.bdpa.cnptia.***embrapa***.br/consulta/
Database of agricultural research documents—EMBRAPA.

http://www.***fao***.org/faostat/
FAOSTAT provides free access to food and agriculture data for over 245 countries and territories.

http://www.***snis***.gov.br/
Sanitation and water supply—SNIS.

Geodata, maps

http://mapas.***ibge***.gov.br/interativos
Interactive maps in a GIS-application or census data, starting from the Brazilian macroregions.

http://www.visualizador.***inde***.gov.br/
Visualization tool for geospatial data.

http://sit.***mda***.gov.br/mapa.php
Territorial information system: data and maps by territory on demographic aspects, education, economy, agriculture, and more.

http://sigcabure.***cprh***.pe.gov.br/
The system allows for visualizing themes, such as indigenous and official settlement areas, agroecological and ecological-economic zoning, hydrology, conservation units and biodiversity conservation relevancy, waste disposal.

http://mapas.***mma***.gov.br/i3geo/datadownload.htm
Portal with downloadable Brazilian geographic data on a wide range of topics such as river basins, regional mappings, etc.

http://sigel.***aneel***.gov.br/portal/home/index.html
Geographic data of the electrical sector.

http://metadados.***ana***.gov.br/geonetwork/srv/pt/
GeoNetwork of ANA with cartographic material.

http://www.***apac***.pe.gov.br/sighpe/
Agroecological zoning for the Pernambuco state: contains soil maps and hints for agricultural potential.

http://portalinfohidro.***igam***.mg.gov.br/downloads/mapoteca/4806-bases-cartograficas
Cartographic database of the Minas Gerais state with hydrologic data such as river basins and monitoring.

https://***sosgisbr***.com/
Collection of maps, cartographic bases and reports from environmental studies.

http://www.***snirh***.gov.br/
National information system of water resources, maps and data related to water quantity, quality, and governance—SNIRH.

https://***modis***.gsfc.nasa.gov/; https://lpdaac.usgs.gov/get_data/
Images and list of tools for analysis of MODIS Data (MODIS: satellite images on land use reference, resolution: 0.5°). Check MODIS gallery and tools.

https://lta.cr.usgs.gov/***SRTM***; search tool: https://earthexplorer.usgs.gov/
Page of USGS with data of NASA SRTM (Shuttle Radar Topography Mission): Digital elevation, resolution 90m.

Flora

http://www.virboga.de/collection.php?collection=***itapa***
Flowers of the Caatinga in the Itaparica region—Jörn's online collection.

http://www.hvasf.***univasf***.edu.br/livro/
This is the database of plants of the Caatinga, which accompanies the book "Flora das Caatingas do Rio São Francisco: história natural e conservação".

http://www.***splink***.org.br/
Database of the Brazilian Species Link network.

http://www.***cnip***.org.br/bdpn/index.php
Checklist of plants from Brazil's Northeast region (click checklist in menu on left).

http://www.***theplantlist***.org/
Working list of all known plant species globally.

Fauna

http://www.ansi.okstate.edu/***breeds***/
A database briefly presenting livestock breeds of the world.

http://***amphibiaweb***.org/
A database that provides information on amphibian conservation and taxonomy.

http://www.***fishbase***.org/
A global information system on fish species.

Water

http://www2.***ana***.gov.br/Paginas/institucional/SobreaAna/uorgs/sof/geout.aspx
Water permits released by ANA: Excel files are provided, which can be sorted in many ways (e.g., region, type of intended use). The actual licenses can then be found and downloaded from the web.

http://www2.***ana***.gov.br/Paginas/servicos/saladesituacao/v2/saofrancisco.aspx
Daily water monitoring data in the reservoirs and other locations of the São Francisco River Basin.

http://www.***ana***.gov.br/PortalSuporte/frmSelecaoEstacao.aspx
Data on water levels, sediments, water quality, and others, from selected stations.

http://www.snirh.gov.br/***hidroweb***/
Time series of rainfall and water flow gauges in Brazil.

http://www2.***ana***.gov.br/Paginas/institucional/SobreaAna/resolucoesana.aspx
ANA database with resolutions/licenses, searchable by year.

http://perh.***semarh***.al.gov.br/
Portal of the Alagoas state plan on water resources with reports, graphs, maps and a cartographic/tabular database.

