DEVELOPMENT OF AN ENVIRONMENTAL FLOW APPROACH APPLIED TO THE PIABANHA RIVER WATERSHED

Camilla Hellen Peixoto de Lima

Tese de Doutorado apresentada ao Programa de Pós-graduação em Engenharia Civil, COPPE, da Universidade Federal do Rio de Janeiro, como parte dos requisitos necessários à obtenção do título de Doutor em Engenharia Civil.

Orientadores: Renato Nascimento Elias
Stuart Edward Bunn
Francisco Olivera

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Junho de 2019

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DESENVOLVIMENTO DE UMA PROPOSTA METODOLÓGICA PARA ESTUDOS DE VAZÕES AMBIENTAIS NA BACIA DO RIO PIABANHA

Camilla Hellen Peixoto de Lima

Junho/2019

Orientadores: Renato Nascimento Elias
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Programa: Engenharia Civil

Embora no Brasil a ciência das vazões ambientais ainda seja um tema pouco explorado, a estrutura de gestão de recursos hídricos do país apresenta uma grande oportunidade para sua implementação por meio do engajamento de comitês de bacias hidrográficas durante a construção de Planos de Recursos Hídricos. Este estudo propôs uma adaptação da estrutura dos Limites Ecológicos de Alteração Hidrológica (ELOHA) ao contexto de comitês de bacias hidrográficas brasileiras. A adaptação inclui a adição das etapas: envolver/consultar o comitê da bacia hidrográfica por meio de oficinas, questionários e mapeamento participativo; classificação das alterações hidrológicas; proposta de inclusão de uma base ecológica; e propor vazões ambientais com base nas diferentes legislações estaduais e no método de Tennant modificado. As oficinas, questionários e mapeamento participativo foram capazes de facilitar a participação dos membros do comitê de bacias a comunicarem suas necessidades. A bacia não possui alteração hidrológica significativa em seus rios, quando classificados os rios estão em uma condição não impactada e ou de baixo impacto. A hipótese ecologia-alteração hidrológica apontou uma ligação entre as alterações hidrológicas e a riqueza de espécies de peixes. Esses links precisam ser mais investigados. As categorias Excepcional e Excelente do método Tennant forneceram maior proteção do rio em comparação com os métodos brasileiros. Este estudo foi capaz de propor e aplicar uma metodologia de vazões ambientais adaptada ao contexto de comitês de bacia brasileiros.

Abstract of Thesis presented to COPPE/UFRJ as a partial fulfillment of the requirements for the degree of Doctor of Science (D.Sc.)

DEVELOPMENT OF AN ENVIRONMENTAL FLOW APPROACH APPLIED TO THE PIABANHA RIVER

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June/2019

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Although in Brazil the science of environmental flows is still little explored, the structure of water resources management of the country presents a great opportunity for its implementation through the engagement of watershed committees during the construction of Water Resources Plans. This study proposed an adaptation of the Ecological Limits of Hydrologic Alteration (ELOHA) framework to the context of Brazilian watershed committees. The adaptation includes the addition of new steps: engage/consult the watershed committee through workshops, surveys, and participatory mapping; classification of the hydrological alterations; proposal of the inclusion of an ecological foundation; and propose different e-flows recommendations based on the different state legislations and the Tennant method. The workshops, surveys, and participatory mapping were able to facilitate the watershed members to participate and communicate their needs. The basin does not have significant hydrological alteration on its rivers when classified the rivers fall in the category of un-impacted and low impact condition. The flow ecology hypothesis pointed out a link between the hydrological alterations and the fish species richness. These links need to be further investigated. Outstanding and Excellent categories from Tennant method presented the highest values for instream flow protection compared with the current Brazilian methods. This study was able to propose and apply an environmental flow approach adapted to the context of Brazilian watershed committees.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

It is known and described in the literature that the hydrological regime plays a major role in determining the biotic composition, structure, and function of aquatic, wetland and riparian ecosystems (Richter *et al*., 1996). Junk *et al*. (1989) described the flood pulses as a driving force for the biota in river-floodplain systems which is especially affected by the hydrology.

In order to protect freshwater biodiversity and maintain the essential goods and services provided by rivers, scientists agree with the importance to mimic components of natural flow variability, taking into consideration the magnitude, frequency, timing, duration, rate of change and predictability of flow events, and the sequencing of such conditions (Arthington *et al*., 2006).

During their studies, Poff & Ward (1989) created a stream classification system based on multi-site analysis of long-term hydrographs that were decomposed into ecologically relevant flow metrics such as the magnitude, frequency, timing and predictability of extreme flow events (i.e. floods and droughts). Those metrics help to understand how changes in flow can alter the ecosystem. It was an advance which would lead in the future into the creation of several indices to predict the ecological outcome of hydrological alterations (Richter *et al*., 1996, Richter *et al*., 1997).

In addition, Bunn & Arthington (2002) reported the relationship of hydrology with aquatic biodiversity showing that the flow regime plays an important role in the formation of physical habitat in streams, life history strategies of aquatic species and maintenance of natural patterns of longitudinal and lateral connectivity essential to the viability of populations of many riverine species.

The problem lies within the manner that humans use water resources and can alter the natural regime of many rivers. The allocation of water within river basins is usually conducted with a view of the benefit of human beings and /or some species of animals considered important because of its economic value. For example, in some laws as the Brazilian National Policy of Water Resource, when the water resource is scarce the priority use of water is human consumption and watering livestock (Brasil, 1997), while the relevance of maintenance of the riverine ecosystems is pushed aside.

An interesting fact is that Arthington *et al*. (2006) once said that the words river and rivalry have a common etymology in Latin, *rivalis,* marking the age-long conflicts associated with water resources. Freshwater is a finite resource and because of this, in many parts of the world, there are several conflicts over water use and often the environment is ignored in this discussion.

The human intervention leads to rivers all over the world to suffer hydrologic alterations that changed its ecosystems on local, regional and a global scale sometimes these changes are irreversible. Some of the findings from Vörösmarty *et al.* (2010) in a global study was that 80% of the world population lives in an area where the threat to human water security or biodiversity is very high (exceed 75 percentile). The northeast and southeast regions of Brazil are included in the highlighted areas. The study from Vörösmarty *et al.* (2010) also pointed to future problems that the Paraiba do Sul region could have related to water security.

Formiga-Johnsson *et al.* (2007) emphasized that, in southeast Brazil, awareness of water problems has been awakened both by unusual drought events (*e.g.* due environmental change such as deforestation and erosion) and by systematic deterioration of resources as a result of pollution (*e.g.* industrial effluents and discharge of untreated sewage in rivers and lagoons).

Rosenberg *et al*. (2000) report global-scale effects on the environment due to hydrological alterations caused by dam construction and associated water diversion, exploitation of groundwater aquifers, stream channelization, and inter-catchment water transfer. Nilson *et al*. (2005) conducted a global scale studied of dam-based impacts on large river systems and as a result, the authors concluded that over half of the rivers studied were affected by dams.

In the past decades, there has been an increase in studies of the relationship between the hydrological changes and the possible ecological responses and river scientists proposed the release of infrastructure (*e.g.* dams and diversions) flows that met not only for the human purpose but also for the ecological. These studies motivated the creation of the science of environmental flows also known as e-flows.

The field started at the late-1980s with minimum flows focused on singles species, usually with monetary value, and evolved into a comprehensive approach that involves whole-community and ecosystem perspectives (Poff & Matthews, 2013).

Several authors such as Poff & Matthews (2013) and Arthington (2015) adopted the definition of environmental flow as settled at the Brisbane Declaration (2007): “the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems”.

A relevant study on this subject was conducted by Poff & Zimmerman (2010). These authors raised the impacts caused by changes in river flow regime and the response of biota. Furthermore, they highlighted the importance of the development of monitoring programs and use biological data already collected (when available) to reveal important relationships and information gaps to guide research in the science of environmental flows.

Although the topic environmental flows are widely discussed by several authors around the world and environmental flow regimes were adopted in several countries such as USA, Australia, China, and South Africa, in Brazil this topic is still little explored.

Pinto *et al.* (2016) ratify that despite the fact that there is no single flow value capable of conserving an ecosystem, in Brazil, no state or even federal legislation incorporated this issue into its water laws.

After reviewing the Brazilian water law at state and federal level, Benetti *et al.*, (2004) pointed out that e-flows are still in their early stages of development in Brazil and at the state level they are mainly focused in hydrological methods such as minimum average 7-day flow expected to occur once every 10 years, while at the federal level, no environmental flow policy was created.

Souza (2009) affirms that the concept of e-flows is not well known in Brazil and that sometimes people misuse it defining it as the maintenance of low flows downstream.

Collischonn *et al.* (2005) publicize that the current criterion used in Brazil for the maintenance of flows equal to or greater than certain limits (ecological flows) during the dry season does not guarantee the maintenance of the ecosystem.

Pinto (2015) affirms that the remaining minimum flows determined by the Brazilian legislation appear incompatible with the needs for ecosystem maintenance. Apart from this fact, the structure of water resources management in Brazil presents a great opportunity for implementation of environmental flows not just at the local level but for the entire basin as proposed for Poff & Matthews (2013) and Arthington (2015).

1.1. Motivation

The motivation for this work was based on three key points:

(1) Currently, the minimum flows determined by the Brazilian legislation, appears incompatible with the needs for ecosystem maintenance (Collischonn et al., 2005; Amorim et al., 2009; Pinto, 2015; Pinto, 2016).

(2) There is a need to adapt environmental flow method from abroad to be used in Brazil was stated by several authors (Benetti et al., 2004; Farias Júnior, 2006; Longhi & Formiga, 2011).

(3) In Brazil no e-flow study was made in basin scale - for the conservation of rivers and their biodiversity, the ideal unit is the basin (Arthington, 2015).

This approach is possible because the Brazilian National Policy of Water Resources has a foundation based on the premise that the water resources management needs to be decentralized, including the participation of the government, users and civil society. To achieve such goal, the government has created Watershed Committees jointly with the National Water Agency as part of the National Water Resource Management System. The watershed committees must promote discussion of issues related to water resources and coordinate the activities of the entities involved (government, users and civil society). It is also the responsibility of these committees to approve the Water Resources Plans.

Water Resources Plans require data from the system of information about the availability of water in quantity and quality, besides the demands for multiple uses aggregated to the hydrographic basin. They aim to ground and orient the implementation of water policies at the level of basins, defining the priority uses and the investment program for the development, sustainable usage, recovery and conservation of hydrous resources of the basin (Braga *et al*., 2008).

Aforementioned fact creates the opportunity to engage these stakeholders to include and implement environmental flows in the decision-making process of water allocation within the basin. Once Watershed Committees learn about its importance and trade-offs, they have the power to suggest its inclusion in the Water Resources Plans and implement it in a participatory manner that meets the targets of the government, users, civil society, and environment.

This approach tackles the challenge of implementing e-flows mentioned by Pahl-Wostl *et al.* (2013) where the dialogue among scientists, policy-makers, water managers and users and the local population is taken into account to achieve sustainable water usage.

Additionally, this study also involves the Sustainable Development Goal 6 proposed by the United Nations, by trying to ensure availability and sustainable management of water in watershed scale for all, by also addressing the targets 6.5, 6.6 and 6.B in special by supporting local communities to improve water management.

Such idea of using the Brazilian watershed units for managing e-flows is also aligned the statement made by Arthington (2015): for the conservation of rivers and their biodiversity, the ideal unit is the basin its associated supporting resources and hydrological system.

Furthermore, this work addresses the need of an adaptation of environmental flow method from abroad to be used in Brazil as was stated by several authors (e.g. Benetti *et al.*, 2004; Farias Júnior, 2006; Longhi & Formiga, 2011).

As highlighted by Dyson et al. (2008) the absence of environmental flows puts at risk not only the very existence of ecosystems but also people and economies. By redesigning e-flows methods from abroad and start implementing them in basin-scale together with Brazilian watershed committees not only the environment would benefit but all for all the sectors (government, users and civil society).

1.2. Objective

Develop an environmental flow methodology based on the Ecological Limits of Hydrological Alteration (ELOHA) framework adapted to the context of Brazilian watershed committees.

1.3. Goals

During this application the steps developed include:

(1) Design the methodology to be applied;

(2) Select a watershed committee for the study case;

(3) Engage/consult the watershed committee regarding the implementation of environmental flows within the basin;

(4) Gather social, hydrological and ecological data to be used in the study;

(5) Turn the input from the watershed committee through participatory mapping into maps that can communicate their spatial knowledge of the basin;

(6) Generate and validate future water use scenarios within the basin;

(7) Build a hydrological foundation;

(8) Measure the hydrologic alterations that occurred within the basin;

(9) Build an ecological foundation;

(10) Create a relationship between the flow alteration with the ecological response from the ecosystem; and

(11) Propose e-flows recommendations.

1.4. Key question

With the present configuration of the Brazilian National Policy of Water Resource is it possible for Brazilians Watershed Committees to contribute for the proposal of a regime of environmental flows, to be applied at the level of the river basin to improve the water management system?

1.5. Thesis overview

This thesis contains five chapters that will be described as follows:

Chapter 1 is an introduction of the theme of the thesis, its motivation, objective, goals, the key question, and the thesis overview.

Chapter 2 contains the literature review about environmental flows, the history explaining how the field started and why, e-flows methods, future prospects and applications of in Brazil. Besides this, there is some overview of watershed committees structure and legislation in Brazil.

Chapter 3 outlines the methods applied for this study case. It contains the Ecological Limits of Hydrological Alteration (ELOHA) original steps and the suggestion of adaptations for Brazilian watershed committees, a description of the study area, the steps to engage/ consult the watershed committee, the construction of the hydrological and ecological foundation, the hydrological alterations that occurred within the basin and its classification, the flow alteration vs. ecological response proposed links and the environmental flow proposition.

Chapter 4 flows on the discussions of the results found during the proposed study case. This chapter presents the member's consultation inputs and outputs, the hydrological and ecological foundation challenges, the hydrological alterations and classifications, the flow-ecology linkages and the proposed regime of environmental flows.

Chapter 5 contains the conclusion, limitations and futures prospects of this study case.

2. BACKGROUND

2.1. Environmental flows overview

Human population increase, economic development, climate change, and other drivers alter water resource availability and use, resulting in increased risks of extreme low and high flows, drastically altered flow regimes, threats to water quality and water demands surpassing renewable supply (Pahl-Wostl *et al*., 2013).

Pastor *et al*. (2014) conducted a global study of the environmental flow requirements and one of the results was that 37% of the annual discharge would be required to sustain the e-flows and this percentage would increase during low-flow periods (46-71% of average low-flow). But we know that most part of the time human water consumption would require much more than that to sustain its lifestyle.

Besides the fact that the water resource is decreasing its availability through time, an important point of the studies of environmental flows (e-flows) is to recognize that when the river or ecosystem has not been changed it has services to offer.

Human activities all over the globe have caused a change in the environment leading to the decrease of those benefits and sometimes eliminating them. Some examples of how humans can alter the ecosystem and change its services can be seen in Table 1.

Table 1: Threats to freshwater ecosystem services from human activities (Postel & Richter, 2003)

Human activity	Impact on ecosystems	Benefit/ Service at Risk
Dam construction	Alters timing and quantity of river flows, water temperature, nutrient and sediment transport, delta replenishment, blocks fish migrations	Provision of habitat for native species, recreational and commercial fisheries, maintenance of deltas and their economics, the productivity of estuarine fisheries
Dike and levee construction	Destroys hydrologic connection between river and floodplain habitat	Habitat, sport, and commercial fisheries, natural floodplain fertility, natural flood control
Excessive river diversions	Depletes streamflow to damaging levels	Habitat, sport, and commercial fisheries, recreation, pollution dilution, hydropower, transportation
Draining of wetlands	Eliminates key component of the aquatic environment	Natural flood control, habitat for fish and water fowl, recreation, natural water purification
Deforestation/ poor land use	Alters runoff patterns, inhibits natural recharge, files water bodies with silt	Water supply quantity and quality, fish and wildlife habitat, transportation, flood control
Uncontrolled pollution	Diminishes water quality	Water supply, habitat, commercial fisheries, recreation

According to Vörösmarty *et al.* (2018), the availability of renewable and reliable water resources depends on well-functioning environments capable of supporting adequate resources in quantity, quality, and timing.

Dudgeon (2014) present a point of view that biodiversity matters and should be preserved even if the ecosystem doesn't have services to offer for humans with economical values that would justify preserve it for some species. According to this author, the ecosystems services approach could be emphasized when it takes to a better outcome for biodiversity conservation, the reader can see Table 2 that contain major ecosystem services that could be provided by rivers governed by flows.

Table 2: Major ecosystem services of rivers governed by their flows (Gopal, 2016)

Category	Ecosystem service
Provisioning	Making water available (including groundwater) for different uses (domestic, irrigation, hydropower) Water for the transport of materials and people Plant material (for food, fiber, fuel, biochemical Animals (fish, prawn, grazers) for food and other uses Sediments (including gravel) for construction
Regulating	Moderation of microclimate along the river Water quality improvement (waste assimilation) Renewal of soil fertility Erosion control and flood regulation (riparian/floodplain vegetation) Storm protection (through mangroves) in tropics Regional climate (through influence on sea salinity) Regulation of pests and diseases
Supporting	Soil formation (as in floodplains) Habitats for biodiversity (all groups)
Cultural	Water-based recreation and sport Cultural/religious activities Specific spiritual/inspirational links Heritage sites Opportunity for livelihoods Enhanced aesthetics of the riverscape

In a certain point of time, due to the increase of human impacts and consequences scientists started to study the relationship between hydrology changes and impacts on the environment.

Table 3 was proposed by Yang *et al*. (2016) based on a study of 102 papers with environmental flows proposals across the globe. The table portrait the relationships among the number of case studies of environmental flow releases, dam construction and operation, and theoretical advances in environmental flow methodologies. It is possible to see that countries that had a higher number of case studies also had a higher number of dams and environmental flow methodologies (United States).

Table 3: Environmental flow releases case studies information (Yang *et al*., 2016)

Countries	**Case studies of e-flows releases**	**Number of dams constructed (WCD, 2000)**	**Number of e-flows methodologies (Tharme, 2003)**
United States	42	6375	77
Australia	22	486	37
Switzerland	9	-	0
South Africa	8	-	20
China	4	1855	0
France	3	569	10
Germany	3	311	0
United Kingdom	3	517	23
New Zealand	2	-	20
Canada	2	793	22
Japan	1	1077	0
Sweden	1	-	0
Norway	1	335	0
Croatia	1	-	0

Arthington *et al*. (2006) highlight that the acknowledgment that rivers and wetlands require water of good quality to sustain its ecological process and services is recent. Also according to this author, the first e-flow methods were created at late 1940 focusing on minimal flows but that at some point more than 200 methods were developed within four categories: (1) hydrological rules; (2) hydraulic rating methods; (3) habitat simulation methods and; (4) holistic methodologies.

According to Amorim (2009), the holistic methodologies emerged in order to overcome failures found in strictly hydraulic and hydrological methods, especially because they included the needs of the ecosystem and the solutions in a participatory way involving the stakeholders.

Horne *et al.* (2016) reviewed 42 environmental studies worldwide and created a map (see Figure 1) that display different methods usage spatial distribution across the globe Among those 42 studies, 27 used hydrological indices, 13 used habitat-based methods and 2 used population-based methods. It is possible to see that most parts of the regions used hydrological indices and only the USA used the population-based method.

According to Horne *et al.* (2016), this type of models is available there due to the focus of environmental flows on fish species protected by the Endangered Species Act (1973). Befits in using population-based methods include: (1) a population model focusing on the relevant fish species is likely to align with the objectives of an environmental water manager; and (2) ability to evaluate the interactions and sequencing between individual flow releases and their ultimate environmental effect.

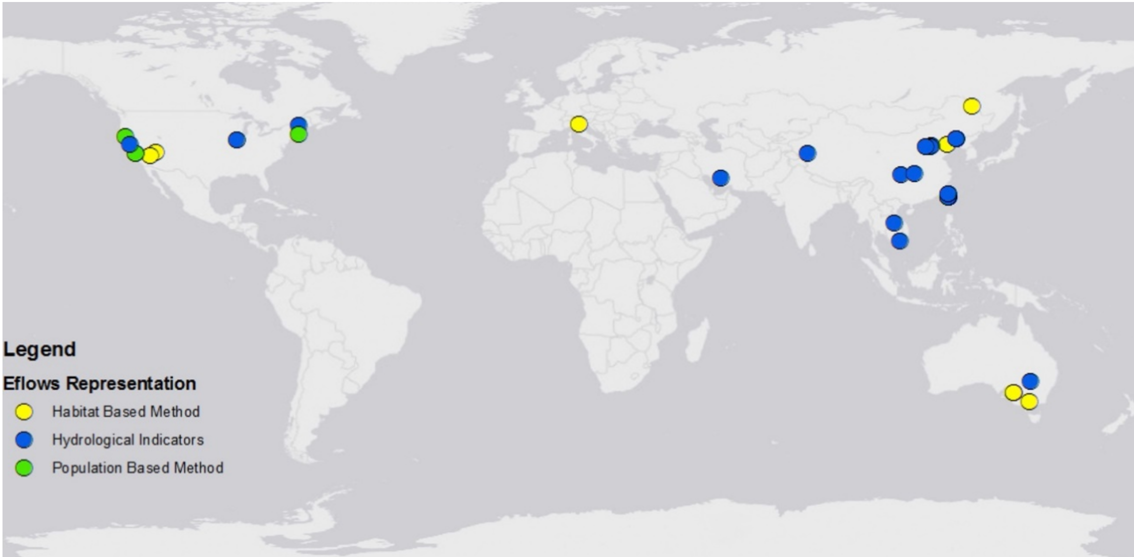

Figure 1: Map of the location of identified studies and the way that environmental water requirements have been represented (Horne *et al*., 2016)

Although each year more and more methods of e-flows are developed not many countries and stakeholders took possession of those to apply at their reach/river/basin/region. Many problems such as lack of data (*e.g.* hydrological, biological, social) and funding can be pointed out as reasons. If there is lack of data to propose a more robust e-flow approach Horne *et al.* (2017) suggest the use of one of the numerous "hydrology only" methods that have been developed to try and set limits on hydrologic alteration.

Yang *et al.* (2016) also found that the effect of environmental flow release projects for biodiversity and ecosystem services were significantly and positively correlated in rivers.

Arthington (2015) commented how complex and urgent freshwater ecosystems protection and restoration will be in the future, but that the existing methods of environmental flows will be able to give choices to society to do so. Another remark was that when these methods are integrated to conservations plans and integrated water resources management, for example, it will lead to an integrated perspective of environmental flows improving its relationship with biodiversity conservation, river basin management, and social-ecological sustainability.

2.2. Environmental flow methods

2.1.1. Ecological Limits of Hydrologic Alteration (ELOHA)

The framework Ecological Limits of Hydrologic Alteration (ELOHA) was developed by Poff *et al*. (2010) and consists of five steps described by the authors:

(1) Build a hydrological foundation - the hydrologic foundation serves several important purposes, such as: facilitates the use of ecological information collected throughout the region, thereby expanding the number of sites that can be used in developing flow alteration-ecological response relationships beyond only those sites having streamflow gauges; provides a basis for comparing present-day flow regimes to baseline conditions; enhances the ability of water managers and planners to understand the cumulative impacts of hydrologic alteration that have already taken place across the region, so that those alterations can be linked to observed changes in ecological conditions and ecosystem services as a basis for forecasting future ecological change in the context of regional water management planning;

(2) Classify river segments based on the similarity of flow regime and geomorphic features - river classification is a statistical process of stratifying natural variation in measured characteristics among a population of streams and rivers to delineate river types that are similar in terms of hydrologic and other environmental features;

(3) Compute hydrological alteration - ELOHA is grounded in the premise that increasing degrees of flow alteration from baseline condition is associated with increasing ecological change;

(4) Develop flow alteration-ecological response relationships - these relationships are hypothesized to vary among the major river types, as ecological responses to the same kind of flow alteration are expected to depend on the natural (historic) flow regime in a given geomorphic context; and

(5) Use flow alteration-ecological response relationships for environmental flow management - flow alteration-ecological response relationships developed for various river types can be used by water managers to guide the development of flow standards for individual rivers or river segments, or for sub-catchments of individual rivers, not just for entire classes of rivers.

For authors such as McManamay *et al*. (2013), Poff *et al*. (2010) and Richter *et al*. (2012), ELOHA is the most holistic regional framework for environmental flow management. The framework with some details in each phase is shown in Figure 2.

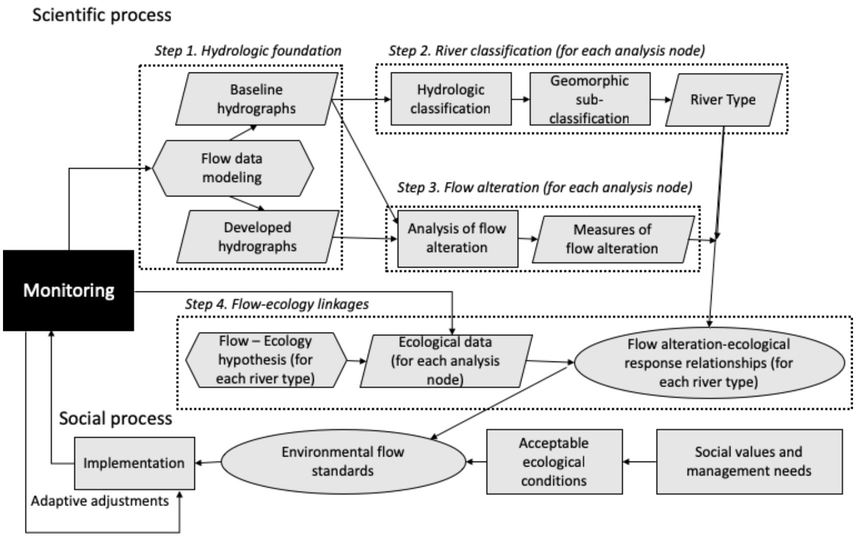

Figure 2: ELOHA Framework (Poff *et al*., 2010)

Due to the fact that ELOHA is a flexible framework, some authors such as Finn & Jackson (2011) proposed changes in its phases. In their study case, the object of study was indigenous values as you can see in Figure 3.

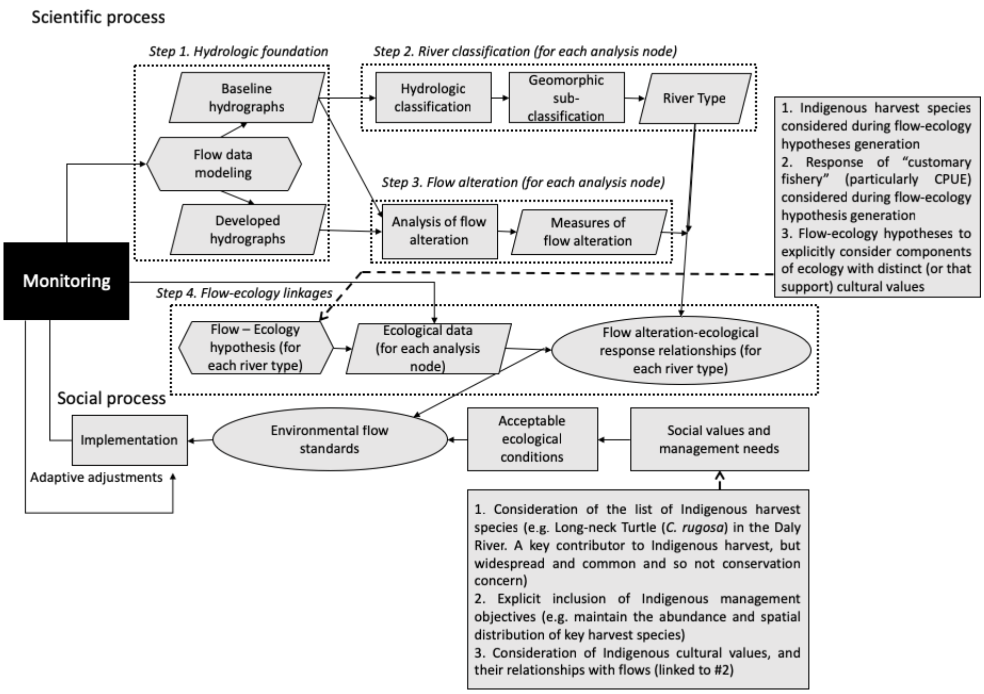

Figure 3: Suggested inclusions in the ELOHA framework to improve its ability to account for indigenous needs (Finn & Jackson, 2011)

2.2.2. Environmental Flow Component (EFC)

The environmental flow components (EFCs) are a set of 34 streamflow statistics computed by the Indicators of Hydrologic Alteration (IHA) software, which is used for environmental flow assessments and developing environmental flow recommendations (Fitzhugh, 2014). The IHA calculates parameters for five different types of Environment Flow Components (EFCs): low flows, extreme low flows, high flow pulses, small floods, and large floods (TNC, 2009). An example of the environmental flow components within a hypothetical year can be seen in Figure 4. Each EFC component type, parameters, and ecosystem influence is described in the following Table 4.

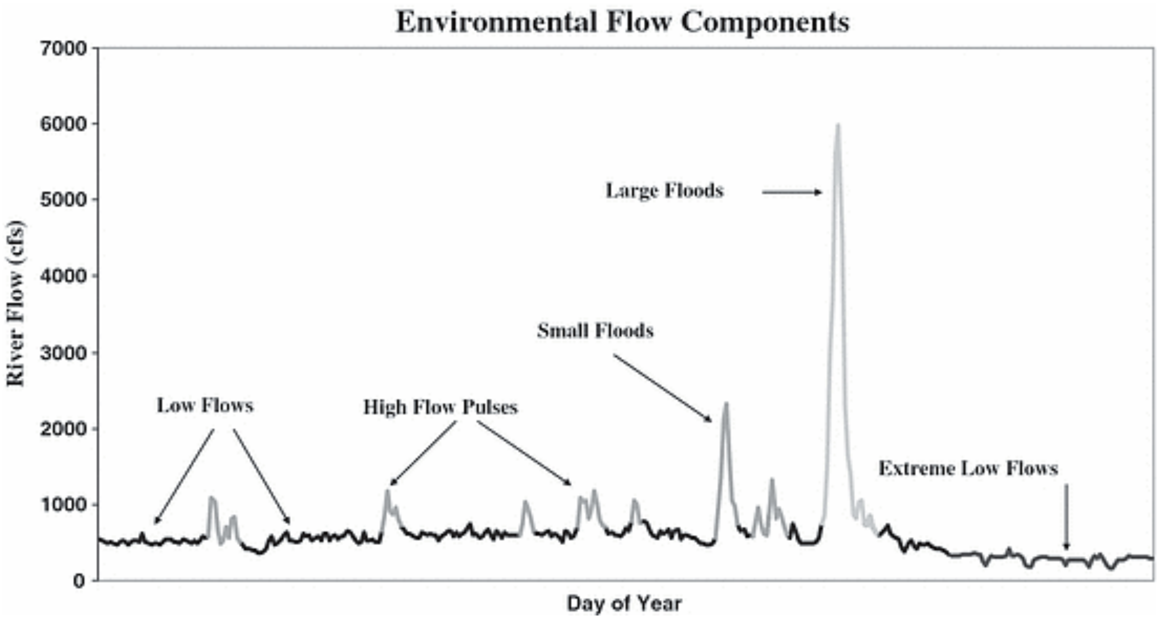

Figure 4: Environmental flow components (Mathews & Richter, 2007)

Table 4: Summary of Environmental Flow Component (EFC) parameters and their Ecosystem Influences (TNC, 2009)

EFC type	Hydrologic Parameters	Ecosystem influences
1. Monthly low flows	Mean or median values of low flows during each calendar month **Subtotal 12 parameters**	Provide adequate habitat for aquatic organisms; Maintain suitable water temperatures, dissolved oxygen, and water chemistry; (… Provide drinking water for terrestrial animals; Keep fish and amphibian eggs suspended; Enable fish to move to feed and spawning areas; Support hyporheic organisms (living saturated sediments)
2. Extreme low flows	Frequency of extreme low flows during each water year or season Mean or median values of extreme low flow event: Duration (days) Peak flow (minimum flow during the event) Timing (Julian date of peak flow) **Subtotal 4 parameters**	Enable recruitment of certain floodplain plant species; Purge invasive, introduced species from aquatic and riparian communities; Concentrate prey into limited areas to benefit predators
3. High flow pulses	Frequency of high flow pulses during each water year or season Mean or median values of high flow pulse event: Duration (days) Peak flow (maximum flow during the event) Timing (Julian date of peak flow) Rise and fall rates **Subtotal 6 parameters**	Shape the physical character of the river channel, including pools, riffles; Determine the size of streambed substrates (sand, gravel, cobble); Prevent riparian vegetation from encroaching into the channel; Restore normal water quality conditions after prolonged low flows, flushing away waste products and pollutants; Aerate eggs in spawning gravels, prevent siltation; Maintain suitable salinity conditions in estuaries
4. Small floods	Frequency of small floods during each water year or season Mean or median values of small flood event: Duration (days) Peak flow (maximum flow during the event) Timing (Julian date of peak flow) Rise and fall rates **Subtotal 6 parameters**	Applies to small and large floods: Provide migration and spawning cues for fish; Trigger new phase in life cycle (i.e insects); Enable fish to spawn in floodplain, provide nursery area for juvenile fish; Provide new feeding opportunities for fish, waterfowl; Recharge floodplain water table; Maintain diversity in floodplain forest types through prolonged inundation (i.e. different plant species have different tolerances);Control distribution and abundance of plants on floodplain; Deposit nutrients on floodplain

Table 4: Continued

EFC type	Hydrologic Parameters	Ecosystem influences
5. Large floods	Frequency of large floods during each water year or season Mean or median values of large flood event: Duration (days) Peak flow (maximum flow during the event) Timing (Julian date of peak flow) Rise and fall rates **Subtotal 6 parameters**	Applies to small and large floods: Maintain balance of species in aquatic and riparian communities; Create sites for recruitment of colonizing plants; Shape physical habitats of floodplain; Deposit gravel and cobbles in spawning areas; Flush organic materials (food) and woody debris (habitat structures) into channel; Purge invasive, introduced species from aquatic and riparian communities; Disburse seeds and fruits of riparian plants; Drive lateral movement of river channel, forming new habitats (secondary channels, oxbow lakes); Provide plant seedlings with prolonged access to soil moisture

2.2.3. BBM – Building Block Methodology

This methodology originates from South-Africa developed by researches and the DWF - South African Department of Water Affairs and Forestry. It was used by King & Louw (1998).

According to Freire (2013), BBM has been used mostly in developing countries because it is based on knowledge and experience of experts and helps to overcome the typical scarcity and fragmentation of secondary data about the studied system. Besides this fact, it is also based on a process that interacts with the community (Tharme, 2003).

King *et al*. (2008) described the use of the BBM as it follows. It has three main parts, which encompass preparations for and running of the BBM Workshop, and follow-up activities that link the workshop with the engineering and planning concerns.

Part one of the Building Block Methodology - preparation for the workshop: A structured set of activities is followed to collect and display the best available information on the river for consideration by the workshop participants.

The sequence is the appointment of a study coordinator; determination of the present habitat integrity of the area likely to be affected by the development; holding of the Planning Meeting; identification of representative reaches and sites within the study area; completion of a social survey of the study area; determination of the importance of the study area; Determination of the Ecological Management Class for the river in the study area; description of the virgin and present daily flow regime; surveying and hydraulic analysis of channel cross-sections at each site; assessment of the geomorphological characteristics of the study area; assessment of the past, present and required future water chemistry of the study area; completion of biological surveys at selected points throughout the study area, and of literature surveys; and for ephemeral, sand bed rivers, analysis of groundwater hydrology at each site

Part two of the Building Block Methodology - the workshop: Each BBM Workshop involves the water managers, engineers and river scientists involved in part one of the methodology. The sequence is: (1) a visit to each site by the full team; (2) the exchange of information; (3) compilation of the Environmental Flow Requirement; and (4) the final session of the workshop.

Part three of the Building Block Methodology - linking environmental and engineering concerns

2.2.4. R2Cross

The Instream Flow Council (2002) called this method as a Standard Setting instream flow-assessment technique. It can also be considered as a riffle-based approach because has its foundation on the assumption that maintaining riffle habitat during summer provides conditions adequate to sustain fish communities in nearby habitats (Armstrong, 2004).

To determine the streamflow requirements for habitat protection in riffles the flows must meet a criterion based on three hydraulic parameters: mean depth, percent of bankfull wetted perimeter, and average water velocity (see Figure 5 and Table 5). Those criteria were developed in Colorado, USA. This method could produce similar results for some sites as ones produced by the Instream Flow Incremental Methodology – IFIM (Espegren,1996).

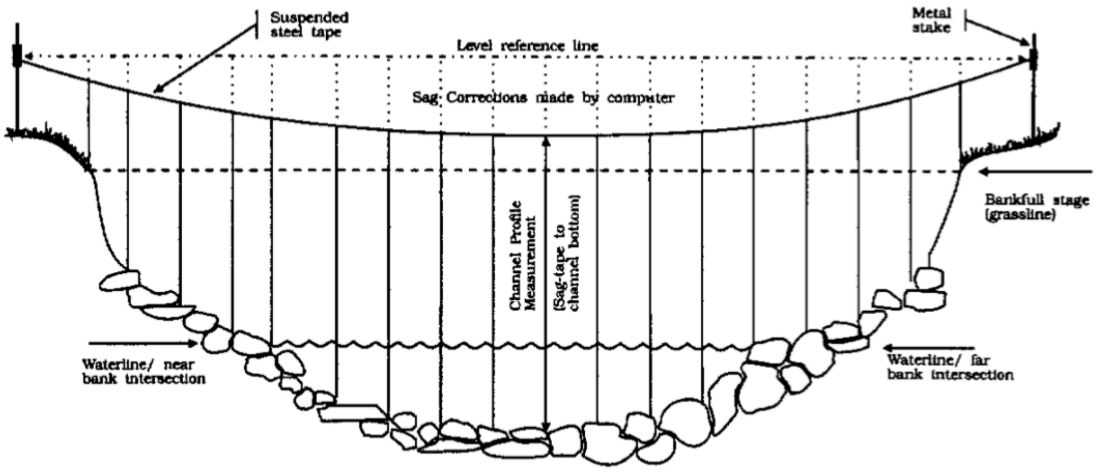

Figure 5: Typical stream cross session (Espegren, 1996)

Table 5: Key flow parameters used to determine minimum flow requirement using R-2 Cross Single Transect Method (Nehring, 1979)

Stream width (ft)	X Average depth (ft)	Z Bankfull wetted perimeter (%)	Y Average velocity (ft/s)
1-20	0.2 or greater	50	1.0
21-40	0.2–0.4	50	1.0
41-60	0.4–0.6	50 to 60	1.0
61-100	0.6–1.0	70 or greater	1.0

2.2.5. Instream Flow Incremental Methodology – IFIM

This methodology is classified as a habitat-based tool. This tool is built to evaluate the environmental effects of different water and land use practices (Bovee, 1986).

It became largely used in some states of the USA such as Idaho, California, Colorado, Washington, and Oregon and it was starting to be expanded in other countries such as Canada e New Zealand (Scott & Shirvell, 1987).

Bovee (1986) described three possible categories of habitats developed in this method (the recommendation was that for the category II and III selection of appropriate area): (1) Category I - criteria are based on professional judgment, with little or no empirical data; (2) Category II - criteria have as their source, microhabitat data collected at locations where target organisms are observed or collected; (3) Category III - correction of the utilization function for environmental availability creates category III, or "preference" criteria, which tend to be much less site-specific than category II criteria.

2.2.6. Tennant/ Montana method

The Tennant method, proposed by Tennant (1976), is also known as Montana Method. It assumes that some proportion of the average annual flow (AAF; synonymous of mean annual flow - MAF) is required to sustain the biological integrity of a river ecosystem and was developed based on original field data collected from 11 rivers in Montana, Nebraska and Wyoming and further supplemented with additional data from hundreds of gauged flow regimens in 21 states (Linnansaari *et al.*, 2012).

Tennant (1976) recommended percentage values of MAF predicted to sustain predefined ecosystem attributes. The recommendations range from 10% of the MAF (severe degradation state) to 200% of the MAF (flushing or maximum), see Table 6.

The low flows and high flows periods were proposed based on the region where the method was developed (North-Central USA), but they can be adapted to other regions to match their low and high flows seasons.

According to Linnansaari *et al*. (2012), 10% of the MAF could sustain short-term survival of aquatic life while > 30% MAF could provide flows where the biological integrity of the river ecosystem as a whole is sustained.

Table 6: Flow recommendations as per the Tennant method (Tennant, 1976)

Description of flows	Recommended flow regime (% of Mean Annual Flow)	
	Oct-Mar (low flows)	**Apr-Sept (high flows)**
Flushing or maximum	200%	
Optimum range	60-100%	
Outstanding	40%	60%
Excellent	30%	50%
Good	20%	40%
Fair or degrading	10%	30%
Poor or minimum	10%	10%
Severe degradation	<10%	

2.2.7. Flow-duration curve (FDC)

The flow-duration curve is a cumulative frequency curve representing the percent of the time during which the average discharge (flow rate) equaled or exceeded a particular value at a given location. It may be based on daily, weekly or monthly values of discharge. According to Gopal (2013) this method, when prepared for long-term data (10-50 years), is useful in assessing the availability of water at a particular location. Because of this reason, several hydrological indices were developed based on it, among those, Q90 and Q95 (daily flows exceeding 90% and 95% of the time respectively).

Although this method was adopted in many countries, such as Brazil, USA, and the UK. There is a debate if the Q90 and Q95 is or is not a method to prescribe environmental flows. Some authors disagree and classify it as highly inadequate to meet environmental flow requirements and even the growth of some fish species (Caissie & El-Jabi, 1995; Annear *et al.,* 2004; Armstrong & Nislow, 2012 cited by Gopal 2013).

2.2.8. 7Q10

This method is a hydrological index that defines the lowest flow recorded for seven consecutive days within a 10-year return period. Despite the fact that is easy to be applied and a popular index around the globe to prescribe environmental flows (also adopted in many states in Brazil) some authors believe that does not represent an environmental flow method and could even lead to degradation of the fisheries and adverse biological effects on aquatic habitats (Tharme, 2003; Annear *et al.,* 2004; Caissie *et al.,* 2007; Richter *et al.,* 2012 cited by Gopal, 2013).

2.3. Future prospects of environmental flows

Many authors made suggestions for future prospects of e-flows, part of them are taken into account in this research. Some examples of suggestions are provided below.

We suggest that a region-by-region and country-by-country analysis using hydrological classification methods combined with ecological calibration could fairly rapidly provide global environmental flow guidelines within the coming decade (Arthington *et al*., 2006).

A global review of scientific advances, methods and implementation progress, the lessons learned, ecological and societal benefits achieved, and emerging socio-ecological perspectives would be a grand theme for the next environmental flows convention (Arthington, 2015).

Pahl-Wostl *et al*. (2013) analyzed the frameworks of environmental flows requirements (EFR) regarding the water governance and identified a clear need for a more systematic approach to EFR analysis on both the natural and social science fronts and, in particular, on the interaction between social/political and environmental systems. It is possible to see in Table 7 that until 2013 amount of environmental studies involving governance, ecosystem services, and stakeholders was very reduced.

Table 7: SCOPUS analysis of the number of publications on selected topics (Pahl-Wostl *et al*., 2013)

Search terms	2000	2005	2008	2010	2011	2013
Environmental flow	17	45	73	111	115	123
Environmental flow AND implementation OR management	3	20	35	59	71	70
Environmental flow AND policy	0	6	10	18	13	15
Environmental flow AND governance	0	3	0	1	4	2
Environmental flow AND ecosystem service	0	0	2	5	6	2
Environmental flow AND stakeholder	0	1	1	4	3	4
Ecosystem service AND governance	1	1	7	31	38	52
Water AND governance	18	58	153	232	288	327
Ecosystem service	36	123	401	841	1018	1199

According to Poff & Matthews (2013), for e-flows to contribute most effectively to sustainable freshwater management on a global scale it is necessary to move from a focus on restoration to one of adaptation to climate and other environmental change stressors; expand its scale from single sites to whole river basins; and broaden its audience to embrace social-ecological sustainability that balances freshwater conservation needs with human well-being in both developing and developed economies alike. The authors also illustrate in Figure 6 the past of the e-flows together with the expected future prospects for the next decade that would include: climate adaptation and global change; governance framework; global e-flow assessment; integrative perspective; poverty alleviation; and socio-ecological sustainability.