http://www.***apac***.pe.gov.br/sighpe/
Map of Pernambuco with data on rainfall, agrimeteorology, hydrology, reservoirs and their water quality (only state water bodies, hence not including São Francisco River).

https://en.***climate-data***.org/
A webpage with both rainfall and temperature from stations all around the world. We cannot judge the source and quality of the data, although very useful for general information.

http://www.***ons***.org.br/operacao/vazoes_naturais.aspx
Data of historic naturalized water discharges.

http://www.***eu-watch***.org/data_availability
Meteorological data used by global hydrological or land surface models and model outputs produced in the 20th and 21st Centuries.

http://***cmip***-pcmdi.llnl.gov/cmip5/
Climate modeling datasets.

http://www.***moneris***.igb-berlin.de/index.php/moneris-113.html
MONERIS is a nutrient emission model to be used for regional, national and international studies of water quality in catchment areas. It was developed at IGB-Berlin.

http://www.***opentelemac***.org/
TELEMAC-MASCARET modeling system, used for simulations, open source.

http://www.***paraview***.org/
paraView software for visualization of results, open source.

http://www.smileconsult.de/
Software for creating or editing grids/meshes, commercial.

http://www.***fao***.org/nr/water/aquastat/main/index.stm
FAO's global water information system—data and information by country on water resources, water uses, agricultural water management.

Contributing authors, and institutions involved in the INNOVATE project

The contributing authors of the INNOVATE Guidance Manual

Text content has been contributed by people indicated as the lead authors of recommendations and/or those that contributed to the introductory chapters:

Anne Biewald, PIK: senior scientist in Climate Impacts and Vulnerabilities Group, postdoc in impacts of global change within INNOVATE

Arne Cierjacks, TUB: senior scientist in the Department of Ecology, Ecosystem Science / Plant Ecology Group, coordinator of INNOVATE's biodiversity group

Birgit Kleinschmit, TUB: head of the Department of Geoinformation in Environmental Planning

Célia Afonso, TUB: student assistant to the Environmental Assessment and Planning Research Group

Christine Beusch, TUB: doctoral candidate in Soil Science/Ecosystem Science

Christoph Reiber, UHOH: senior scientist in Animal Breeding and Husbandry in the Tropics and Subtropics

Edvânia Gomes, UFPE: full professor in Geography, head of the Nexus research group

Elena Matta, TUB: doctoral candidate in Water Resources Management and Modeling of Hydrosystems

Eliza Maria Xavier Freire, UFRN: professor in the study programs Psychobiology and Development/Environment

Érika Marques, UFPE: doctoral candidate in Development and Environmental Research

Florian Selge, TUB: doctoral candidate/PhD in Environmental Technology/Water Quality Control

Frederike Gröner, IGB: doctoral candidate in Ecophysiology and Aquaculture

Gerald Souza da Silva, UFPE: doctoral candidate in Civil Engineering (Economic Assessment)

Gérsica Nogueira da Silva, UFPE: doctoral candidate in Civil Engineering and Water Resources

Günter Gunkel, TUB: head of the limnology working group within the Department of Water Quality Control, coordinator of INNOVATE's aquatic ecosystem functions group

Hagen Koch, PIK: senior scientist in Climate Impacts and Vulnerabilities Group, co-coordinator of the INNOVATE modeling group and postdoc in down-scaling climate scenarios

Heinrich Hagel, UHOH: doctoral candidate/PhD in Business Management in Agriculture

Janaina Assis de Oliveira, UFPE: doctoral candidate in Civil Engineering in climate variability and climate change scenarios

Jarcilene Almeida-Cortez, UFPE: permanent docent in Plant Biology, Laboratory of Multitrophic Interactions

Johann Köppel, TUB: head of the Environmental Assessment and Planning Research Group

Maiara Melo, UFPE: doctoral candidate/PhD in Development and Environment

Márcia Alcoforado de Moraes, UFPE: professor in Economics, coordinator of INNOVATE's economics group

Marianna Siegmund-Schultze, TUB: senior scientist in animal production systems, INNOVATE's scientific project manager in the Environmental Assessment and Planning Research Group

Maricela Rodriguez, IGB: doctoral candidate in Experimental Limnology

Markus Venohr, IGB: senior scientist in Ecohydrology

Peter Fischer, IGB: doctoral candidate in Ecohydrology

Pierson Barretto, UFPE: postdoc in Environment and Development

Sarah Gottwald, TUB: MSc/student assistant to the Environmental Assessment and Planning Research Group

Sonja Hölzl, TUB: student assistant to the Environmental Assessment and Planning Research Group

Verena Rodorff, TUB: doctoral candidate in the Environmental Assessment and Planning Research Group

The following project members contributed as co-authors:

Ana Lígia Chaves,
Anne Valle Zárate,
Bárbara Laine Ribeiro da Silva,
Clécio Souza Júnior,
Christa Hoffmann,
Christin Höhne,
Déborah Oliveira,
Fernanda Meira Tavares,
Fred Hattermann,
Guilherme José Ferreira de Araújo,
Iaponira Sales de Oliveira,
Jan Mertens,
José Ferreira Irmão,
José Roberto Azevedo,
Karin Stock de Oliveira Souza,
Katharina Schulz,
Liron Steinmetz,
Maike Guschal,
Maria do Carmo Sobral,
Maria Olívia Cano,
Martin Kaupenjohann,
Mira Siemann,
Nailza Arruda,
Peter Casper,
Raphaela Santos da Costa von Gehlen,
Reiner Doluschitz,
Reinhard Hinkelmann,
Rita de Cassia Araújo Pereira,
Robert Koch,
Stephan Pflugmacher-Lima,
Werner Kloas,
Werônica Souza.

Institutions involved in the INNOVATE research project

Institution	Town	Section
Brazil		
Federal University of Pernambuco (UFPE)	Recife	In the Center of Philosophy and Human Sciences: Research Group "NEXUS" of Society and Nature; Postgraduate Program in Environment and Development (PRODEMA) Departments of the Center for Technology and Geoscience: Civil Engineering; Chemical Engineering; Cartographic Engineering Departments of the Center for Natural Sciences: Fundamental Chemistry; Nuclear Energy Department of Botany (Center for Biosciences) Department of Economics (Centre for Applied Social Sciences)
Federal Rural University of Pernambuco (UFRPE)	Recife	Departments: Forest Science; Economics; Animal Production; Veterinary Medicine
Federal Institute of Pernambuco (IFPE)	Recife	Working Groups: Environmental Planning (Sanitary Engineering); Environmental Technology and Bioprocesses (Agronomy); Ecosolutions (Civil Engineering)
Brazilian Agricultural Research Corporation	Recife	EMBRAPA Soils: Research and Development
Agronomic Institute of Pernambuco (IPA)	Recife	Botany Laboratory and Herbarium; Agricultural Systems
Bahia State University (UNEB)	Paulo Afonso	Department of Biology
Federal University of Rio Grande do Norte (UFRN)	Natal	Department of Botany and Zoology

Institution	Town	Section
Federal University of Ceará (UFC)	Fortaleza	Department of Geography
Germany		
Technische Universität Berlin (TUB)	Berlin	Research Groups in the Institute for Landscape Architecture and Environmental Planning: Environmental Assessment and Planning; Geoinformation in Environmental Planning; Landscape Economy Research Groups in the Department of Ecology: Soil Science; Ecosystems Sciences/Plant Ecology; Ecological Impact Research and Ecotoxicology Research Group in the Institute for Civil Engineering: Water Resources Management and Modeling of Hydrosystems Research Group in the Department of Environmental Technology: Water Quality Control
Universität Hohenheim (UHOH)	Stuttgart	Research Groups in the Hans-Ruthenberg Institute of Agricultural Sciences in the Tropics: Agroecology in the Tropics and Subtropics; Animal Breeding and Husbandry in the Tropics and Subtropics Research Group in the Institute of Farm Management: Computer Applications and Business Management in Agriculture
Leibniz-Institute of Freshwater Ecology and Inland Fisheries (IGB)	Berlin	Departments: I Ecohydrology; II Experimental Limnology; V Ecophysiology and Aquaculture; VI Chemical Analytics and Biogeochemistry Program Section: Aquatic Boundaries and Linkages
Potsdam Institute for Climate Impact Research (PIK)	Potsdam	Research Domain II—Climate Impacts & Vulnerabilities Research Domain III—Sustainable Solutions (Working Group on Land Use Management) Department of Global Change and Natural Systems
Senckenberg Natural History Collections Dresden (SNSD)	Dresden	Museum of Zoology (Herpetology)

Note: see the Portuguese version of the Guidance Manual ("Manual de Diretrizes") for the Portuguese group names.