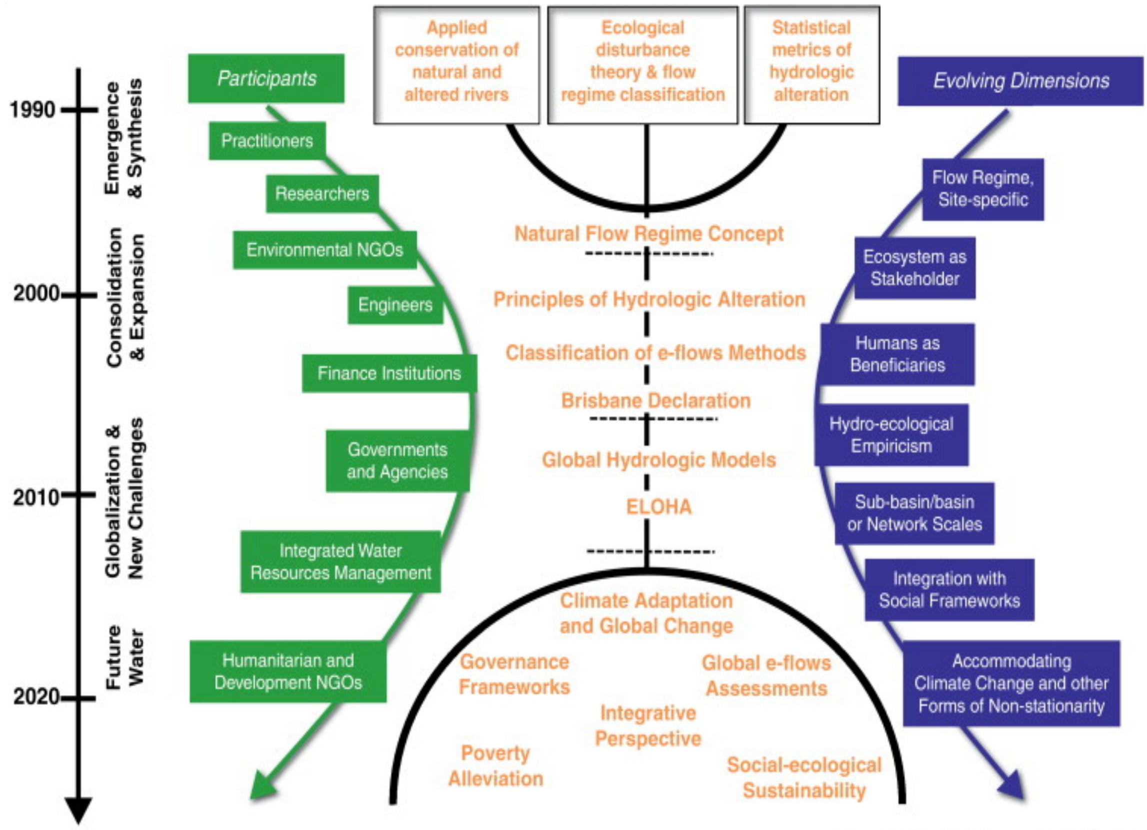

Figure 6: History and prospects of the future e-flows (Poff & Matthews, 2013)

Horne *et al.* (2017) highlight the importance of engaging all stakeholders in the complex processes of the water management cycle. As environmental flow process is advanced and reaching the implementation phase, the link between stakeholder, institutions, processes and govern become essential.

Van Niekerk *et al.* (2019) suggest that future environmental flow studies should also take into account global change pressures such as pollution, living resource exploitation and physical destruction of habitat.

2.4. Application of environmental flows in Brazil

Overall most part of the environmental flow studies conducted in Brazil was based on one or two points within a river or focused on dam operation. Among the 9 studies identified it is possible to find hydrological, hydraulics, habitat and holistic methods (see Figure 7).

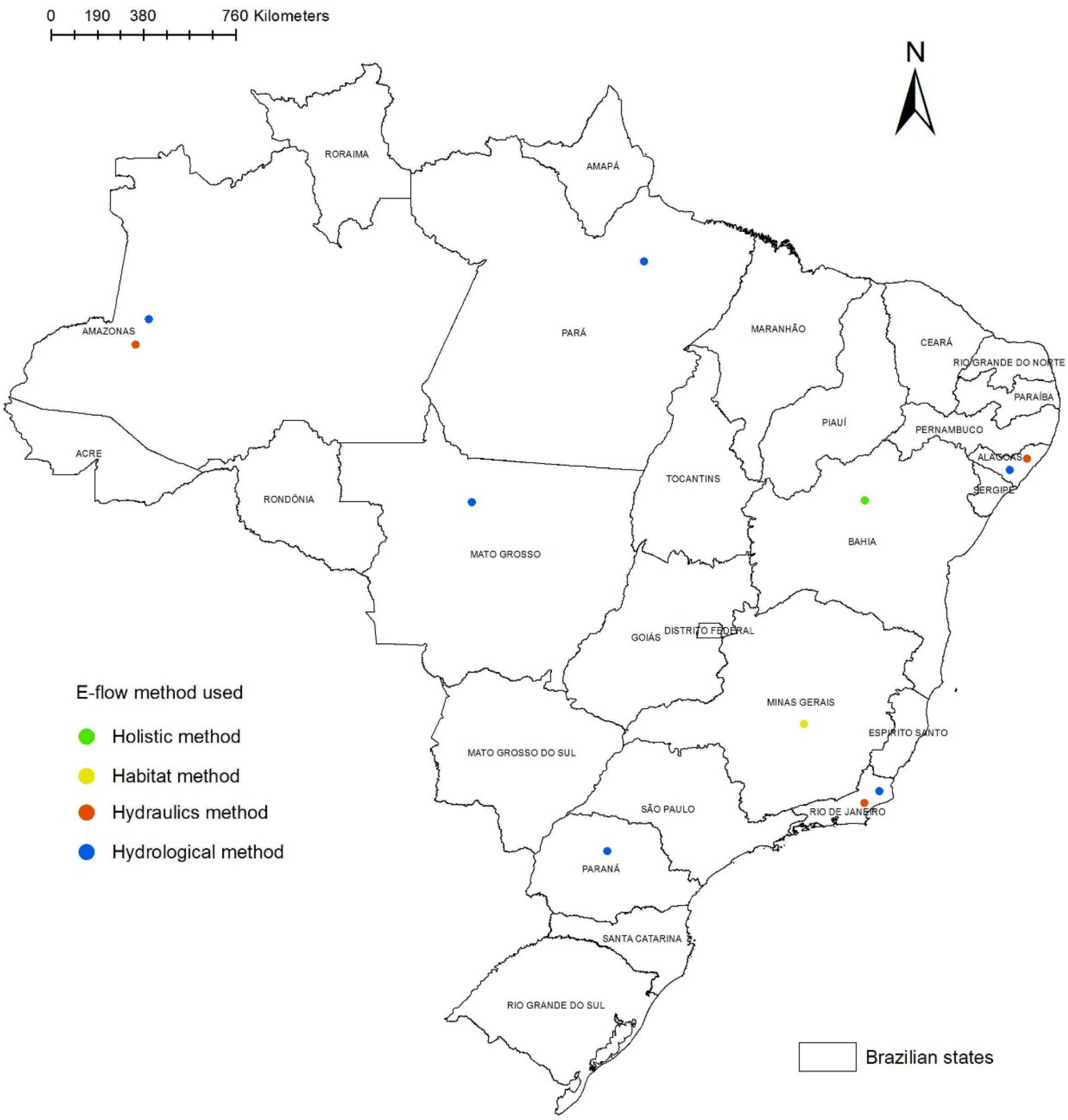

Figure 7: Map of the location of Brazilian e-flow studies and the way that environmental water requirements have been represented

In 2006, a group of the Federal University of Bahia State (Rede Ecovazão, 2010) did what they called “trial study” using the BBM – Building Block Methodology to propose e-flows to change the operation of Sobradinho dam in São Francisco River in the Bahia state.

Farias Júnior (2006) estimated e-flows using hydrological and hydraulic methods for one point of two different rivers, Coruripe River in Alagoas and Solimões River in the Amazon state. The methods used were: 7Q10, the curve of permanence (Q90), Texas, wetted perimeter, Tennant (or Montana) and the basic flow (or mobile average).

Reis (2007) recommended e-flows based on habitat classification models (WAIORA and RHYABSIM) in one reach of the Pará river, downstream the Cajurú hydropower plant, located in the south-central region of the Brazilian state of Minas Gerais.

Souza (2009) proposed a method to subsidize e-flows selection using Indicators of Hydrological Alteration for a study case of two dams in Brazil, Belo Monte located in the Xingu River and Manso in the Brazilian Pantanal.

Vestena *et a*l. (2012) estimated e-flows with the hydrological method of the minimum flow named 7Q10 (minimum flow with 7 days duration within a 10-year recurrence time) with Weibull distribution for reaches of the River “Rio das Pedras”, in the city of Guarapuava, Paraná State.

Silva (2012) determined e-flows with hydrological and hydraulic methods using data of one gaging station for one point of the Piabanha river at the Rio de Janeiro state, Brazil. The methods used were: 7Q10 (Weibull distribution), modified Montana, wetted perimeter and flow-duration curve.

Pinto (2015) proposed environmental flows based on a habitat methodology for two points of a river in Espírito Santo Stream Basin (ESSB), located in Juiz de Fora, Minas Gerais state.

Medeiros *et al.* (2015) provided an e-flow guideline based on BBM for a downstream stretch of Pedra do Cavalo Hydroelectric Power Plant in Bahia state.

Guedes *et al.* (2016) designed an environmental flow regime based on a habitat method in a 1 km stretch of the Formoso River, Minas Gerais state, using River2D model.

2.5. Watershed committees in Brazil

Officially the watershed committee's systems in Brazil were created by the Brazilian National Policy of Water Resources, Law n° 9.433, on January of 1997. Two years later the Brazilian National Water Agency was created (Law n° 9.984 of 2000). These two laws together with state laws play the main role in the expansion of watershed committees in the country.

Formiga-Johnsson *et al.* (2007) affirm that this reform transformed water management by designing a new set of decision-making organisms - especially the river basin committees that include active societal participation.

Although the watershed committee system was established in 1997 the first watershed committee organized with the French administration style was created in 1988. Jocobi & Monteiro (2006) state that the difference between the Brazilian system and the French model (which the Brazilian was patterned after) is that the Brazilian grant basin organizations a decision-making role rather than an advisory one.

The watershed committees are composed by members of the government, water users and civil society. Nowadays there are small and big watershed committees (*e.g.* for Mosquito basin and Paraíba do Sul) and the number of members of each sector and its criteria for selection is established by the bylaws of each committee (Cardoso, 2003).

The story of the first Brazilian watershed committee was summarized by Agência Nacional de Águas (2011): in 1985 many complains about the contamination of the Sinos river mobilized the civil society and technicians to require the increase of inspection related to wastewaters deposited in the river; in 1987, groups of civil society, university, and technicians of the state organized a seminar about this issue and proposed the creating of the Committee for Preservation, Management e Research of the Sinos River; and in the next year (1988), the committee was created by the state decree n. 32.774/1988 with members of the university, civil society, companies, city hall, council men chamber, and other organizations. This was considered the first watershed committee created in Brazil.

The number of state committees in Brazil increased very little since 1988, but after the Brazilian National Policy of Water Resource (1997) to 2010 the number jumped from 23 to 164 state committees and from 1 to 9 interstates committees. The evolution of this scenario in numbers can be seen with more details in Figure 8. Is also possible to see that the creation of the state and national water agency also had an influence in this process.

According to Formiga-Johnsson & Kemper (2005), most parts of the watershed committees were created in the South and Southeast regions and almost all at the state level. It is possible to see this affirmation in a national map, see Figure 9 shows the national distribution of the committees in Brazil from the year 1988 to 2010.

Almost 20 years have passed since the water policy was implemented and many committees were created but according to Brannstrom (2004), despite the fact that the water management was decentralized, and some states developed different models to apply it (*e.g.* Bahia, Paraná, and São Paulo), most parts of them focus on collection of water tariffs.

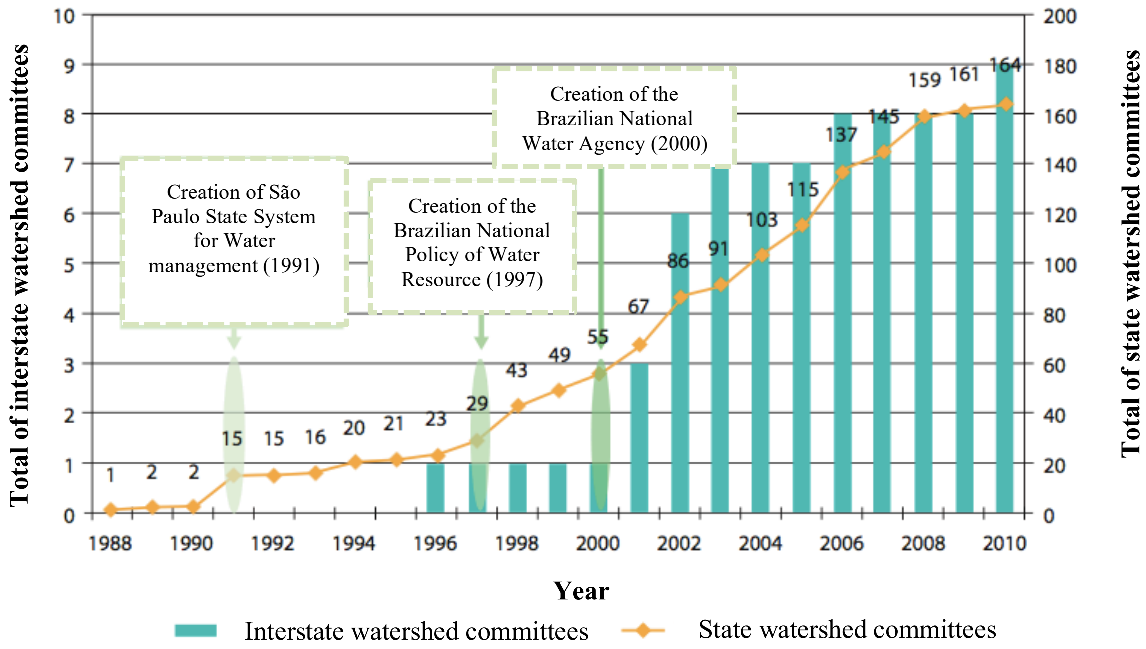

Figure 8: State and interstate watershed committees in numbers since 1988 (Agência Nacional de Águas, 2011)

Create mechanisms for charging for the use of water resources is not the only duty of watershed committees. The Brazilian National Policy of Water Resource attribute to the watershed committees, for example, the duties: to promote the debate on issues related to water resources and articulate the actions of the intervening entities; to arbitrate conflicts related to water resources; and to approve, monitor the Water Resources Plan of the basin and suggest measures necessary to achieve its goals.

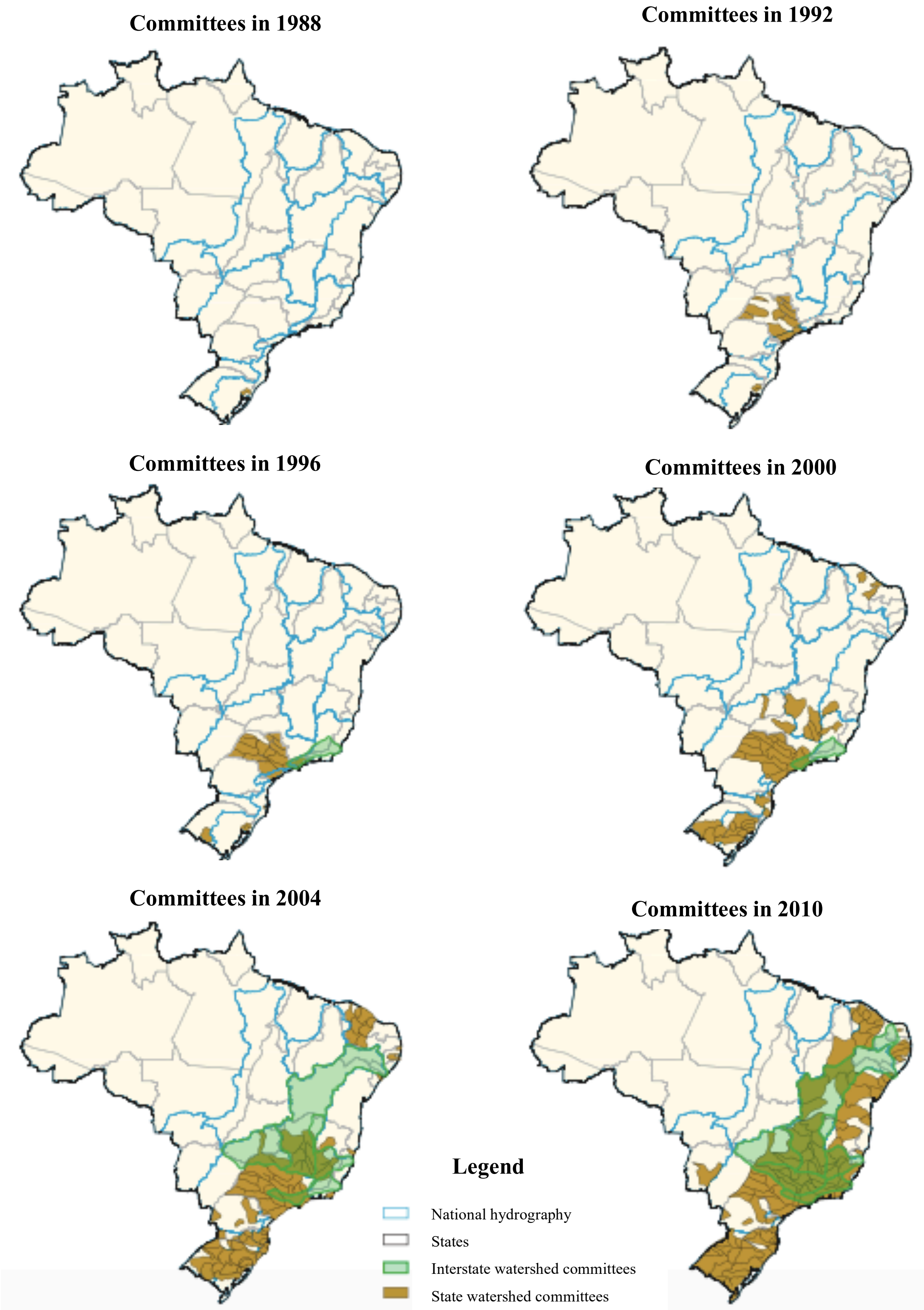

Figure 9: Evolution of the watershed committees in numbers from 1988-2010 (Agência Nacional de Águas, 2011)

In Rio de Janeiro state, the State Water Policy was created in 1999, by the law n° 3.239, in August of 1999 (Brasil, 1999). This law establishes the watershed committees at the state level, stated that they must be recognized and qualified by the State Water Resources Council (CERHI) and their composition as:

(1) users of water and the population concerned, by means of entities legally constituted and with representativeness proven;

(2) entities of civil society, with related actions to water and environmental resources; and

(3) public authorities of municipalities located, wholly or in part, in the basin, and federal and state agencies active in the region and related to water resources.

Fundação Coppetec (2013) report that until the year of 2013 there was installed nine watershed committees in Rio de Janeiro state and that the creation process lasted around 10 years (see Table 8). The distribution of these committees was described in the law Resolução CERHI-RJ nº 107/2013. It defined that the territory of the State of Rio de Janeiro, for the purposes of water resources management, has nine hydrographic regions (see Figure 10): (1) RH I: Região Hidrográfica Baía da Ilha Grande; (2) RH II: Região Hidrográfica Guandu; (3) RH III: Região Hidrográfica Médio Paraíba do Sul; (4) RH IV: Região Hidrográfica Piabanha; (5) RH V: Região Hidrográfica Baía de Guanabara; (6) RH VI: Região Hidrográfica Lagos São João; (7) RH VII: Região Hidrográfica Rio Dois Rios; (8) RH VIII: Região Hidrográfica Macaé e das Ostras; and (9) RH IX: Região Hidrográfica Baixo Paraíba do Sul e Itabapoana.

Table 8: Rio de Janeiro watershed committees’ creation timeline (ANA, 2019)

Date of creation	Region	Watershed committee	Law of creation
03/04/2002	RH II	CBH do Rio Guandu	Dec. 31.178
08/12/2004	RH VI	CBH Lagos São João	Dec. 36.733
04/11/2003	RH VIII	CBH dos Rios Macaé e das Ostras	Dec. 34.243
14/09/2005	RH IV	CBH do Rio Piabanha	Dec. 38.235
08/12/2004	RH V	CBH da Baia de Guanabara	Dec. 38.260
11/09/2008	RH VII	CBH Rio Dois Rios	Dec. 41.472
11/09/2008	RH III	CBH Médio Paraíba do Sul	Dec. 41.475
03/03/2009	RH IX	CBH Baixo Paraíba do Sul e Itabapoana	Dec. 41.720
07/10/2011	RH I	CBH da Baía da Ilha Grande	Dec. 43.226

Figure 10: Rio de Janeiro hydrographic regions (Brasil, 2013)

3. METHODOLOGY

3.1. Ecological Limits of Hydrologic Alteration (ELOHA) framework adaptation

As described in the background session ELOHA framework was developed by Poff *et al.* (2010) and consists in five steps: (1) Build a hydrological foundation; (2) Classify river segments based on similarity of flow regime and geomorphic features; (3) Compute hydrological alteration; (4) Develop flow alteration-ecological response relationships; and (5) Use flow alteration-ecological response relationships for environmental flow management.

McManamay *et al.* (2013), Poff *et al.* (2010) and Richter *et al.* (2012) consider ELOHA as the most holistic regional framework for environmental flow management.

In previous studies authors as Finn & Jackson (2011) proposed changes on ELOHA as well, their object of study was indigenous values. Pahl-Wostl *et al.* (2013) renamed the alterations based on ELOHA to Sustainable Management of Hydrological Alterations (SUMHA) Framework. It had the social sciences as an essential part of the assessment, without a distinction between scientific and social processes.

Because of the framework flexibility and capacity of adaptation to different focus ELOHA was chosen to be applied in this case study. The proposed adaptation of the ELOHA framework to be applied for Brazilian watershed committees can be seen in Figure 11, it includes the following steps:

(1) Engage/consult the watershed committee;

(2) Build a hydrological foundation;

(3) Classify river segments based on the similarity of flow regime and geomorphic features;

(4) Compute the hydrological alteration and its classification;

(5) Build an ecological foundation;

(6) Develop flow alteration-ecological response relationships; and

(7) Use flow alteration-ecological response relationships for environmental flow management.