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AAE—SEA Strategic Environmental Assessment *(Avaliação Ambiental Estratégica)*

ADAGRO Livestock and Crop Health Protection and Monitoring Agency of Pernambuco *(Agência de Defesa e Fiscalização Agropecuária de Pernambuco)*

ANA Federal Water Agency *(Agência Nacional de Águas)*

ANEEL Brazilian Electricity Regulatory Agency *(Agência Nacional de Energia Elétrica)*

APAC Pernambucan Agency of Water and Climate *(Agência Pernambucana de Águas e Clima)*

APP Permanently protected area *(Área de Preservação Permanente)*

ATER Agricultural Extension Services *(Assistência Técnica e Extensão Rural na Agricultura Familiar e na Reforma Agrária)*

BA Bahia *(State)*

BMBF German Federal Ministry of Education and Research *(Bundesministerium für Bildung und Forschung—Ministério Federal de Educação e Pesquisa da Alemanha)*

BN Bayesian Networks *(Redes Bayesianas)*

BNDS National Bank for Economic and Social Development *(Banco Nacional de Desenvolvimento Econômico e Social)*

CAPES Coordination for the Improvement of Higher Education Personnel *(Coordenação de Aperfeiçoamento de Pessoal de Nível Superior)*

CBHSF Committee of the São Francisco River Basin *(Comitê da Bacia Hidrográfica do Rio São Franscisco)*

CCR Regional Advisory Boards *(Câmaras Consultivas Regionais)*

CEMIG Power Company of Minas Gerais State *(Companhia Energética de Minas Gerais S.A.)*

CHESF São Francisco Hydroelectric Company *(Companhia Hidrelétrica do São Francisco)*

CNPE Federal Council for Energy Policy *(Conselho Nacional de Política Energética)*

CNPQ Brazilian National Council for Scientific and Technological Development *(Conselho Nacional de Desenvolvimento Científico e Tecnológico)*

CNRH Federal Council for Water Resources *(Conselho Nacional de Recursos Hídricos)*

CODEVASF Development Company for the São Francisco and Parnaíba Valleys *(Companhia de Desenvolvimento dos Vales do São Francisco e Parnaíba)*

COGEPPI Management Committee for the Governance of the Public Irrigation Schemes *(Comitê Gestor de Governança de Perímetros Públicos de Irrigação de Base Familiar)*

COMPESA Pernambucan Sanitation Company *(Companhia Pernambucana de Saneamento)*

CONAMA Federal Council for the Environment *(Conselho Nacional do Meio Ambiente)*

CONSEMA State Council for the Environment *(Conselho Estadual do Meio Ambiente)*

COPASA Sanitation Company of Minas Gerais *(Companhia de Saneamento de Minas Gerais)*

CPP Pastoral Council of Fishermen *(Conselho Pastoral dos Pescadores)*

CPRH Pernambuco State Agency for the Environment [and Water Resources] *(Agência Estadual de Meio Ambiente [e Recursos Hídricos], Pernambuco)*

CPRM Geological Service of Brazil *(Companhia de Pesquisa de Recursos Minerais)*

DNOCS National Department of Works Against the Droughts *(Departamento Nacional de Obras Contra as Secas)*

EMBASA Sanitation Company of Bahia *(Empresa Baiana de Águas e Saneamento)*

EMBRAPA (Solos) Soil Section of the Brazilian Agricultural Research Corporation at Recife *(Empresa Brasileira de Pesquisa Agropecuária)*

EPAMIG Agricultural Research Corporation of Minas Gerais *(Empresa de Pesquisa Agropecuária de Minas Gerais)*

EPE Federal Energy Research Corporation *(Empresa de Pesquisa Energética)*

FAO Food and Agriculture Organization of the United Nations *(Organização das Nações Unidas para a Alimentação e a Agricultura)*

FONA Research for Sustainable Development Framework Program *(Forschung für Nachhaltige Entwicklung—Pesquisa para Desenvolvimento Sustentável)*