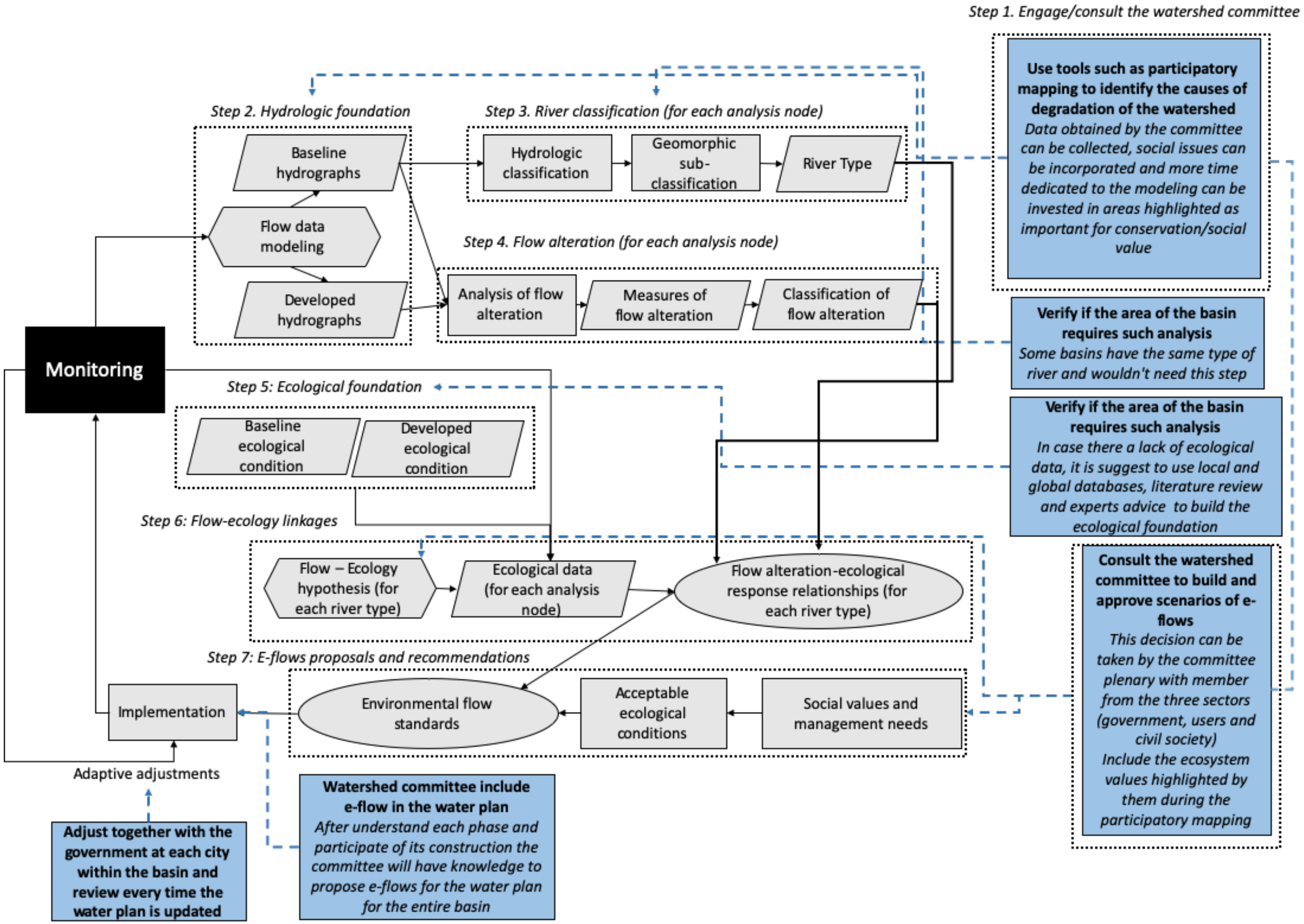

Figure 11: Adaptation of the ELOHA framework structure (modified from Poff *et al*., 2010)

The seven proposed steps from the ELOHA adaptation are going to be described in detail in this chapter. The proposed framework makes no distinction between the scientific process and the social process and needs to be started by a moderator.

The framework application started by the moderator (the author of this thesis) with the Step 1 applied in a study case within a Brazilian watershed committee. The Piabanha watershed was selected because:

(1) was subject of several projects at the Federal University of Rio de Janeiro (Universidade Federal do Rio de Janeiro - UFRJ) which facilitates in obtaining hydrological, ecological, and social data;

(2) has a watershed committee that agreed to collaborate with this research;

(3) plays an important role to the Southeast region of Brazil, because it is a tributary of the Paraíba do Sul River, which has socioeconomic relevance for the State of Rio de Janeiro (area that produces crops); and

(4) it is one of the last preserved fragments of Atlantic Forest of the Rio de Janeiro region.

The following session provides more details about the study area and after that there is a description of the steps used during the ELOHA adaptation.

3.2. Study area

3.2.1. Location

The case study was conducted at the Piabanha basin, located in the state of Rio de Janeiro in Brazil (see Figure 12). This basin has four major rivers (Fagundes, Piabanha, Preto and Paquequer) and is a sub-basin of a federal river basin, the Paraíba do Sul river basin. While the total area of drainage for the Piabanha basin is 2065 km^2, Paraíba do Sul drainage area is as large as 55000 km^2 (de Paula, 2011; Molinari, 2015).

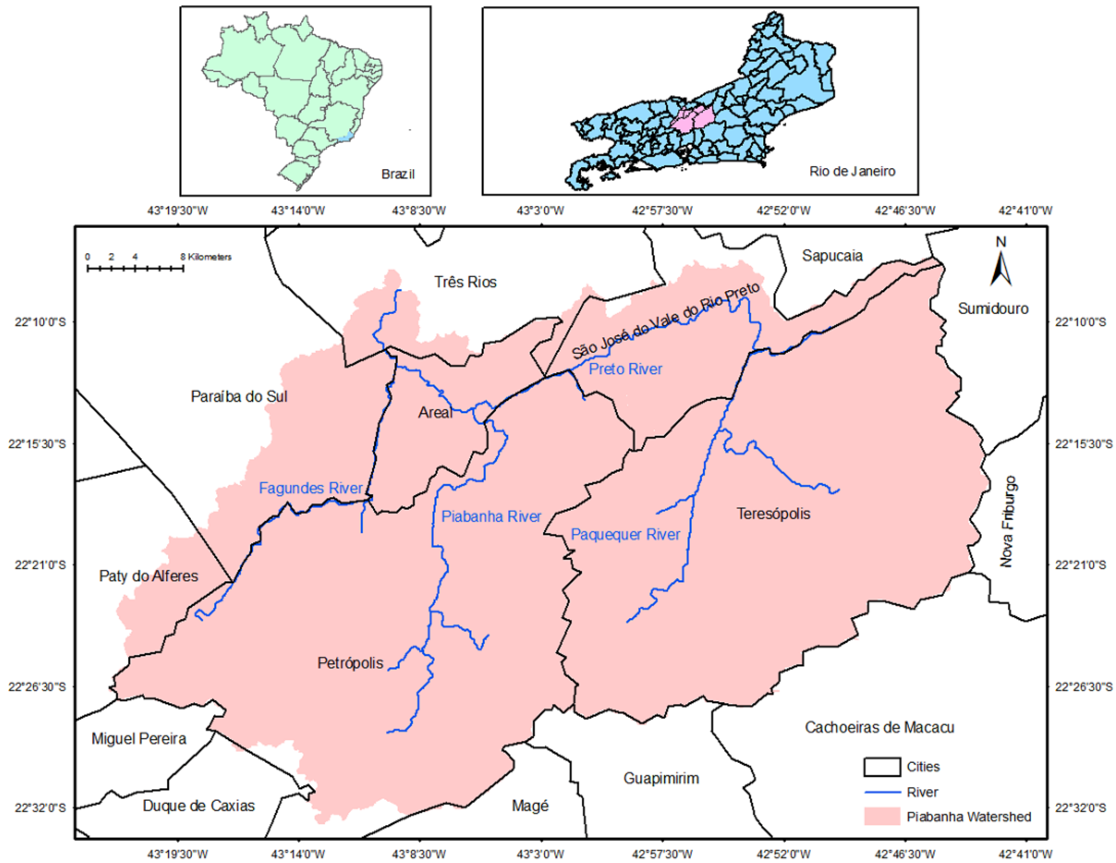

Figure 12: Piabanha River Basin

Within Piabanha basin there are seven cities. Some have almost its entire area inside the basin, while other only a small portion. The cities are: Areal, Paraíba do Sul, Paty Alferes, Petrópolis, São José do Vale do Rio Preto, Teresópolis, Três Rios. The total area of each city and also the portion within the basin was described by Rosário (2013) shown in Table 9.

This author also described the categories of soil and land along with its distribution within the basin (see Table 10). At least 54% of the basin is still remains as forest, reforestation or early stage of secondary vegetation.

Table 9: Cities within the Piabanha basin and its respective area and portion inside the basin (Rosário, 2013)

City	Total area (km²)	% within the basin
Areal	111.5	100
Paraíba do Sul	580.2	23.5
Paty Alferes	319.7	13.9
Petrópolis	773.2	94.8
São José do Vale do Rio Preto	240.0	84.1
Teresópolis	776.3	100
Três Rios	323.8	17.2

Table 10: Categories of soil and land use along with its distribution in the Piabanha basin (Rosário, 2013)

Soil and land use	Area (km^2)	%
Rocky outcrop	83.03	4.03
Agriculture	43.67	2.12
Coffee agriculture	3.82	0.19
Forest	979.77	47.58
Urban occupation of low density	17.79	0.86
Urban occupation of medium density	64.92	3.15
Pasture	724.03	35.16
Pasture in floodplain	0.18	0.01
Reforestation	0.21	0.01
Early-stage of secondary vegetation	138.71	6.74
Water	3.10	0.15

3.2.2. Population growth

The occupation of the land at the Piabanha basin started at beginning of the XIX century and the proximity to the Rio de Janeiro city affected the number of people that migrated to the region (Lou, 2010).

The major city in terms of population, Petrópolis, had its occupation mainly influenced by the textile industry. According to Plácido & Cunha (2010) in the 1940s the number of residents in Petrópolis was 75418. Two decades later (1960) the population doubled reaching 150300 residents, ten years later (1970) the city had 189140 residents. It was only between the years of 1964 -1975 that the urban area started to expand to the river’s perimeter.

Population growth for cities that have at least 80% of the territory within the basin from the decade of 1960 to 2018 can be seen in Table 11. From the 1980s to 2018 all the cities present a major growth in the number of residents, for Teresópolis and Areal the population doubled. In Petrópolis, which is the biggest city in terms of population, from the 1960s to 2018 the number of residents was also duplicated.

The change in % of the urban and rural area for cities that have at least 80% of the territory within the basin from the decade of 1970 to 2010 can be seen in Table 12 and 13. Petrópolis, Teresópolis, and Areal currently have at least 80% of its territory classified as urban areas. Only São José do Vale do Rio Preto remains mainly rural area.

Table 11: Population within the basin between years of 1980 to 2018 (IBGE, 2018)

City	1980	1991	2000	2010	2018
Petrópolis	242009	256673	287318	295917	305687
Teresópolis	98705	120709	138081	163746	180886
São José do Vale do Rio Preto	-	15169	18644	20251	21670
Areal	6295	8228	9899	11423	12471

Table 12: Change in % of the urban area between 1970 - 2010 (IBGE, 2018)

City	1970	1980	1991	2000	2010
Petrópolis	81.71	83.55	97.5	94.46	95.06
Teresópolis	73.33	80.03	83.85	83.43	89.29
São José do Vale do Rio Preto	-	-	46.48	46.72	44.48
Areal	-	-	-	90.45	86.87

Table 13: Change in % of the rural area between 1970 - 2010 (IBGE, 2018)

City	1970	1980	1991	2000	2010
Petrópolis	18.29	16.45	2.5	5.54	4.94
Teresópolis	26.67	19.97	16.15	16.57	10.71
São José do Vale do Rio Preto	-	-	53.52	53.28	55.52
Areal	-	-	-	9.55	13.13

3.2.3. Environmental impacts

The state environmental agency of Rio de Janeiro listed some of the major impacts at the Piabanha basin: irregular occupation of the land and soil movement in areas of permanent preservation; discharge of industrial effluents and untreated sewage into water bodies; deforestation of the Atlantic Forest fragments within the region; action hunters against the abundant wildlife of the region; intensive use of pesticides in rural areas; and fires in the forest (Instituto Estadual do Ambiente, 2016).

Although the basin area has half of the wastewater collected (54,7%) not even half of this amount is treated before reaching the rivers, only 14,6% (Agência da Bacia do Rio Paraíba do Sul – AGEVAP, 2016). Another water quality issue, which was highlighted by Carvalho Junior (2013) is the fact that many crops are cultivated close to the river banks and reaches in areas of permanent preservation which can compromise the water quality of the rivers due to the use of pesticides.

Silva *et al*. (2013) analyzed the temporal variation of the Normalized Difference Vegetation Index (NDVI) between the years 2000 and 2011 and pointed out that vegetation has been reduced. They suggested further studies with that index to help find out how much vegetation has been lost over the years and the actual state of the basin.

Silva (2014) also studied the decrease in vegetation between the years 1986 to 1998 attributing it to anthropogenic changes. The loss of vegetation within the basin is extremely linked to the increase of population, deforestation of the Atlantic forest to grow crops and use for pasture and the fires as pointed by the Instituto Estadual do Ambiente (2016) and Silva (2014).

Due to the concentration of rainfall in the summer, disorderly urban growth, increased surface runoff and soil sealing the city strong flood occur and affect the city of Petrópolis (Plácido & Cunha, 2010)

The rapid speed of drainage of the water within the Piabanha basin is favored by the presence of steep slopes, intense rainfalls and by the increase of the urbanization in the region, these factors, acting together with interventions in the river canals, contribute to the change in the hydrological pattern of the rivers, causing sedimentation and flooding in urban areas (Vieira & Da Cunha, 2008; Lou, 2010; Silva *et al*., 2012 cited by Marques *et al.*, 2017).

3.2.4. *Climate and hydrological regime*

Costa (2014) described the basin as the tropical wet weather in the mountainous region with average and low temperatures. The marshlands regions have a sub-humid climate and its temperature vary during summer and winter. In the cities of Petrópolis and Teresópolis at their steep slopes, the average annual rainfall can exceed 2.500 mm.

The hydrological year starts on September where the higher measures of flow occur in December, January, February and March and the low flows in July, August, and September (Mascarenhas, 2007; Villas Boas, 2018).

The watershed time of concentration (response of a watershed to a rain event) at Pedro does Rio streamflow station is eight hours (Gonçalves, 2008; Araujo, 2016). According to Villas Boas (2018), the short time of concentration in Piabanha basin is influenced by the physiographic characteristics of the basin, this characteristic also influences the small duration of maximum flows.

Rosário (2013) described that almost 47% of the relief of Piabanha Basin is mountains and some of the altitudes can surpass 2000 m. The relief has levels from 500 m to 2000 m (Costa, 2014).

The rain distribution was discussed by Araujo (2016). The author presented the average rain distribution for years of 1939-2015 (see Figure 13) in stations within the Piabanha basin. The rain season starts in September and lasts until April, while the driest period occurs between June to August. There is a similarity between the series of 2243010 and 2243011 stations and 2243012 stations presented less rainfall and more asymmetrical distribution. The 2243268 station has higher average values during the year.

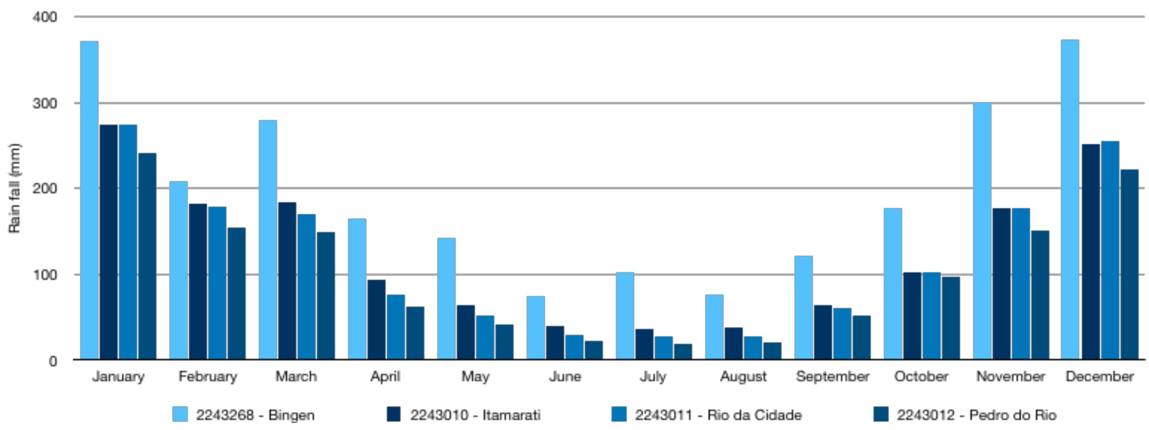

Figure 13: Monthly mean rainfall between 1939-2015 (Araujo, 2016)

Marques *et al.* (2017) studied rainfall vs. flow correlations within the Piabanha basin. These authors identified a good correlation between rainfall and stream gauges data (R^2 between 0.55-0.58) and also a cyclicity of about 15 years bounded by the driest years as shown in Figure 14. The R^2 for Moura Brasil (streamflow) vs. Sobradinho (rainfall) was 0.57.

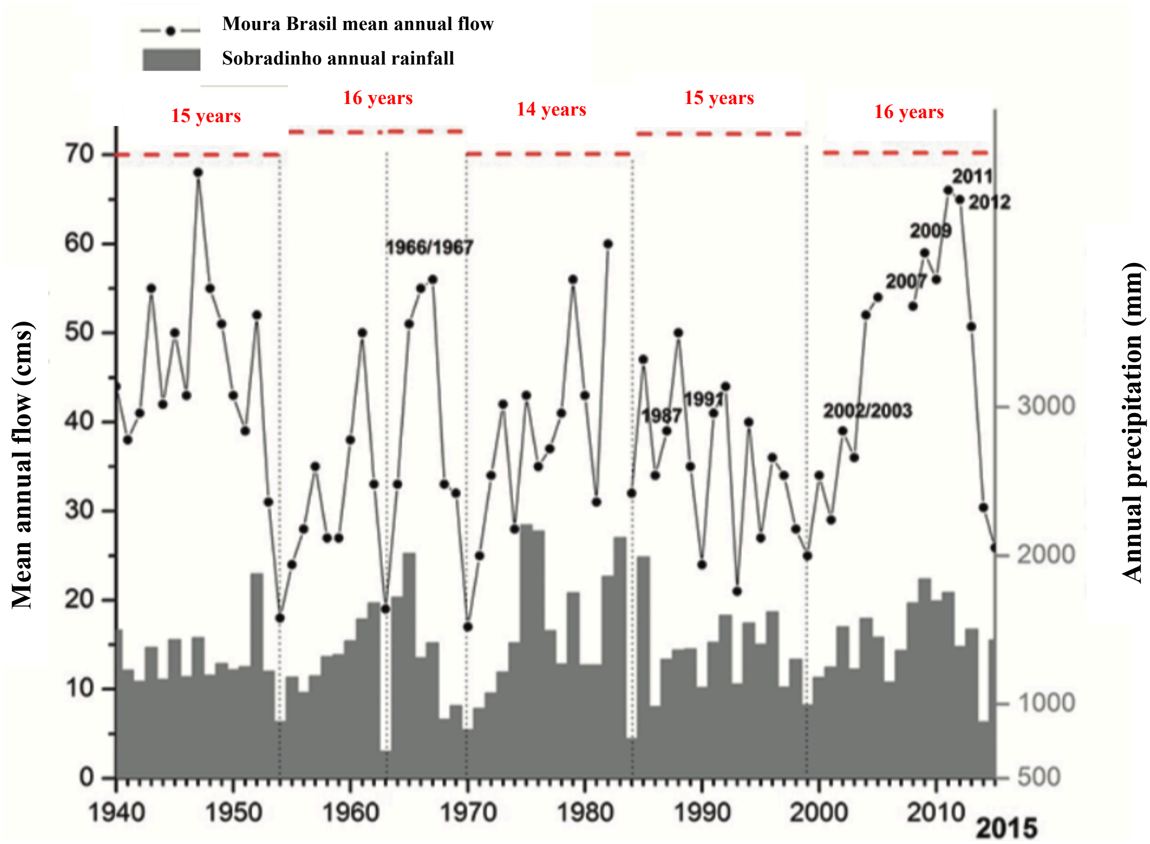

Figure 14: Mean annual flow vs annual precipitation between 1940-2015 (Marques *et al.*, 2017)

Marques *et al.* (2017) study also highlight that for the last cycle (2000-2015), rainfall and discharge trends are not very clear, they suggest that it could be a sign of an anthropogenic effect together with the higher number of natural disasters frequency.

The occurrence of natural disasters within the Piabanha basin was usually linked by events of elevated flow and rainfall. Marques *et al.* (2017) listed natural disasters of great magnitude that occurred in the basin between the years of 1966-2012 (see Table 14).

Table 14: Natural disasters (landslides, floods, and flash floods) of great magnitude in Teresópolis and Petrópolis municipalities (Marques *et al*., 2017)

Year	Event
1966; 1967	Landslides and floods in the Serra do Mar region
1987	Floods in Petrópolis and Teresópolis; State of emergency in Petrópolis
1991	Flash floods and state of emergency in Teresópolis
2002; 2003	Flash floods and landslides in Petrópolis and Teresópolis
2007	Landslides in Petrópolis and Teresópolis
2009	Landslides in Petrópolis; State of emergency in Petrópolis
2011	Major disaster in Petrópolis and Teresópolis; Both cities declare state of emergency
2012	Landslides in Petrópolis and Teresópolis

3.2.5. Watershed committee

According to Agency of the Paraíba do Sul River Basin (Agência da Bacia do Rio Paraíba do Sul – AGEVAP, 2016) the Piabanha watershed committee was created on November of 2003 by the Rio de Janeiro State Water Council and qualified by the law “Decreto Estadual nº 38.235” in September of 2005. Five years later its bylaws were approved in a plenary meeting on March 2010 and they started working with a plenary of 30 members including the three sectors (9 government members, 12 water users, and 9 civil society members) and a directory board of six members. Currently, the number of plenary members vacancies increased to 36 (12 vacancies for each sector).

Although each sector had 12 vacancies available for the years of 2013-2017, the plenary of the watershed committee had enrolled 12 members of the government, 8 water users and 12 from the civil society. While for 2017-2021, the plenary remained with the same number of members from the government and civil society, but water users increased from 8 to 9 members.

Representing the government sector there are members from state and national environmental agencies and different municipality city halls. Water users include industries, private water supply company, the state wastewater company, and an association of organic producers. The civil society is represented by universities, wastewater, and water suppliers’ workers’ union and associations (engineers, architects, farmers, national parks, defense of human rights, etc.).

Its bylaws indicate that on average there will be three meetings in each semester and six per year. If necessary, the plenary can open calls for extraordinary meetings.

Besides the plenary, the committee has technical chambers and “groups of work”. Figure 15 portrait a meeting of the technical chamber in the Piabanha watershed committee.

The issues that cannot be discussed during the plenary or need technical advice are discussed at the technical chambers and if necessary “groups of work” are created, once the issue is extremely discussed the outcome is presented to the plenary again.

Some of the actions completed/ ongoing within the committee are: the first water plan for this basin was created in 2009 and is currently being updated; in 2016, the committee deliberated about the water’s value, the Unitary Public Price was updated. Although farming activities accounting for about 80% of gross water consumption within the basin the value charged for the water price is very little compared to sanitation and industrial use, this value is under review at the moment, as well a strategy to charge water tariff for small individual agricultural consumers (they are tax-exempt at the moment).

Figure 15: Technical chamber meeting in November 2018

3.3. Engage/Consult the watershed committee

As a first step of the application of the ELOHA, it would be necessary to build a hydrological foundation. This research proposes to engage/consult the watershed committee before even start the hydrological foundation.

The committee engagement is important because as Hermoso *et al.* (2012) outlined some of the reasons why stream restoration projects failed is that the costs/benefits were not clear, the scale of the project wasn't properly addressed (the ideal is to be for the catchment scale), lack of ecological understanding of catchment processes, the causes of the degradation weren't addressed and there was an inefficient incorporation of social issues. By doing this, the causes of degradation of the watershed can be addressed, social issues can be incorporated, and more time dedicated to the impacts assessment and modeling can be invested in areas highlighted as important for conservation/ social value.

During this phase, to maximize the social inputs from the watershed committee in a qualitative approach, it was created: (1) a workshop to introduce the topic of environmental flows and this research proposal to the members; (2) a survey to access the members background; (3) maps that could communicate their spatial knowledge through participatory mapping; (4) a workshop to present the members input gathered from the items 2 and 3; (5) a survey to validate the future water allocation scenarios.

The outcome of this application would guide future steps of ELOHA that would lead to the proposal of environmental flow standards. As mentioned by Arthington (2015), environmental flows studies have more chances to be accepted by water managers and stakeholders when there is substantial evidence of the processes linking flow, ecological processes and ecological outcomes.

To be successful, the environmental flow proposal will have to be an integrated system that considers all the aspects (social, economic, ecological, cultural and so on). It must be done in a manner that stakeholders can fully understand and agree with it. The key point is having a process that is transparent and that values/engage the stakeholders. Basco-Carrera *et al.* (2018) through a case study, demonstrated that the companion modeling approach could reduce disputes, enhance collaboration among stakeholders, this way improving the decision-making process.

3.3.1. Workshops

The first workshop created had three parts:

(1) Oral presentation with an overview of environmental flows, ecosystem services, the Brazilian National Water Policy; the doctorate research proposal (adaptation of ELOHA framework); how the watershed committee could connect environmental flows to water plans, how to answer the survey, how to participate of the map creation, the future use of their answer and the following steps of the research;

(2) Participants had to answer the survey "Members background knowledge", this survey gathered their basic info, questions related to their participation within the watershed committee with multiple choice and some open-ended questions regarding the topics of the workshop.

(3) The participants worked in the creation of the maps (Map 1 and Map 2). Map 1, also known as "The basin today", contains their views of the main activities developed within the basin and what the actual condition of the river can provide as an ecosystem service. Map 2, also known as "The future basin", contains their views of the future prospects activities to be developed within the basin and the services considered important to be conserved or preserved in the future.

The second workshop created had two parts:

(1) Oral presentation to report the results of the first survey and the maps build with the member's input followed by the explanation of how to fill the survey to validate the future scenarios.

(2) Participants had to answer the survey using a Likert scale methodology to validate future scenarios. These scenarios were developed based on the input collected during the participatory mapping. The goal was to validate the scenarios and define a scale of priority among them.

3.3.2. Survey - Members background

After the workshop, all members of the committee received the printed material with instructions, the survey, and material for the maps. Most of the members agreed on to participate in this research.

Although the “Members background knowledge” collected information to identify the member who was filling it, to make the members more comfortable, for the form involving the maps, the participants could identify themselves or supply the answers anonymously.

The answers to the survey and development of the maps occurred in three rounds, but all of them were executed by the same moderator:

(1) During the “48ª Reunião Ordinária do Comitê Piabanha” meeting on August 10th of 2015 (see Appendix A, that contains the official plenary call); (2) As asked for part of the members, the survey and map materials were sent through e-mail to the water agency of the committee and they would return their answers to the water agency or to the person that was leading the research; and (3) During another meeting “49ª Reunião Ordinária do Comitê Piabanha”, that occurred in October 20th of 2015 at the city of Petrópolis the members had another chance to participate in the research (see Figure 16).

Figure 16: Plenary meeting of the watershed committee in October of 2015

The survey used open-ended questions aiming to gather the feedback from the members with their own words.

3.3.3. Participatory mapping - the basin today and the future basin

The maps “The basin today” and “The future basin” were developed under a participatory mapping method. Participatory mapping method was chosen because as demonstrated by Corbett (2009): (1) it can support the stakeholders to articulate and communicate spatial knowledge; (2) record and archive their knowledge; (3) it can be a tool for land-use planning and resource management; (4) it can increase capacity within communities; and (5) it can address resource-related conflicts.

Another point of relevance during the selection of this method was due to the fact that watershed committee members have different backgrounds, and as stated by Christmann *et al.* (2016), social cartography can be used as a social technology to empower community members taking into account their different background.

For the creation of the maps the moderator provided for each member a printed material that included: two copies of the watershed map with the identification of the major rivers, the cities within the basin and points where ecological data was available; two types of table, for the map "The basin today", one with the codes from 1 to 7 for activities that occurs within the basin and can provoke impact and A-H for services that occurs within the basin (see Table 15); and two types of table, for the map "The future basin", one with the codes from 1 to 7 describing future prospects of activities within the basin and A-F for services that they would like to preserve in the future or that the basin could have (see Table 16).

Table 15: The basin today - Activities that cause impact and services available

Code	Current activity	Code	Service
1	Wastewater	A	Harmony landscape (local with social/ cultural importance)
2	Industrial activities	B	Preservation of aquatic communities
3	Farming activities	C	Irrigation
4	Small hydropower plants	D	Fishery
5	Deforestation	E	Swimming
6	Urban Development	F	Water supply for human consumption
7	Water withdraw	G	Navigation
-	-	H	Preservation of riparian vegetation

Table 16: The future basin - prospects of activities within the basin and services

Code	Future activity	Code	Service
1	Treating domestic sewage	A	Harmony landscape (local with social/ cultural importance)
2	Expand industries	B	Preservation of aquatic communities
3	Expand agricultural activities	C	Fishery
4	Increase the number of small hydropower plants	D	Swimming
5	Reforest the Atlantic Forest	E	Navigation
6	Increase urban development	F	Preservation of riparian vegetation
7	Expand the abstraction and distribution of water	-	-

Members were advised to only add contributions to the parts of the basin where they had the background. It was explained that they could add more info to the map based on their background by creating and describing the meaning of the new codes.

3.3.4. Survey - Validation of future scenarios

Answers from this survey occurred in one round and were collected during the "68ª Reunião Ordinária do Comitê Piabanha" meeting on December 3th of 2018 (see Appendix B, that contains the official plenary call). The method used to get the answers in this survey was a Likert scale - the level of agreement. The scale adopted ranges from strongly disagree to strongly agree, the full scale used can be seen in Figure 17.

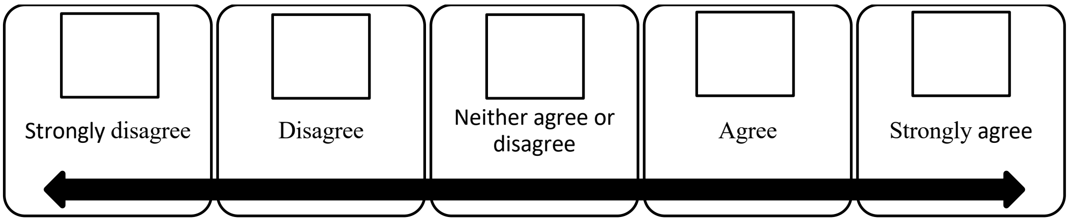

Figure 17: Likert scale used in the survey

Members were instructed to write an X in the sector that they represented in the watershed committee (government, water users, civil society and guests) and to agree or disagree with the scenarios proposed for validating according to their perspective of importance. Four scenarios were evaluated: (1) expand farm activities; (2) expand industries; (3) expand water abstraction and distribution; and (4) treatment of domestic sewage. These future scenarios reflected their answers in the participatory mapping step. After the application, the answers were computed, the counts and valid percent were calculated for each sector and for all the sectors combined and as last step graphs were generated with the results.

3.3.5. Workshops outcomes

After the collection of their handwritten answers: the survey responses were analyzed, and graphics were generated; four digital maps were created summarizing their participatory mapping inputs using ArcGIS version 10.3.1.; future scenarios for water allocation emerged and also areas to preserve aquatic communities and fishery; and preferred scenarios for water allocation were validated. The results are going to be presented in the next chapter.

3.4. Build a hydrological foundation

The hydrological foundation is an important step in environmental flows proposals because the stream flow database can be used together with ecological information to develop flow alteration-ecological responses.

According to Poff *et al.* (2010), ELOHA framework requires a database of stream flows that can represent the pre-development and developed conditions of the site in the study. This database must be long enough to represent climate variability, the time-series could be daily, weekly or monthly.

Kennard *et al.* (2010) indicate that the hydrological foundation with time series of 15 years of discharge record could be used in hydrologic analyses that aim to detect important spatial variation in hydrologic regimes. Kendy *et al.* (2012) suggest that at least 20 years of discharge record must be considered to represent climate variability.

Williams (2018) debated how long the hydrological foundation time series should be and some of the conclusions were: (1) there is no good shortcut for estimating how long a record is needed for an environmental flow assessment; (2) there is no single set of analytical steps that will build a good hydrologic foundation; and (3) investigators should use all of the data that are available to them, rather than select data from some common period or window.

Based on this time series discussion the phases adopted to build the hydrological foundation were (1) data collection; (2) data analysis; (3) definition of the pre-development condition and developed condition; and (4) data preprocessing. Each step is going to be described in the following sessions.

3.4.1. Data collection

As a first step based on previous works within the basin the codes for existent streamflow data gaging stations were consulted. After that, streamflow data for those stations were obtained from the Brazilian National Water Agency (Agência Nacional de Águas, ANA) online database. The list of selected stations together with their code, name, elevation, drainage area, city, a period of record can be found in the following Table 17.

Table 17: Streamflow stations within the Piabanha watershed

Gauge number	Gauge name	Elevation (m)	Drainage area (km^2)	City	Period of record	Part of the hydrological foundation?
58400000	Petrópolis	807.0	43.1	Petrópolis	08/01/1938 - 08/19/1987	No
58405000	Pedro do Rio	645.0	435.0	Petrópolis	08/01/1930 - 12/31/2017	Yes
58409000	Areal-RN	444.0	514.0	Petrópolis	07/01/1933 - 12/31/1975	No
58420000	Fazenda Sobradinho	704.0	719.0	Teresópolis	11/01/1935 - 12/31/2017	Yes
58425000	Moreli (Parada Moreli)	518.0	930.0	São José do Vale do Rio Preto	09/01/1947 - 12/31/2017	Yes
58427000	Tristão Câmara	-	1030.0	Petrópolis	09/01/1930 - 06/30/1941	No
58434000	Fagundes	-	275.0	Petrópolis	09/01/1936 - 12/31/2017	Yes
58440000	UHE Simplício Moura Brasil	278.0	-	Três Rios	08/01/1930 - 12/31/2016	Yes
58442000	UHE Ilha dos Pombos Fazenda Barreira	191.0	2040.0	Três Rios	09/01/1951 - 12/31/2012	No

3.4.2. Data analysis

The goal of this phase was to select the stations that would compose the hydrological foundation. For this the following steps were performed:

(1) identify if data downloaded contained gaps;

(2) identify if the streamflow station was still activated;

(3) check if the data was raw or consisted;

(4) in case the baseline conditions of historic flow regimes contained gaps, check if these gaps could be estimated with linear interpolation by the software Indicator of Hydrological Alterations (IHA);

(5) if part of the gauging stations had a short period of data monitored or they were deactivated and did not cover the current period, remove them from the analysis;

(6) define the streamflow stations that would become part of the hydrological foundation;

(7) run statistical tests for the stations that compose de hydrological foundation, Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test (see Appendix C), Student's t‑test (see Appendix D) and Pettit's test (see Appendix E) and

(8) check for the stations that compose de hydrological foundation the classification of their annual streamflow events based on their variation across the years using the Hydrological Condition of the Basin (HyC) proposed by Genz & Luz (2007).

HyC method is capable to classify the variation of the flow conditions through the years within a basin between very dry, dry, average, wet and very wet. HyC defines the variability of annual streamflow around the Qm by normalizing the series, which is called an "anomaly" in climatology. The anomaly for the streamflow is defined as follows:

$$Anomaly = (Q_i - Q_m)/\sigma \quad \text{(Equation 1)}$$

where Q_i is the annual average streamflow (m^3/s) in the year i, Q_m is the mean annual streamflow (m^3/s), and σ is the standard deviation (m^3/s).

Genz & Luz (2012) suggest that once the anomalies were defined and 1σ was adopted to establish the limits, a rank of classes of HyC of the basin can be established based on Table 18. In addition, the authors affirm that the use of the anomaly is an important feature when it is necessary to compare data from other gauging stations or even other types of variables (e.g. precipitation).

Table 18: Classification of HyC based on the anomaly of annual average streamflow and 1σ (Genz & Luz, 2007)

Limits	HyC class	Value of HyC
Anomaly < –1.5	Very dry	-2
–1.5 < Anomaly < –0.5	Dry	-1
–0.5 < Anomaly < 0.5	Average	0
0.5 < Anomaly < 1.5	Wet	1
Anomaly > 1.5	Very wet	2

3.4.3. Definition of pre-development and developed condition

The Piabanha basin rivers are mainly unregulated and the basin did not undergo through major changes of soil and land use across the decades. According to Rosário (2013) around 54% of the Piabanha basin soil cover still remains as Atlantic Forest. Therefore, for this study, the pre and post-development streamflow condition was defined based on the changes of land use due urban growth within the major cities within the basin.

The years 1970 to 1990 were defined as pre-development condition and the developed condition from the years 1990 to 2016/2017. This decision was also based on the fact that the occupation of the river's perimeter areas started between 1964 -1975 according to Plácido & Cunha (2010) and from the population growth data obtained in IBGE database for the region.

3.4.4. Data preprocessing

In order to use the IHA software, the streamflow data cannot contain gaps. Gaps were identified in the stations and they were replaced by the number -1 to be interpolated.

3.5. Compute hydrological alteration

ELOHA is grounded in the premise that increasing degrees of flow alteration from baseline condition is associated with increasing ecological change (Poff *et al*., 2010). Indicator of Hydrological Alterations (IHA) was used to access the hydrological alteration and they were classified with the method Dundee Hydrological Regime Alteration Method (DHRAM).

3.5.1. Indicators of Hydrological Alteration (IHA) and Environmental Flow Components (EFCs)

This index was developed by scientists at The Nature Conservancy to facilitate hydrologic analysis in an ecologically-meaningful manner (Richter *et al*, 1996). The software program assesses 67 ecologically-relevant statistics derived from daily hydrologic data (The Nature Conservancy, 2009). Among those 67 statistics, 33 are IHA parameters and 34 EFC parameters. For this study, the 33 IHA parameters will be used (see Table 19).

Mathews & Richter (2007) drafted a conceptual ecological model for a hypothetical species that demonstrated how the IHA components could influence a species in a single life stage, see Figure 18.

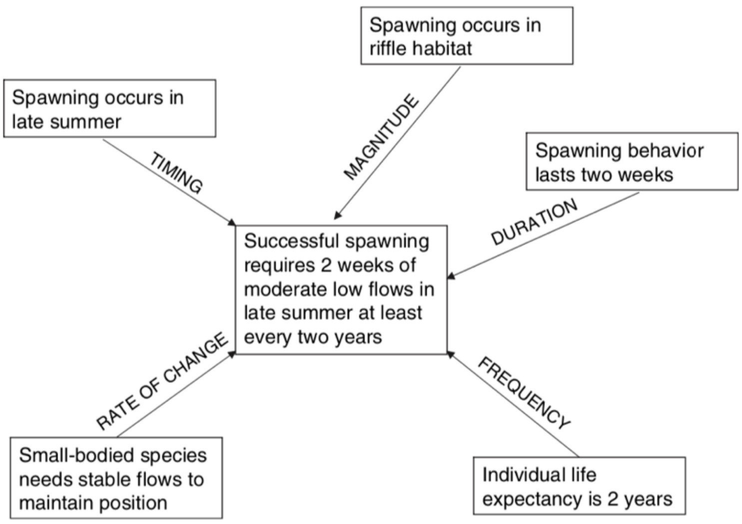

Figure 18: Conceptual Ecological Model for a Hypothetical Species (Mathews & Richter, 2007)

Olden & Poff (2003) proved that the IHA could represent the 171 hydrological indices. For this analysis it was used the function parametric statistics, in other words, the data is characterized by a mean and standard deviation.

Table 19: Summary of IHA Parameters and their Ecosystem Influences (TNC, 2009)

Group	IHA Parameter	Ecosystem influence
1. Magnitude of monthly water conditions	Mean or median value for each calendar month **Subtotal 12 parameters**	Habitat availability for aquatic organisms; Soil moisture availability for plants; Availability of water for terrestrial animals; Reliability of water supplies for terrestrial animals
2. Magnitude and duration of annual extreme water conditions	Annual minima, 1-day mean Annual minima, 3-day means Annual minima, 7-day means Annual minima, 30-day means Annual minima, 90-day means Annual maxima, 1-day mean Annual maxima, 3-day means Annual maxima, 7-day means Annual maxima, 30-day means Annual maxima, 90-day means Number of zero-flow days Base flow index: 7-day minimum flow/mean flow for the year **Subtotal 12 parameters**	Balance of competitive, ruderal, and stress- tolerant organisms; Creation of sites for plant colonization; Structuring of aquatic ecosystems by abiotic vs. biotic factors; Structuring of river channel morphology and physical habitat conditions; Soil moisture stress in plants; Dehydration in animals; Anaerobic stress in plants; Volume of nutrient exchanges between rivers and floodplains; Duration of stressful conditions such as low oxygen and concentrated chemicals in aquatic environments.
3. Timing of annual extreme water conditions	Julian date of each annual 1-day maximum Julian date of each annual 1-day minimum **Subtotal 4 parameters**	Compatibility with life cycles of the organism; Predictability/avoidability of stress for organisms; Access to special habitats during reproduction or to avoid predation; Spawning cues for migratory fish; Evolution of life history strategies, behavioral mechanisms
4. Frequency and duration of high and low pulses	Number of low pulses within each water year Mean or median duration of low pulses (days) Number of high pulses within each water year Mean or median duration of high pulses (days) **Subtotal 4 parameters**	Frequency and magnitude of soil moisture stress for plants; Frequency and duration of anaerobic stress for plants; Availability of floodplain habitats for aquatic organisms; Nutrient and organic matter exchanges between river and floodplain; Soil mineral availability; Access for water birds to feeding, resting, reproduction sites; Influences bedload transport, channel sediment textures, and duration of substrate disturbance (high pulses)
5. Rate and frequency of water condition changes	Rise rates: Mean or median of all positive differences between consecutive daily values Fall rates: Mean or median of all negative differences between consecutive daily values Number of hydrologic reversals **Subtotal 3 parameters**	Drought stress on plants (falling levels); Entrapment of organisms on islands, floodplains (rising levels); Desiccation stress on low-mobility streamedge (varial zone) organisms

3.5.2. Dundee Hydrological Regime Alteration Method (DHRAM)

DHRAM utilizes the Indicators of Hydrologic Alteration approach to classifying the risk of damage to in-stream ecology using a five-class scheme compatible with the requirements of the EC Water Framework Directive (Black *et al.*, 2005).

Classes range will be decided based on the number of points attributed by the hydrological alteration, calculated in % change in the IHA group (see Table 20).

Table 20: % change in IHA group scores (Black *et al.*, 2005)

IHA summary indicator	Lower threshold (1 impact point)	Intermediate threshold (2 impact points)	Upper threshold (3 impact points)
1a (Group 1 means)	19.9	43.7	67.5
1b (Group 1 CVs)	29.4	97.6	165.7
2a (Group 1 means)	42.9	88.2	133.4
2b (Group 1 CVs)	84.5	122.7	160.8
3a (Group 1 means)	7.0	21.2	35.5
3b (Group 1 CVs)	33.4	50.3	67.3
4a (Group 1 means)	36.4	65.1	93.8
4b (Group 1 CVs)	30.5	76.1	121.6
5a (Group 1 means)	46.0	82.7	119.4
5b (Group 1 CVs)	49.1	79.9	110.6

The equation used for the estimation of the percentage difference between pre-alteration and post-alteration values is:

$$\%\ difference\ in\ parameters = 100x\,\frac{(POAV - PEAV)}{PEAV} \quad \text{(Equation 2)}$$

where POAV is the post-alteration value and PEAV is the pre-alteration value.

Once the points of alteration are estimated, the final class of impact can be accessed, this classification varies from an un-impacted condition to a severely impacted condition.

The higher the score, the greater the impact the system has on the flow regime and the higher the risk of damage to the ecosystem. Table 21 displays the points range and its corresponding class.

Table 21: Points classification (Black *et al.*, 2005)

Class	Points range	Description
1	0	Un-impacted condition
2	1-4	Low risk of impact
3	5-10	Moderate risk of impact
4	11-20	High risk of impact
5	21-30	Severely impacted condition

3.6. Classify river segment

Poff *et al.* (2010) highlighted two goals of this phase:

(1) relationships between ecological metrics and flow alteration can be developed for an entire river type based on data obtained from a limited set of rivers of that type within the region (Arthington *et al.*, 2006); and

(2) combining the regional hydrologic modeling with a river typology facilitates efficient biological monitoring and research design.

Based on the size of the watershed and expert consultation this phase was skipped. If other watersheds decide to classify their river, Table 22 contains suggestions of the phases and methods that could be used in this step.

Table 22: Classify rivers segments phases and methods

Phase	Description
Hydrologic classification	Classifying rivers according to the similarity in hydrologic regime (4 to 12 classes)/ Use of the Indicator of Hydrological Alterations (IHA) to compute flow statistics
Geomorphic sub-classification	Based on Kennard *et al*. (2010) and McManamay *et al*. (2012)
River-type	Based on Kennard *et al*. (2010) and McManamay *et al*. (2012)

3.7. Build an ecological foundation

The original ELOHA framework does not include this phase. In Brazil, most states mainly monitor the rainfall and streamflow, sometimes water quality information is available for some sites, but no ecological data is available at national and state scale.

Even though there is no legislation that promotes and support national/state programs to monitor ecological data, according to Van Niekerk *et al.* (2019), long-term monitoring can improve the confidence of the input data. Horne *et al* (2017) also advise that without monitoring, there can be no adaptive learning, complete the adaptive management cycle, nor update future management in light of new knowledge.

The goal of its inclusion is to instigate the creation of an ecological foundation with current data available (when there is lack of long-term data) to be able to understand how future flow alterations will affect the ecology within that stream/watershed.

This phase contains information regarding: (1) the keys components to propose flow alteration-ecological response relationships; (2) sources of ecological data; (3) when there is no national database available what is the alternative way to access important information regarding certain species.

3.7.1. Keys components to propose flow alteration-ecological response relationships

The selection of the key components will guide what kind of information needs to be collected in the next phase (data collection).

Poff *et al.* (2010) proposed seven types of ecological indicators that could be used to propose flow alteration-ecological response relationships: (1) mode of response; (2) habitat responses linked to biological chances; (3) rate of response; (4) taxonomic groupings; (5) functional attributes; (6) biological level of response; and (7) social value (see Table 23).

For this case study case, it was taken into account the following ecological indicators: mode of response, taxonomic groupings (fishes) and functional attributes.