FRAGSTATS Spatial Pattern Analysis Program for Categorical Maps *(Programa de Análise de Padrões Espaciais para Mapas Categóricas)*

GHG—GEE Greenhouse gases *(Gases de Efeito Estufa)*

GIS—SIG Geographic Information System *(Sistema de Informação Geográfica)*

GLS Green Liver System *(Sistema de Fígado Verde)*

GLUES Global Assessment of Land Use Dynamics on Greenhouse Gas Emissions and Ecosystem Services *(Avaliação Global de Dinâmicas do Uso da Terra sobre Emissões de Gases de Efeito Estufa e Serviços Ambientais)*

GPS Global positioning system *(Sistema de posicionamento global)*

GWh Gigawatt hours *(Gigawatt-hora)*

HIDROSONDAS Company formerly contracted for irrigation schemes, delivering operation and maintenance

IBAMA Brazilian Institute of Environment and Renewable Natural Resources *(Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis)*

ICMBio Chico Mendes Institute for Biodiversity Conservation *(Instituto Chico Mendes de Conservação da Biodiversidade)*

IF Sertão-PE Federal Institute for Education, Science and Technology of the Pernambucan Hinterland *(Instituto Federal de Educação, Ciência e Tecnologia do Sertão Pernambucano)*

IFPE Federal Institute for Education, Science and Technology of Pernambuco *(Instituto Federal de Educação, Ciência e Tecnologia de Pernambuco)*

IGAM Institute for Water Management of Minas Gerais *(Instituto Mineiro de Gestão das Águas)*

IGB Leibniz Institute of Freshwater Ecology and Inland Fisheries *(Leibniz-Institut für Gewässerökologie und Binnenfischerei—Instituto Leibniz de Ecologia de Água Doce e Pesca Interior)*

INCRA National Institute for Settlements and Agrarian Reform *(Instituto Nacional de Colonização e Reforma Agrária)*

INEMA Institute for the Environment and Water Resources of Bahia *(Instituto do Ambiente e Recursos Hídricos)*

INMET National Institute of Meteorology *(Instituto Nacional de Meteorologia)*

INPE National Institute for Space Research *(Instituto Nacional de Pesquisas Espaciais)*

INNOVATE **In**terplay among multiple uses of water reservoirs via in**nova**tive coupling of substance cycles in **a**quatic and **t**errestrial **e**cosystems *(Interação entre os múltiplos usos da água de reservatórios por meio da conexão de ciclos inovadores em ecossistemas aquáticos e terrestres)*

INSA National Institute for Semi-Arid Regions *(Instituto Nacional do Semiárido)*

IPA Agricultural Institute of Pernambuco *(Instituto Agronômico de Pernambuco)*

IPCC Intergovernmental Panel on Climate Change *(Painel Intergovernamental sobre Mudanças Climáticas)*

ITEP Institute for Technology of Pernambuco *(Instituto de Tecnologia de Pernambuco)*

LO Operation License *(Licença de Operação)*

MCTIC Brazilian Ministry of Science, Technology, Innovation and Communication *(Ministério da Ciência, Tecnologia, Inovações e Comunicações)*—formerly MCTI

MI Ministry of National Integration *(Ministério da Integração Nacional)*

MMA Ministry of the Environment *(Ministério do Meio Ambiente)*

MODIS Moderate-resolution Imaging Spectroradiometer *(Espectrorradiómetro de imagens de resolução espacial moderada)*

MONERIS Modeling Nutrient Emissions in River Systems *(Modelagem de emissão de nutrientes em sistemas fluviais)*

MPA Small Farmers' Movement *(Movimento dos Pequenos Agricultores)*

MW Megawatt

NE Brazil Brazil's Northeast *(Nordeste do Brasil)*

NGO—ONG Non-governmental Organization *(Organização não governamental)*

O & M Operation and Maintenance *(Operação e manutenção)*

ONS Federal Electrical Grid Operator *(Operador Nacional do Sistema Elétrico)*

PAA Family Agriculture Food Purchase Program *(Programa de Aquisição de Alimentos da Agricultura Familiar)*

PE Pernambuco *(State)*

PERH State Plan on Water Resources *(Plano Estadual de Recursos Hídricos)*

PIK Potsdam Institute for Climate Impact Research *(Potsdam-Institut für Klimafolgenforschung—Instituto Potsdam de Pesquisas sobre Impactos Climáticos)*