Table 23: Considerations in selecting ecological indicators useful in developing flow alteration-ecological response relationships (Poff *et al*., 2010)

Type	Description
Mode of response	Direct response to flow, e.g. spawning or migration Indirect response to flow, e.g. habitat-mediated
Habitat responses linked to biological changes	Changes in physical (hydraulic) habitat (width-depth ratio, wetted perimeter, pool volume, bed substrate) Changes in flow-mediated water quality (sediment transport, dissolved oxygen, temperature) Changes in in-stream cover (e.g. bank undercuts, root masses, woody debris, fallen timber, overhanging vegetation)
Rate of response	*Fast versus slow* Fast: appropriate for small, rapidly reproducing, or highly mobile organisms Slow: long-life span *Transient versus equilibrial* Transient: establishment of tree seedlings, return of long-lived adult fish to potential spawning habitat Equilibrial: reflect and end-point of ‘recovery’ to some ‘equilibrium’ state
Taxonomic groupings	Aquatic vegetation Riparian vegetation Macroinvertebrates Amphibians Fishes Terrestrial species (arthropods, birds, water-dependent mammals, etc.) Composite measures, such as species diversity, Index of Biotic Integrity
Functional attributes	Production Trophic guilds Morphological, behavioral, life-history adaptations (e.g. short-lived versus long-lived, reproductive guilds) Habitat requirements and guilds Functional diversity and complementarity
Biological level of response (process)	Genetic Individual (energy budget, growth rates, behavior, traits) Population (biomass, recruitment success, mortality rate, abundance, age-class distribution) Community (composition; dominance; indicator species; species richness, assemblage structure) Ecosystem function (production, respiration, trophic complexity)
Social value	Fisheries production, clean water, and other ecosystem services or economic values Endangered species Availability of culturally valued plants and animals or habitats Recreational opportunities (e.g. rafting, swimming, scenic amenity) Indigenous cultural values

3.7.2. Data collection

Data collection was undertaken from four different sources:

(1) Local database collection from the Project "Ecological hydrogram and qualitative and quantitative modeling of basins" (Hidrograma ecológico e modelagem quali-quantitativa de bacias) - This project was executed by the Federal University of Rio de Janeiro between the years of 2012-2016 in the Piabanha basin. This fish database reflects the monitoring period between the years of 2012-2014, considering the wet and dry seasons, where four field trips were executed capturing the sum of 4,590 fish species, distributed into 51 species from six orders and 17 families (Caramaschi *et al*., 2016).

(2) Literature review - papers and books with information about the species from the same basin or similar region in Brazil were consulted;

(3) Experts' consultation - when the data was not available in the database from the project or literature review fish experts were consulted, Professor Erica Maria Pellegrini Caramaschi, Professor Stuart Edward Bunn, Doctor Andressa da Silva Reis, and Researcher Karina Ferreira; and

(4) Global database collection, from FishBase - According to Mancinelli *et al*. (2013), this database was developed in 1989 at the International Center for Living Aquatic Resources Management (ICLARM; currently WorldFish Center) in collaboration, among others, with the Food and Agriculture Organization of the United Nations (FAO) and with support from the European Commission (EC). This database summarizes key taxonomic, ecological and biological information on 34200 species (as of March 2019). In this study, the vulnerability to extinction is going to be used from this database.

3.7.3. Data analysis

For this study the data analysis followed the sequence: (1) Check if the sites with fish data also had streamflow gauging stations near it; (2) Select the stations/species that are going to be used in the analyses; and (3) Define among the sources of data the ones that are going to be used to support flow alteration vs. ecological response relationship.

3.8. Flow alteration vs. ecological response relationship

For this phase steps different steps and manipulation of data were proposed:

(1) creation of a general flow-ecology hypothesis;

(2) classification of the fish species based on the FishBase vulnerability to extinction;

(3) construction of a list of factors/ feature that put the fish species in danger based on expert consultation along with a map of their distribution;

(4) functional groups (breeding, movement, and feeding) description for species with a high level of spatial distribution based on the expert consultation;

(5) breeding calendar for the fish species with a high level of spatial distribution and species that have a high correlation to flow alteration changes.

3.8.1. Flow ecology hypothesis

A flow-ecology hypothesis was created based on the general flow alteration and the possible response of the Species Richness:

If the hydrological alteration increased in a certain river over time, then we will observe the reduction of Species Richness (S)

Veech (2018) define Species Richness (S) as the number of species present in a sample, ecological community, ecosystem, landscape, region, or any defined spatial unit. Because of its simplicity, this indicator has come to be the standard metric for measuring biodiversity.

Arthington *et al*. (2018), suggested that a more robust, dynamic and predictive approach to environmental water science would encourage the measurement of ecosystem states (*e.g.* species richness, assemblage structure) as the variables representing ecological responses to flow variability and environmental water allocations.

The Species Richness was chosen based on expert input and because it is a standard metric for measuring biodiversity. The local fish database has available per point the total number of captured individuals (N), Species Richness (S) and Shannon diversity index (H), see Table 24.

Table 24: Distribution of the total number of captured individuals (N), Species Richness (S) and Shannon diversity index (H) [Caramaschi *et al*., 2016]

Station	N	S	H
Pedro (Pedro do Rio)	203	12	1.58
Fagundes	92	9	1.34
Preto (Moreli)	301	31	2.73
Moura Brasil	86	24	2.71

Shannon-Winer Index was described by Fedor & Spellerberg (2013) as generally based on the concept of evenness or equitability. Simply put, the concept of evenness refers to the extent to which each species is represented among the sample. The extremes would range from one species being dominant and all other species being present in very low numbers (one individual for each species) to all species being represented by equal numbers. In simple terms, maximum diversity (equitability) exists if each individual belongs to a different species. Minimum diversity exists if all individuals belong to one species. The Shannon-Winer Index formula is:

$$H = -\sum_{i=1}^{n} p_i ln p_i \qquad \text{(Equation 3)}$$

where H is the index of species diversity, p_i is the relative abundance of the ith species (N_i is the number of the ith species).

The total number of captured individuals could not be used to compare the stations because different collection methods were used in some of the ecological stations. Nevertheless, expert consultation points out that the Species Richness (S) could be used when the stations were compared. To verify this, the results of the hydrological classification with the ecological station's species richness was compared.

Another information available for three out of the four points that were monitored at the same period of time was the trophic status. The tropic status was measured by Rocha *et al.* (2016) as a function of the concentration of total phosphorus (PT) in the water column. The general classification of the trophic status according to Wetzel (2001) in ascending order is Oligotrophic; Mesotrophic; Eutrophic; and Hypereutrophic. Rocha *et al.* (2016) reported two stations as Hypereutrophic classification, Pedro do Rio and Fagundes, while Rio Preto station was classified as Eutrophic.

3.8.2. Classification of the fish species vulnerability to extinction

Vulnerability to extinction was determined for the 44 species fish species based on FishBase database. The vulnerability can be classified between low, low to moderate,

moderate, moderate to high, high, high to very high, and very high. These categories were determined based on the life history and ecological characteristics of each species (Cheung *et al.*, 2005).

This approach could be used in case there is no expert consultation during the process. This classification could help identify species vulnerable and endangered.

3.8.3. Factors/feature that put the fish species in danger based on expert consultation

A fish expert was consulted if any fish species in the list had a direct or indirect response to flow alteration, habitat requirements or any morphological, behavioral, life-history adaptations that could put it at risk in future if the streamflow conditions or the land use in the watershed changed.

After the consultation, selected species were categorized into eight categories: cryptic, rare, rheophilic, scrapers, pelagic, needs rapids, needs tree shading and needs marginal plants with roots. A map was generated based on this category's distribution within the basin.

3.8.4. Functional group survey for selected species

Based on the expert input it was created a filter to select the species with a high level of spatial distribution (all 4 sites or at least 3 sites). Additionally, the species functional groups (breeding, movement, and feeding) information was accessed based on literature review and expert consultation. The local database from Caramaschi *et al.* (2016) adopted April-September as a dry period and October-March as the wet period.

3.8.5. Breeding calendar

A breeding calendar was built based on reproduction period for selected species suggested by the experts and that display directly correlation to flow alterations. This calendar was based on literature review and expert consultation.

3.9. Environmental flow proposition

Dyson *et al*. (2008) described two types of e-flows implementation:

(1) active (e.g. active management of infrastructure such as dams), when this type of management is applied, an entire flow regime can be generated, including low flows and floods.

(2) restrictive flow management (e.g. reducing the abstractions for irrigation or industries) when this management is used it involves allocation policies that ensure that enough water is left in the river, particularly during dry periods, by controlling abstractions and diversions.

For this study, the e-flow proposals will be based on restrictive flow management methods. The steps followed in this phase include:

(1) analyses of the current e-flows legislation and/or environmental policies involving water allocation;

(2) based on the available data definition of the e-flow methods to be applied;

(3) e-flows based on an adaptation of the Tennant method;

(4) e-flows based on flow-duration curve method;

(5) e-flows based on the 7Q10 method;

(6) an e-flows conceptual model for Piabanha selected fish species/ features;

(7) proposal for e-flow policy and implementation strategy.

3.9.1. Analyses of the current e-flows legislation and policies

Currently, in Brazil, environmental flows are still in early stages of development (Benetti *et al*., 2004), and there is no state or even federal legislation that incorporated environmental flows (Pinto et *al.*, 2015; Pinto et *al.*, 2016).

However, indirectly e-flows are left in the rivers based on state laws that set maximum flow % of water resources permit. This is considered to be restrictive flow management. The used methods (although controversial and not considered e-flows for some authors) to set those rules were built mainly in flow-duration curves (Q90, Q95 and 98) and 7Q10. Table 25 contains the methods used for maximum flow % of water resources permit across the country.

In Rio de Janeiro state, the used method is 50% of the 7Q10. In the region of study, AGEVAP (2017) proposed as e-flow value for the entire Piabanha basin 3.55 (m^3/s).

Table 25: Water permits % across the country (adapted from Pinto, 2015)

Maximum flow % of water resources permit	**% of flows that should remain in the river**	**State**
90% Q_{90}	10% Q_{90}	Sergipe
80% Q_{90}	20% Q_{90}	Bahia; Distrito Federal; Pernambuco; Roraima
75% Q_{90}	25% Q_{90}	Tocantins
20% Q_{90}	80% Q_{90}	Maranhão
80% Q_{95}	20% Q_{95}	Piauí
70% Q_{95}	30% Q_{95}	Goiás; Mato Grosso; Mato Grosso do Sul; Pará
50% Q_{95}	50% Q_{95}	Paraná
50% Q_{98}	50% Q_{98}	Santa Catarina
90% 7Q10	10% 7Q10	Roraima
80% 7Q10	20% 7Q10	Distrito Federal; Roraima
50% 7Q10	50% 7Q10	Espírito Santo; Minas Gerais; Rio de Janeiro; São Paulo

3.9.2. Definition of the e-flow methods to be applied

As restrictive flow management practices are broadly found across the country and as the main source of data to propose e-flows in the Piabanha basin was hydrological, the methods chosen were the adapted Tennant and Flow-duration curve. Besides this, a conceptual model for the link between the hydrological and ecological system was proposed. It is recommended to reevaluate this choice in case hydraulic, habitat and ecological data are available in the future.

3.9.3. Adaptation of the Tennant method

For the adaptation of the Tennant method to the Piabanha hydrological regime six months were selected to represent the wet period, November-April (based on the end of spring and mid of autumn) and six months for the dry period, May-October (winter with low flows).

This choice of these months to present the wet and dry period was also made by Silva (2012) that used Tennant method for Pedro do Rio station. Table 26 contains the general flow recommendations for the low and high flows period in the Piabanha basin, for each station the % was generated based on their mean annual flow values variations.

Table 26: Flow recommendations as per the Tennant method adapted to Piabanha watershed

Description of flows	Recommended flow regime (% of Mean Annual Flow)	
	May-October (low flows)	November - April (high flows)
Flushing or maximum	200%	
Optimum range	60-100%	
Outstanding	40%	60%
Excellent	30%	50%
Good	20%	40%
Fair or degrading	10%	30%
Poor or minimum	10%	10%
Severe degradation	<10%	

3.9.4. Flow-duration curve method

FDCs were computed using the following method:

(1) Sort (rank) average daily discharges for a period of record from the largest value to the smallest value, involving a total of n values;

(2) Assign each discharge value a rank (M), starting with 1 for the largest daily discharge value; and

(3) Calculate exceedance probability (P) as follows:

$$P = 100\ x\ [\frac{M}{(n+1)}] \quad \text{(Equation 4)}$$

where P is the probability that a given flow will be equaled or exceeded (% of the time), M is the ranked position on the listing (dimensionless), and n is the number of events for a period of record (dimensionless).

For each station, different values of FDCs were generated and it was chosen to build a calendar based on the FDC of each month for the Q90, Q95, and Q98.

3.9.5. 7Q10

Kolmogorov-Smirnov test was applied to define what kind of distribution would be used to estimate 7Q10. The significance level used was alpha=0.05. For all the stations, Weibull distribution presented the best fit. Based on this the minimum 7Q10 were calculated for all the stations using Weibull distribution.

3.9.6. E-flow conceptual model for the link between the hydrological and ecological system

A conceptual model was proposed based on Shenton *et al.* (2011), expert consultation and literature review.

3.9.7. E-flow policy and implementation strategy

In this step suggestions of how e-flows policies and strategies could be incorporated into decision making, especially in the water plans are going to be made.

4. RESULTS AND DISCUSSION

4.1. Watershed committee engagement/ consultation

4.1.1. Members background

14 members of the committee answered the survey. Among those, 13 members are part of the plenary, out of 32 total members, plus one guest member. This corresponds to around 40% of the total number of participants in the committee between the years of 2013-2017.

Among the participants, when analyzed by sector (government, water users, civil society, and guests) only the water users did not fill the forms in this phase. More than half of the members that reply it belongs to the civil society, 64% (see Figure 19).

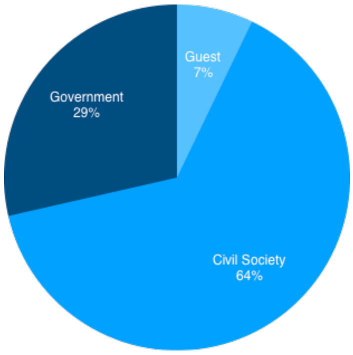

Figure 19: Members participation divided by sector in 2015

The gender distribution was 57% male and 43% female. When it comes to the numbers of years that each member has been working in the watershed committee more than half of the members have between 4-10 years (64%), see Figure 20 for more details.

93% of the members answered that live in a city within the basin region, this factor could give them the background to talk about the basin with more ownership.

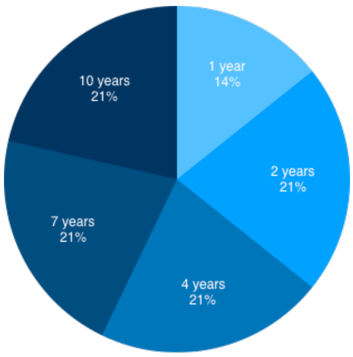

Figure 20: Numbers of years that the members are part of the committee

Most parts of the participants live in the cities of Petrópolis or Teresópolis (the biggest in terms of population and degree of development). The distribution of the cities that the members lived can be seen in the following chart (Figure 21). The members were asked if they knew the Brazilian National Policy of Water Resource, and all of them did. The question had the options no (0%), if they heard about in previous presentations (47%) or if they read the full text (53%).

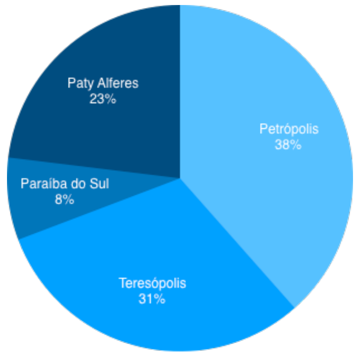

Figure 21: Distribution of the cities that the members live within the watershed basin

The next question was related to e-flows, so the members were asked: "Did you ever hear anything about the subject of environmental flows before this presentation?". More than a half that would be 11 members (79%) said yes and only 3 members (21%) said no. For those who give the answer yes, they had another question that was where they heard about it, most parts of them heard it before at some meeting in the committee, the results can be seen in Figure 22.

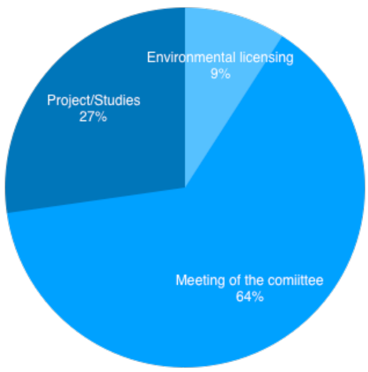

Figure 22: Type of event where members heard about the subject e-flows

It is important to highlight that many times in Brazil e-flows are mistaken for minimal flows only and not take into account a more holistic approach. So, the members were asked: "Do you consider important that the environmental flow issue should be included in discussions of the committees?", all of them said yes as an answer.

The assessment included one more question: “When it comes to the management of water resources, for you the most important point to be discussed is: the environmental aspects; the economic aspects; the social aspects; or all of them have the same importance, the system should be managed in an integrated manner. Once again, all the members marked one answer and that was “all of them have the same importance, the system should be managed in an integrated manner”.

4.1.2. Participatory mapping

The total number of members of the committee that gave feedback regarding the maps were 10. Among those, 9 members of the plenary out of 32, and a guest member. This corresponds to around 30% of the total number of participants in the committee between the years of 2013-2017.

Although the members only created two maps, one for “The basin today” and another for “The future basin”, it was decided that for better visualization of the results they are going to be separated into two maps each:

(1) The basin today

Map 1: Activities that occur in the basin and causes impact (Figure 23); and

Map 2: Activities and ecosystem services that occur within the basin (Figure 24).

(2) The future basin

Map 3: Future prospects of activities within the basin (Figure 25); and

Map 4: Activities and ecosystem services to preserve in the future or that the basin could have (Figure 66).

Besides this, the answers of the maps were also translated from numbers and letters to symbols. The summary of the answers found is described below.

The basin today

Based on their answers, the members of the watershed committee demonstrate that they have awareness of the problems and activities that occur within the basin causing impact. They were able to point the same problems described by previous studies. The member's answers can be seen in Figure 23.

Overall the answers indicate that the basin and each major river have activities suffers impact from wastewater, industrial activities, farming activities, small hydropower plants (except at Fagundes and Paquequer River), deforestation, urban development, and water is withdrawn.

When it comes to the activities and ecosystem services that members identify that occur/are provided within the basin in the present (Figure 24), the only thing in common for all major rivers is irrigation activities and water supply for human consumption. Besides irrigation and harmony of the landscape (local with social/cultural importance) the Piabanha, Fagundes, and Paquequer rivers had in common the services, water supply for human consumption and swimming.

Preservation of aquatic communities and preservation of riparian vegetation were only identified at near the headwater of the Piabanha, Paquequer and Fagundes rivers. While the service of the fishery was only pointed at Fagundes river (the region is the most preserved among others within the basin).

The answers collected point that currently, the main preserved regions are the headwaters of the main rivers and when they leave the rural area to urban features, they start to provide other services more related to human needs.

Harmony landscape, water supply for human consumption and irrigation stand out among other activities and ecosystem services, appearing several times in several stretches of the rivers.

One of the interviewees wrote a note regarding the city of Teresópolis (Paquequer river) saying that the city does not have treatment of public sewage, that all the sewage goes to the river and that the agricultural activities pollute the river with agrochemicals.