PISF Water diversion project [of the São Francisco River with river basins north of it] *(Projeto de Integração do Rio São Francisco com as Bacias Hidrográficas do Nordeste Setentrional)*

PLANVASF Directive Plan for the Development of the São Francisco River Valley *(Plano Diretor para o Desenvolvimento do Vale do São Francisco)*

PNAE National School Nourishment Program *(Programa Nacional de Alimentação Escolar)*

PPA Multiannual plan *(Plano plurianual)*

PRHBSF Water Resources Plan of the São Francisco River Basin *(Plano de Recursos Hídricos da Bacia Hidrográfica do São Francisco)*

SEAD Department of Family Agriculture and Rural Development *(Secretaria Especial de Agricultura Familiar e do Desenvolvimento Agrário)*—formerly MDA

SEBRAE Brazilian Micro and Small Enterprises' Support Service *(Serviço Brasileiro de Apoio às Micro e Pequenas Empresas)*

SEMARH State Agency of the Environment and Water Resources, e.g., of Alagoas or Sergipe *(Secretária de Estado do Meio Ambiente e dos Recursos Hídricos)*

SF São Francisco [River]

SINGREH Federal System for Water Resources Management *(Sistema Nacional de Gerenciamento de Recursos Hídricos)*

SLM Sustainable Land Management *(Gestão Sustentável da Terra)*

SNIS National System for Information about Sanitation *(Sistema Nacional de Informações sobre Saneamento)*

SNSD Senckenberg Natural History Collections Dresden *(Senckenberg Naturhistorische Sammlungen Dresden—Museu Senckenberg Coleções de História Natural Dresden)*

SPU Federal Properties Management Office *(Secretaria do Patrimônio da União)*

SUDENE Northeast Region Development Authority *(Superintendência de Desenvolvimento do Nordeste)*

SWOT—FOFA Strengths, Weaknesses, Opportunities, Threats *(Forças, Oportunidades, Fraquezas e Ameaças)*

TAUS Authorization Term for Sustainable Use *(Termo de Autorização de Uso Sustentável)*

TUB Berlin Institute of Technology *(Technische Universität Berlin—Universidade Técnica de Berlim)*

UFPE Federal University of Pernambuco *(Universidade Federal de Pernambuco)*

UFRPE Federal Rural University of Pernambuco *(Universidade Federal Rural de Pernambuco)*

UHOH University of Hohenheim *(Universität Hohenheim—Universidade de Hohenheim)*

UNIVASF Federal University of the São Francisco Valley *(Universidade Federal do Vale do São Francisco)*

UPE University of Pernambuco *(Universidade de Pernambuco)*

WOCAT World Overview of Conservation Approaches and Technologies *(Panorama mundial das abordagens e técnologias de conservação)*

Universitätsverlag der TU Berlin

Guidance Manual – A compilation of actor-relevant content extracted from scientific results of the INNOVATE project

INNOVATE was a comprehensive, collaborative, and binational research project. It ran from January 2012 through December 2016. Brazil and Brazil's Northeast in particular suffered from a severe drought period from 2012 onwards. Management and governance of natural resources faced serious challenges related to access to water. Important long-term drivers that call for recurrent adaptation of actions are land use change, population growth, climate change, and conflicts from the multiple uses of water. The scientific project addressed this complex situation through research aimed at suggesting practices and pathways towards ecologically and socioeconomically sound management of land, water and biodiversity. The INNOVATE project had one focus on the entire watershed of the São Francisco River and another one on a portion of the watershed – the Itaparica Reservoir and the semi-arid area north of the artificial lake. Researchers with different backgrounds worked within their disciplines, in groups (interdisciplinary) and together with stakeholders (transdisciplinary). The Guidance Manual is a compilation of actor-relevant content extracted from the scientific research results. Most recommendations put forward can be adapted as principles and standards for reservoir and semi-arid regions elsewhere in the world.

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SUSTAINABLE LAND MANAGEMENT

MCTI Ministério da Ciência, Tecnologia e Inovação

CNPq Conselho Nacional de Desenvolvimento Científico e Tecnológico

FONA Research for Sustainable Development BMBF

Universidade Federal de Pernambuco