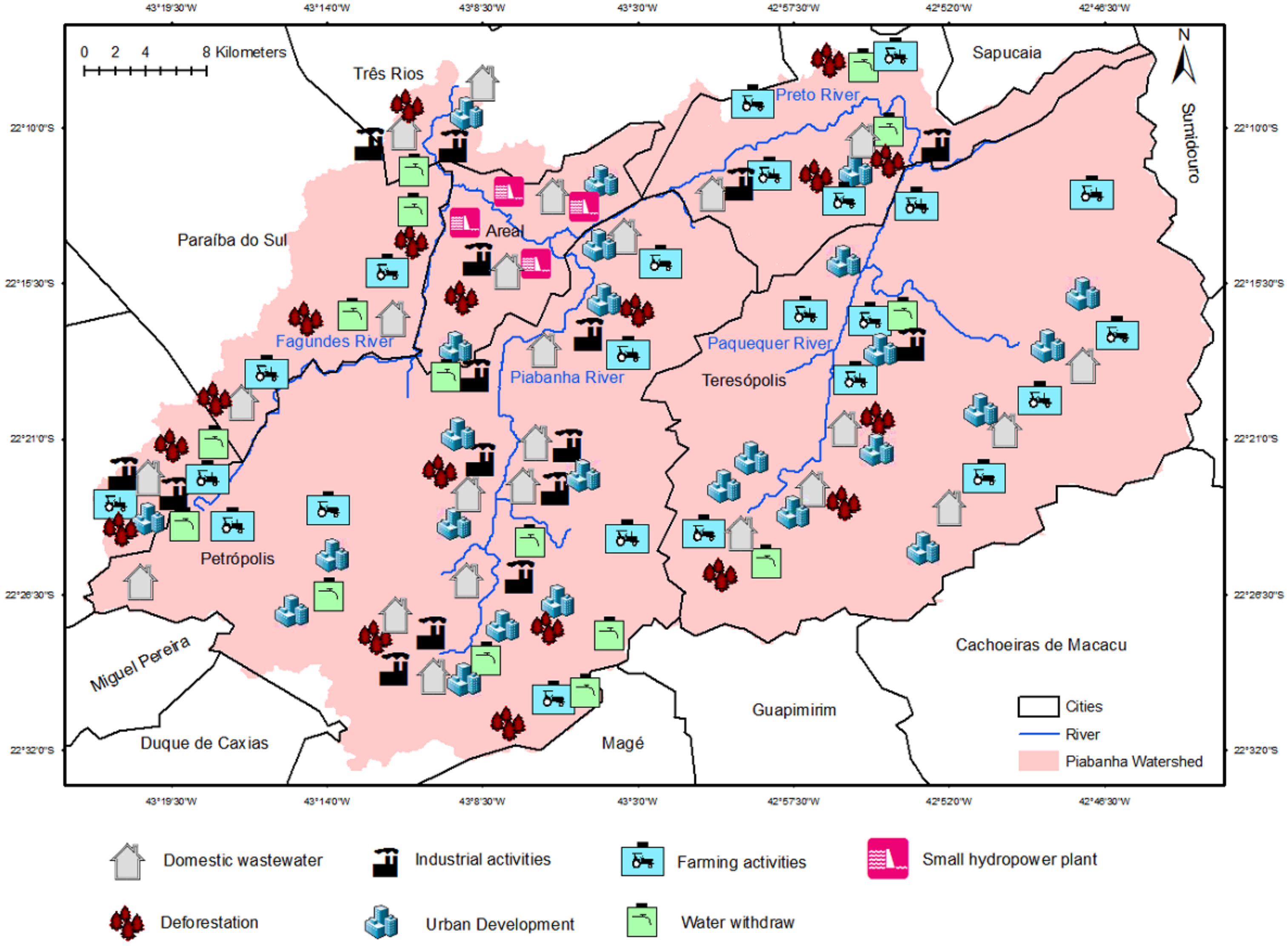

Figure 23: Activities that occur in the basin and causes impact

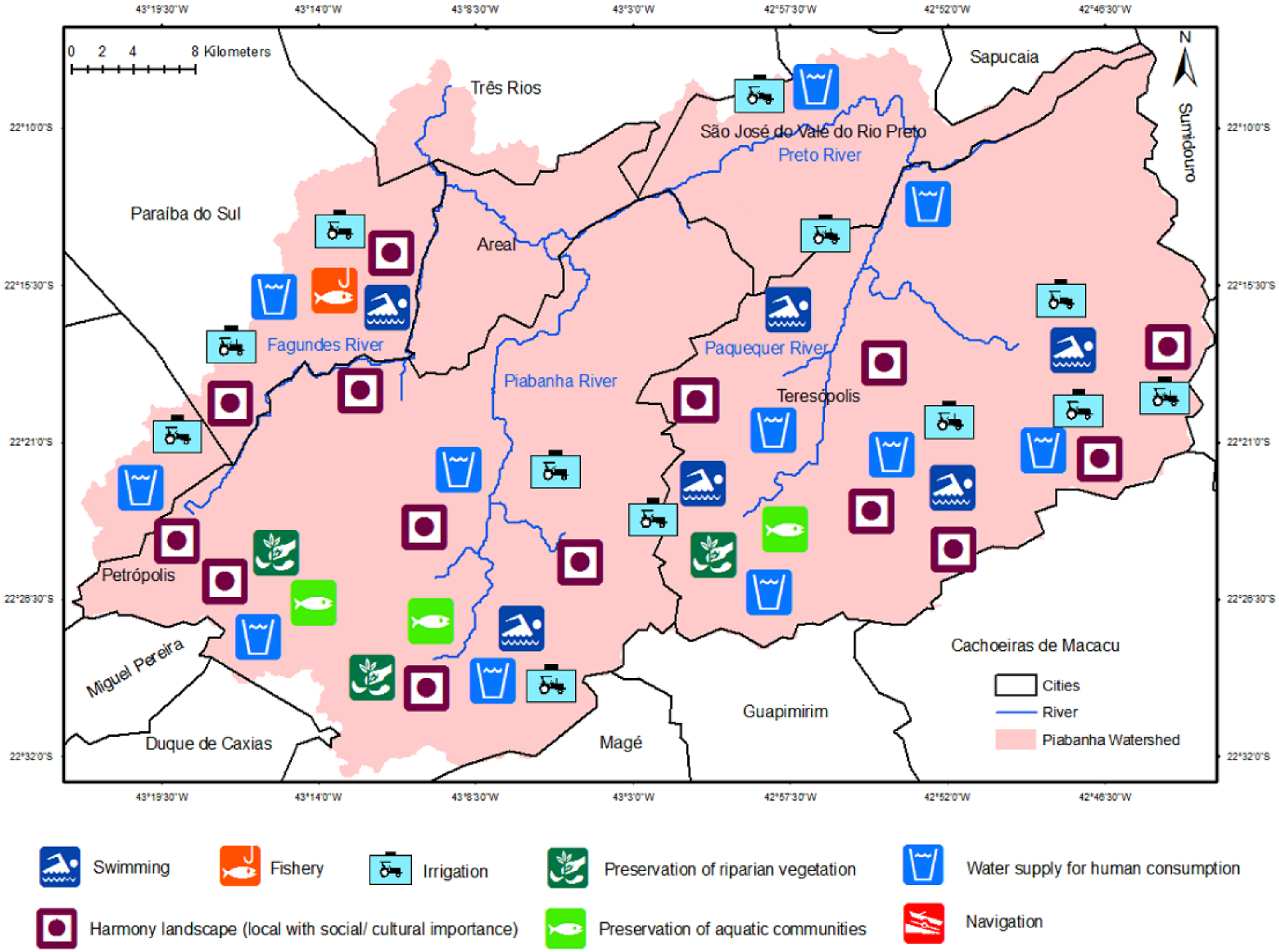

Figure 24: Activities and ecosystem services that occurs within the basin

The future basin

When it comes to the prospects of future activities within the basin (Figure 25), all major rivers have in common the perspective of treating domestic sewage, reforest the Atlantic Forest and expand the abstraction and distribution of water. The members are willing to recover the vegetation and improve water quality but at the same time, they also consider the need of water for human uses, when they point out the need to expand water abstraction and distribution.

For Piabanha and Paquequer rivers it was predicted to increase the number of small hydropower plants. While for Fagundes the forecast was to expand industries and increase urban development. But the members wrote several notes in the map where they mention that the growth should occur in a sustainable manner.

Within all the activities and services to be conserved or preserved in the future, preservation of riparian vegetation, preservation of aquatic communities, harmony landscape and swimming were a common factor among all the rivers (Figure 26).

The preservation of riparian vegetation appeared more frequently between the responses, followed by swimming. There is a desire to use the rivers for fishing in the future not shown as possible in the map representing the present. Navigation in the region of Areal was also a desire pointed out in the map.

Additional comments made by the interviewees include the implementation of agroecological and organic agriculture, bioconstruction: healthy and sustainable materials used for the constructions of new houses in the region, construction of community warehouses to be used by small farmers to attend the region, reusing water in industrial activities and treat its wastewaters before send them back to the river, instead of build more dams try to find other sources of sustainable energy and improve the control of water withdraws from the river.

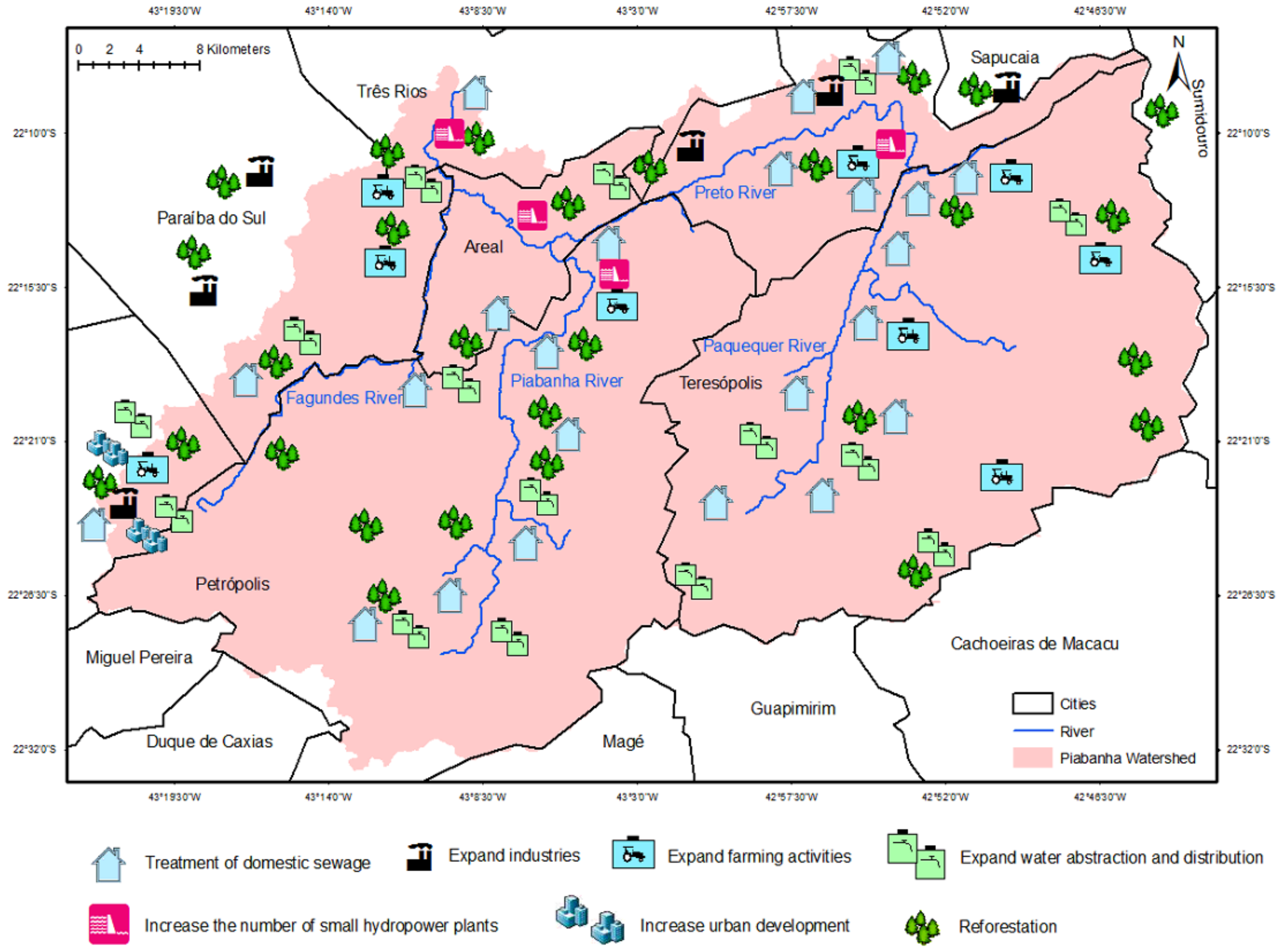

Figure 25: Future prospects of activities within the basin

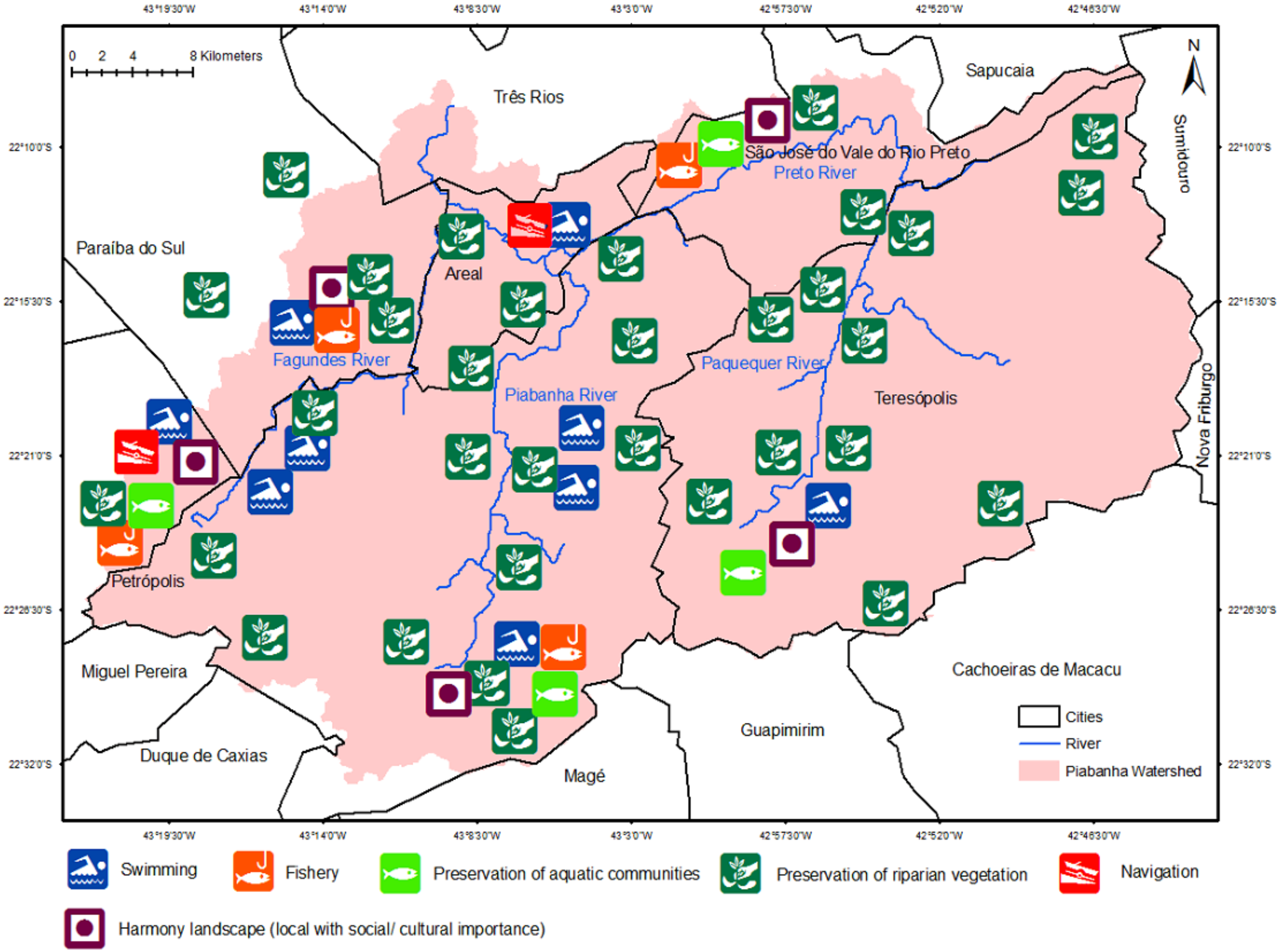

Figure 26: Activities and ecosystem services to preserve in the future or that the basin could have

4.1.3. Future scenarios

21 members of the committee answered the survey. Among those, 19 members are part of the plenary, out of 33 total members, plus two guest members. This corresponds to around 57.5% of the total number of participants in the committee between the years of 2017-2021.

When compared to the first survey participation, the level of engagement among the sectors was improved, this time, all the sectors participated in the survey. Some of the highlights regarding this application:

(1) once again, the civil society had the major engagement and participation, representing 43% of the responses; and

(2) the number of water users' participants increased from 0 to 24% (see Figure 27).

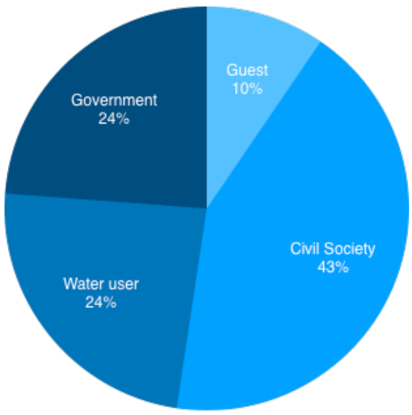

Figure 27: Members participation divided by sector in 2018

Among those participants, 9 members are from the civil society, 5 members from the government, 5 water users and 2 guests. The answers given from each participant can be seen in Table 27.

The answers from all the sectors combined demonstrate that the committee members *strongly agree* that the treatment of domestic sewage is an important scenario (90.48%), see Figure 28. More than half *agree* that expand water abstraction and distribution is an important scenario (52.38%). Most members also *agree* that expand farm activities is important (47.62%). Expand industries was mainly voted as neither *agree or disagree* (33.33%).

Table 27: Likert scale survey answers

Sector	Expand farm activities	Expand industries	Expand water abstraction and distribution	Treatment of domestic sewage
Civil Society	Disagree	Disagree	Disagree	Agree
Civil Society	Strongly disagree	Strongly disagree	Neither agree nor disagree	Strongly agree
Civil Society	Agree	Neither agree nor disagree	Agree	Strongly agree
Civil Society	Disagree	Disagree	Agree	Strongly agree
Civil Society	Disagree	Disagree	Strongly agree	Strongly agree
Civil Society	Neither agree nor disagree	Disagree	Disagree	Strongly agree
Civil Society	Agree	Neither agree nor disagree	Strongly agree	Strongly agree
Civil Society	Agree	Agree	Agree	Strongly agree
Civil Society	Strongly agree	Agree	Disagree	Strongly agree
Government	Neither agree nor disagree	Neither agree nor disagree	Agree	Strongly agree
Government	Disagree	Strongly disagree	Strongly agree	Agree
Government	Agree	Neither agree nor disagree	Agree	Strongly agree
Government	Agree	Neither agree nor disagree	Agree	Strongly agree
Government	Strongly agree	Disagree	Neither agree nor disagree	Strongly agree
Water Users	Agree	Agree	Strongly agree	Strongly agree
Water Users	Agree	Agree	Strongly agree	Strongly agree
Water Users	Disagree	Neither agree nor disagree	Agree	Strongly agree
Water Users	Neither agree nor disagree	Disagree	Agree	Strongly agree
Water Users	Agree	Neither agree nor disagree	Agree	Strongly agree
Guest	Agree	Agree	Agree	Strongly agree
Guest	Agree	Agree	Agree	Strongly agree

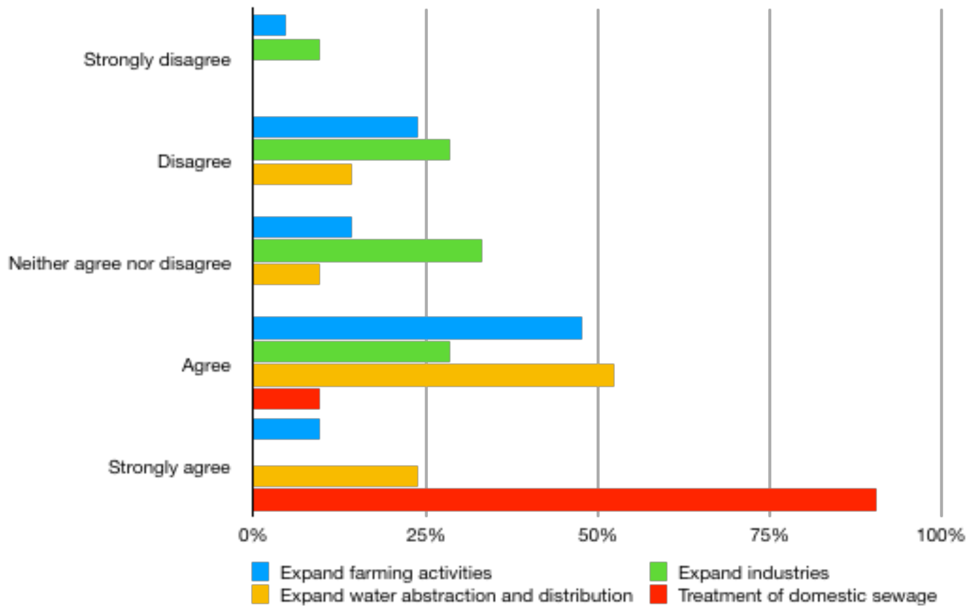

Figure 28: Likert scale valid percent from all sectors

Government members *strongly agree* that the treatment of domestic sewage (80%) is an important scenario see Figure 29. They *agree* that expand water abstraction and distribution is important (60%). Expand farm activities is also mainly voted as *agree* (40%) and expand industries was mainly voted as *neither agree nor disagree* (60%).

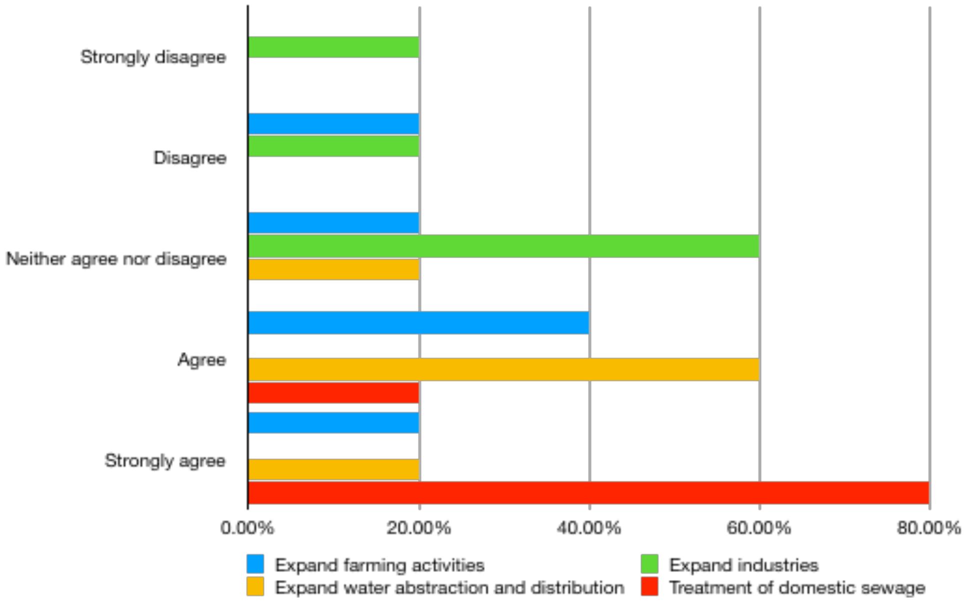

Figure 29: Likert scale valid percent government answers

All water users *strongly agree* that the treatment of domestic sewage is an important scenario see Figure 30. They *agree* that expand farm activities and expand water abstraction and distribution are important (60%). Expand industries had the same valid percent (40%) for *agree* and neither *agree nor disagree*.

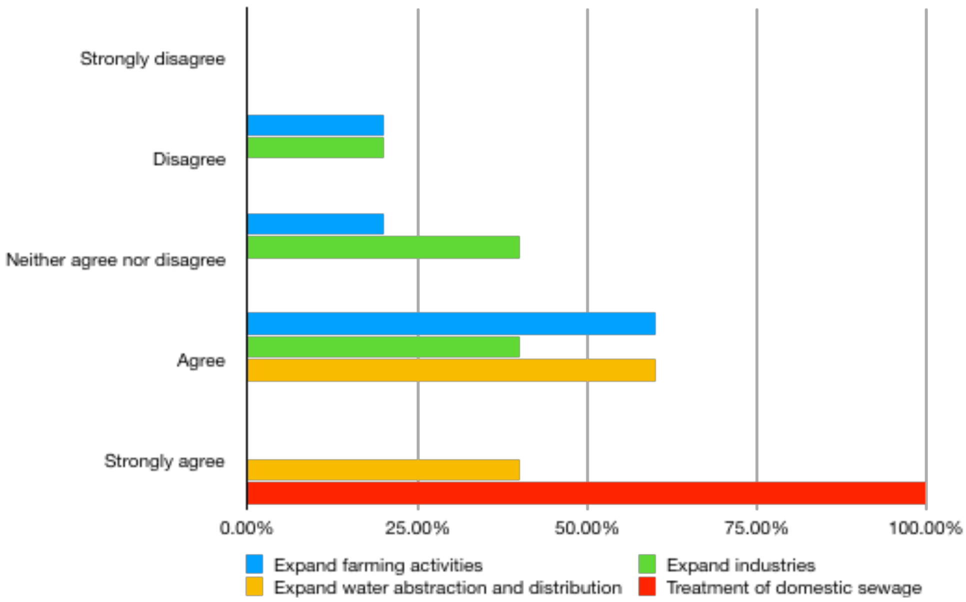

Figure 30: Likert scale valid percent of water users' answers

Civil society *strongly agrees* that the treatment of domestic sewage is an important scenario (88.89%) see Figure 31. They *disagree* that expand industries is important (44.44%). When it comes to expanding farming activities and water abstraction and distribution these scenarios classification had different points of view among the civil society, the valid percent of the *disagree* and *agree* answers were the same (33.33%).

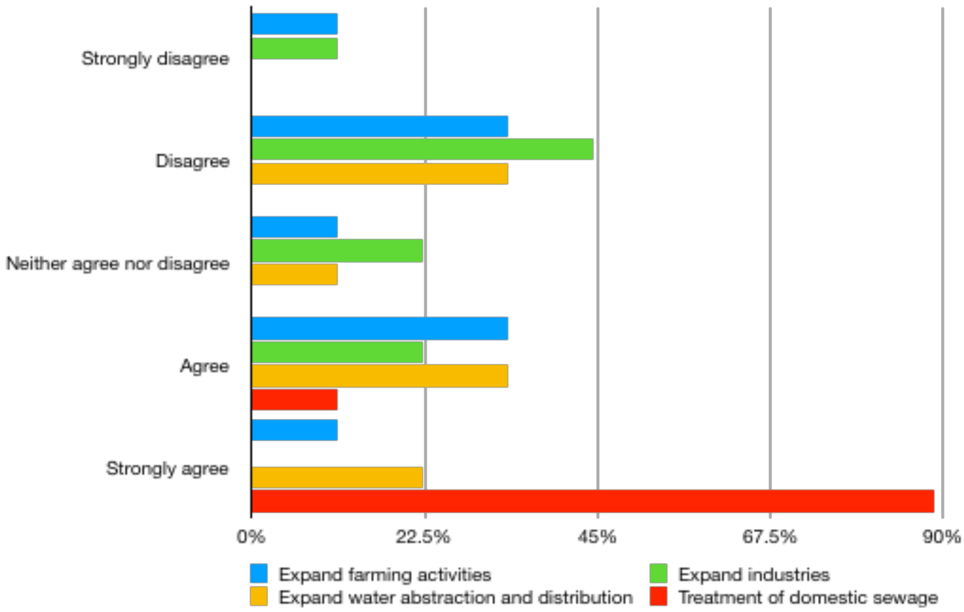

Figure 31: Likert scale valid percent civil society answers

4.2. Hydrological foundation

Among 9 streamflow stations, only 5 were selected to compose the hydrological foundation (Pedro do Rio, Fazenda Sobradinho, Moreli (Parada Moreli), Fagundes and UHE Simplício Moura Brasil). The decision was based on the length of the series and availability of data that represented the pre-development and developed condition.

The period analyzed was from 1970 to 2017, considering 1970-1990 as the pre-development condition and from 1991-2017 as a developed condition. For the station UHE Simplício Moura Brasil, the analysis covers only until 2014, because the year of 2015 was without any data. The gauge information together with the amount of data that were interpolated can be found in Table 28.

Four stations had their streamflow series interpolated by IHA, the station that had most gaps was Fagundes (273 interpolated values). Other stations such as UHE Simplício Moura Brasil had no data interpolated.

Table 28: Streamflow interpolation

Gauge name	Period of record used	Consistency of flow	Interpolate data
Pedro do Rio	01/01/1970 - 12/31/2017	1932-2014 (consisted) 2015-2017 (raw)	63 daily values have been interpolated in the year 2017
Fazenda Sobradinho	01/01/1970 - 12/31/2017	1936-2014 (consisted) 2015-2017 (raw)	31 daily values have been interpolated in the year 2017
Moreli (Parada Moreli)	01/01/1970 - 12/31/2017	1948-2014 (consisted) 2015-2017 (raw)	32 daily values have been interpolated in the year 2015
Fagundes	01/01/1970 - 12/31/2017	1937-1981(consisted) *1982 (no data) 1983-2014 (consisted) 2015-2017 (raw)	31 daily values have been interpolated in the year 1978 76 daily values have been interpolated in the year 1995 71 daily values have been interpolated in the year 2005 95 daily values have been interpolated in the year 2016
UHE Simplício Moura Brasil	01/01/1970 - 12/31/2014	1933-2014 (consisted)	No data was interpolated

The Hydrological Condition of the Basin (HyC) was calculated for all five streamflow stations. The annual average streamflow (m^3/s) and the anomaly time series can be seen in Figure 32 and 33, while the final classification of each event for can be seen in Table 29.

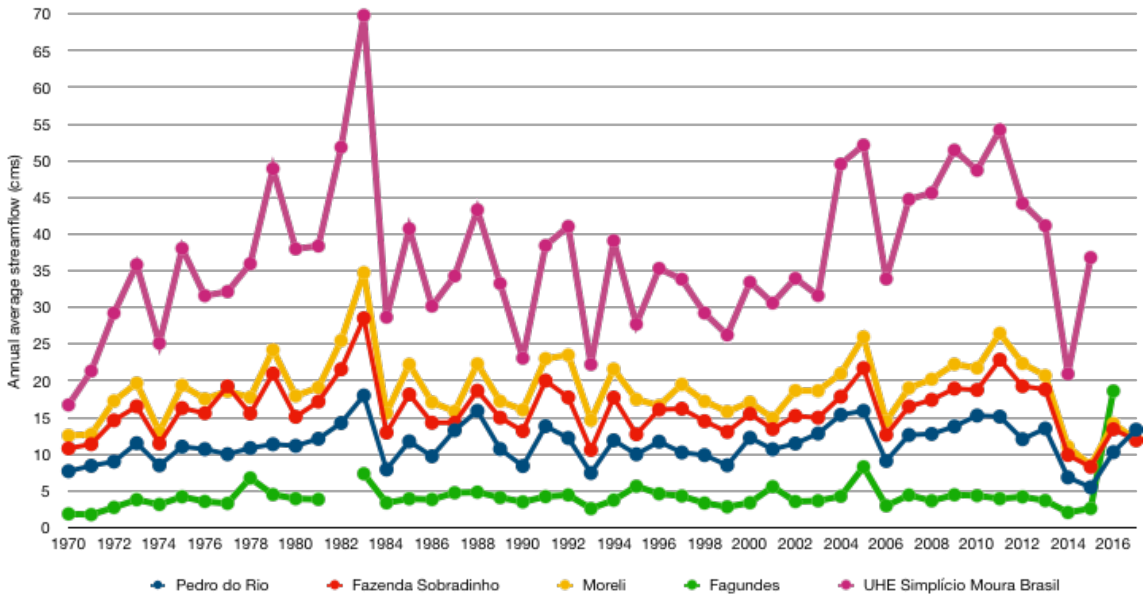

Figure 32: Annual average streamflow time series

Due to the annual average streamflow volume differs among the stations in rare events the maximum value exceeded one another, this occurs in 2016 for Fagundes station where the year was classified as wet.

Overall most part of the events among the five stations fit into the class Average (–0.5 < Anomaly < 0.5). There is only one Very wet event (Anomaly > 1.5), it occurred in Moreli station in 1983. For almost all the stations (except Moreli) the year 1983 was classified a Wet (0.5 < Anomaly < 1.5). Dry events (–1.5 < Anomaly < –0.5) are the second more common classification. For all the stations the year 2014 was classified as Very dry (Anomaly < –1.5). 1970, 1984 and 1999/2000 match patterns of dry periods found by Marques *et al.* (2017).

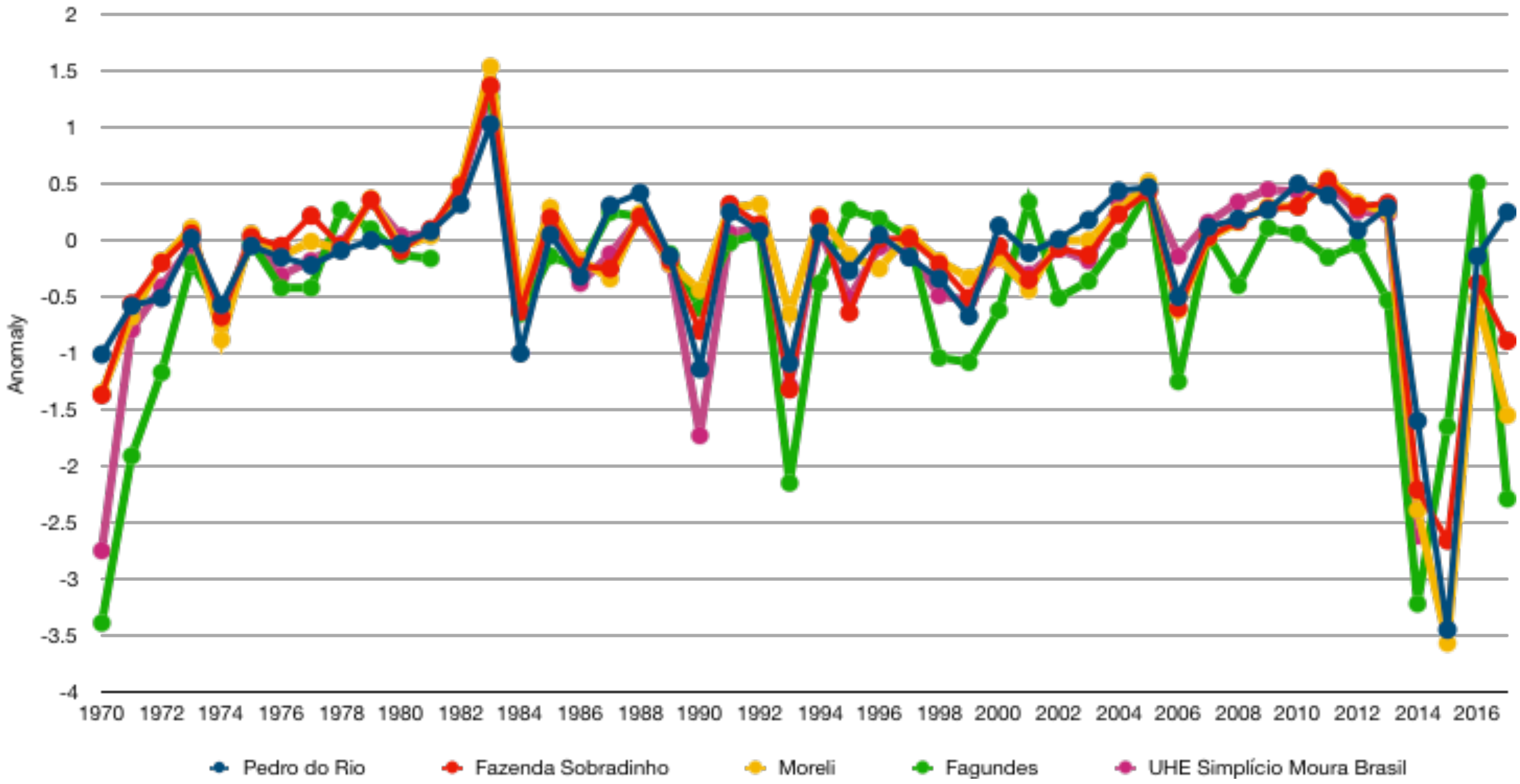

Figure 33: Anomaly time series of annual average flow within the Piabanha watershed

Table 29: Classification of the annual events by the HyC method in Piabanha watershed

Gauge name	Very Dry	Dry	Average	Wet	Very wet
Pedro do Rio	2014, 2015	1970, 1971, 1972, 1974, 1984, 1990, 1993, 1999	1973, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982, 1985, 1986, 1987, 1988, 1989, 1991, 1992, 1994, 1995, 1996, 1997, 1998, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2011, 2012, 2013, 2016, 2017	1983, 2010	-
Fazenda Sobradinho	2014, 2015	1970, 1971, 1974, 1984, 1990, 1993, 1995, 1999, 2006, 2017	1972, 1973, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982, 1985, 1986, 1987, 1988, 1989, 1991, 1992, 1994, 1996, 1997, 1998, 2000, 2001, 2002, 2003, 2004, 2005, 2007, 2008, 2009, 2010, 2012, 2013, 2016	1983, 2011	-
Moreli (Parada Moreli)	2014, 2015, 2017	1970, 1971, 1974, 1984, 1993, 2006, 2016	1972, 1973, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2007, 2008, 2009, 2010, 2012, 2013	1982, 2005, 2011	1983
Fagundes	1970, 1971, 1993, 2014, 2015, 2017	1972, 1974, 1984, 1990, 1998, 1999, 2000, 2002, 2006, 2013	1973, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1985, 1986, 1987, 1988, 1989, 1991, 1992, 1994, 1995, 1996, 1997, 2001, 2003, 2004, 2005, 2007, 2008, 2009, 2010, 2011, 2012	1983, 2016	-
UHE Simplício Moura Brasil	1970, 1990, 2014	1971, 1974, 1984, 1993, 1995, 1999	1972, 1973, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982, 1985, 1986, 1987, 1988, 1989, 1991, 1992, 1994, 1996, 1997, 1998, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013	1983	-

4.3. Hydrological alteration

In this session, the hydrological alterations are going to be described based on the 5 groups of the IHA software and the classification of made with DHRAM method.

4.3.1. Application of the Indicators of Hydrological Alteration

The impact of the hydrological alteration was accessed based on the pre-impact and post-impact flow series. For each station, the pre-development and post-development series are going to be discussed through graphs and the parameters that had higher alteration are going to be highlighted, a summary of the most significant alterations can be found in Table 30.

For this study region, the wet period starts in November and ends in April while the dry period from May to October.

Mean annual flow increased for the gauge stations within Petrópolis city when compared with the pre-impact period, Pedro do Rio station 11.02 m^3/s (pre-impact) to 11.62 m^3/s (post-impact), Fagundes 3.39 m^3/s (pre-impact) to 4.47 m^3/s (post-impact), and UHE Simplício Moura Brasil 35.45 m^3/s (pre-impact) to 37.83 m^3/s (post-impact). For other two stations the mean annual flow decreased, Fazenda Sobradinho 16.21 m^3/s (pre-impact) to 15.76 m^3/s (post-impact), and Moreli (Parada Moreli) 18.82 m^3/s (pre-impact) to 18.45 m^3/s (post-impact).

Overall, for all the stations the main alteration on Group 1 was during the wet period, for the stations Pedro do Rio, Fagundes and UHE Simplício Moura Brasil the mean flow values were higher in the post-impact period, while for Fazenda Sobradinho and Moreli (Parada Moreli) they dropped in the post-impact period (see Figure 34 to 38).

Table 30: Summary of changes under the IHA groups

Gauge name	Group 1	Group 2	Group 3	Group 4	Group 5
Pedro do Rio	Wet period had higher mean flows for the post-impact period especially in January and March	All the maximum flows rate substantially raised in the post-impact (1, 3, 7, 30 and 90 - day maximum)	Date of the maximum was slightly altered	High pulse count minimally decreased and high pulse duration slightly increased in the post-impact	Number of reversals minimally increased in the post-impact
Fazenda Sobradinho	Wet period had a drop in mean flows for the post-impact period especially in February, the trend changed on January	1, 3, 7 day maximum were slightly altered increasing in the post-impact	Date of the minimum and maximum was slightly altered	High pulse count slightly decreased and high pulse duration minimally increased in the post-impact	Fall rate minimally increased in the post-impact and the number of reversals slightly decreased
Moreli (Parada Moreli)	Wet period had a drop in mean flows for the post-impact period especially in February, the trend changed on January	1, 3, 7 day maximum were slightly altered increasing in the post-impact	Date of the minimum and maximum was slightly altered	High pulse count slightly decreased and high pulse duration minimally increased in the post-impact	Rise and fall rate minimally increased in the post-impact
Fagundes	Alterations in all the months of the year, especially during the wet period where the mean flows were higher during the post-impact from January to March	All the maximum flows rate substantially raised in the post-impact (1, 3, 7, 30 and 90 - day maximum)	Date of the minimum and maximum was slightly altered	Low pulse count and duration decreased in the post-impact, high pulse count slightly decreased and high pulse duration slightly increased	Fall rate minimally increased in the post-impact, the number of reversals decreased slightly
UHE Simplício Moura Brasil	Wet period had higher mean flows for the post-impact period especially on January	All the maximum flows rate substantially raised in the post-impact (1, 3, 7, 30 and 90 - day maximum)	Date of the maximum was considerably altered	High pulse count minimally increased and high pulse duration slightly increased in the post-impact	Rise rate slightly, fall rate and number of reversals slightly decreased in the post-impact

Group 1 - Magnitude of monthly water conditions:

Pedro do Rio station: the most significant alterations on Group 1 affected the volume of flows in the wet period, where the flow volume is higher in the post-impact, especially during January, March, and April. The dry period had some small alteration of flow volume during the months of September and October, where the post-impact period presented a smaller volume of flows compared to the pre-impact (see Figure 34).

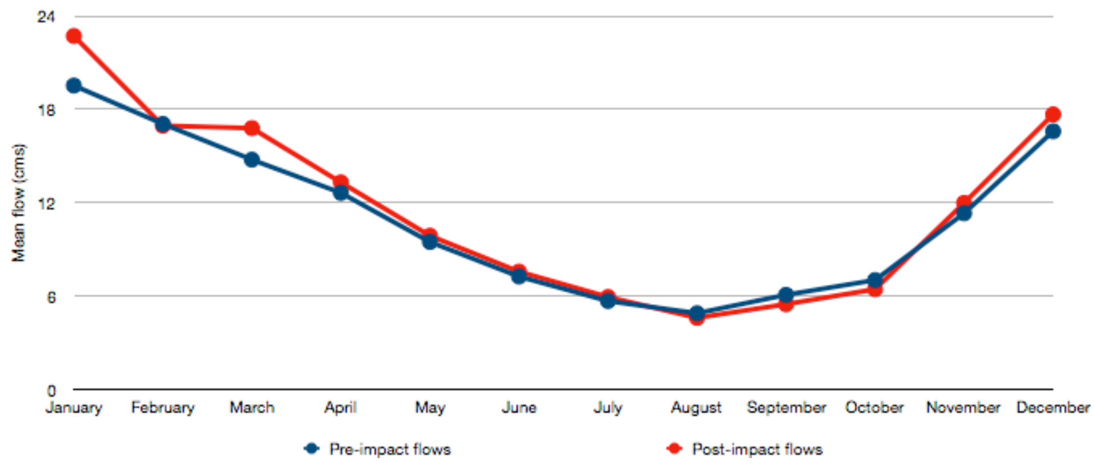

Figure 34: Pedro do Rio monthly flow alterations

Fazenda Sobradinho station: The most significant alterations on Group 1 occurred during the wet period (see Figure 35), where the flows from the post-impact had a smaller volume than the pre-impact (except for the month of January, where the post-impact flows are higher than the pre-impact). The dry period also presented alterations for the months of September and October where the flow volume from the post-impact period decreased compared to the pre-impact.

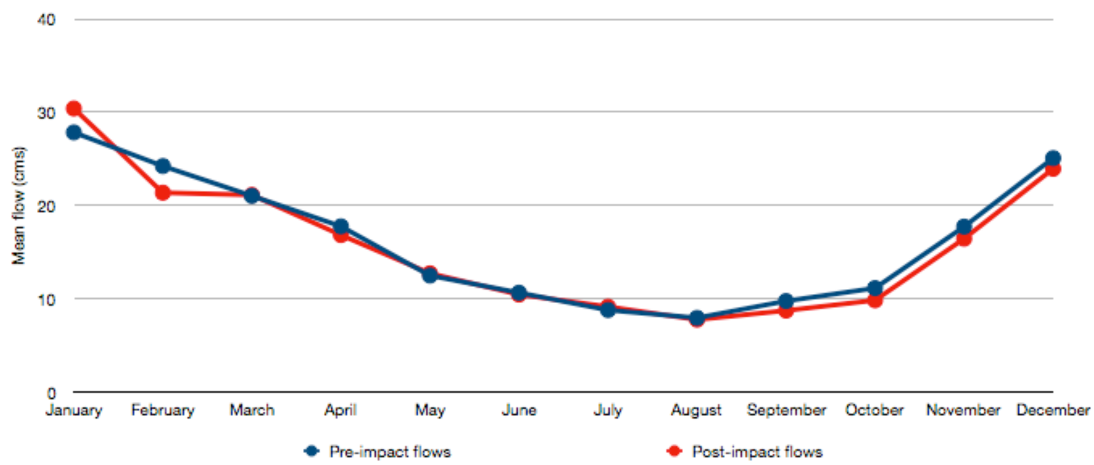

Figure 35: Fazenda Sobradinho monthly flow alterations

Moreli (Parada Moreli) station: The most significant alterations on Group 1 occurred on the months of January and February on the wet period, for January the post-impact flows had a higher volume than the pre-impact while for February the inverse occurred. For the dry period, the month of September and October presented changes where the post-impact flows dropped compared to the pre-impact condition (see Figure 36).

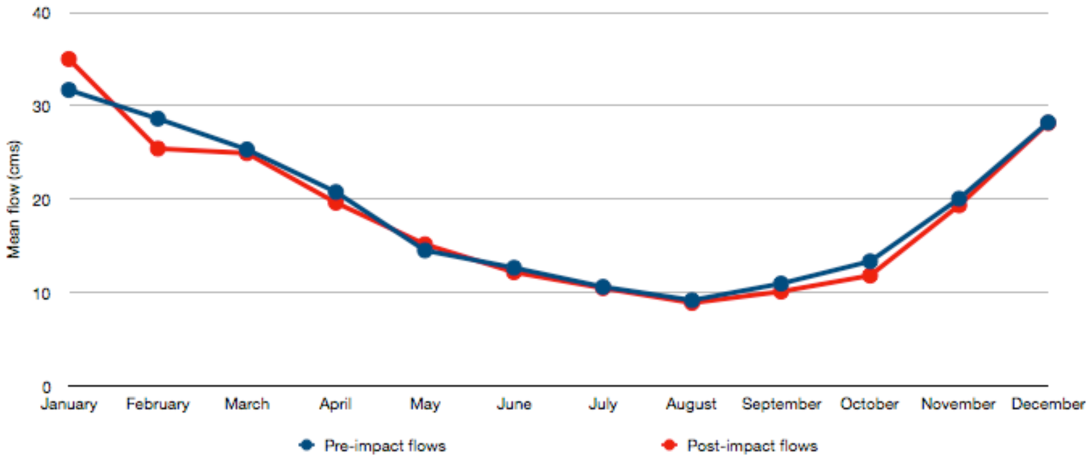

Figure 36: Moreli (Parada Moreli) monthly flow alterations

Fagundes station: Group 1 suffered alterations in all the months of the year (see Figure 37), the most dramatically ones were during the wet season. For the month of January and February, the changes were similar, and the post-impact period had a higher volume of flows when compared to the pre-impact. After August the flows mean became smaller than the pre-impact period until December.

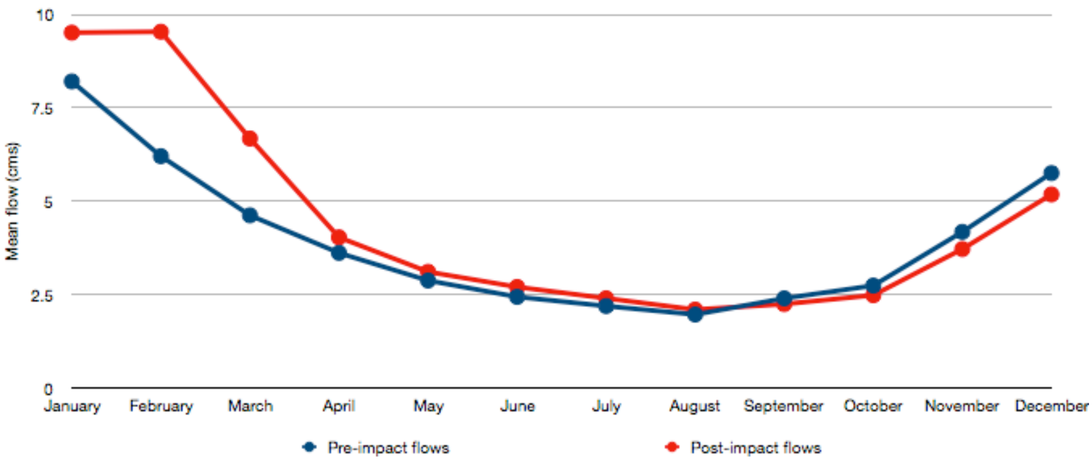

Figure 37: Fagundes monthly flow alterations

UHE Simplício Moura Brasil station: The most significant alterations on Group 1 occurred during the wet period, with an upward trend of flow for months of December, January and March for the post-impact series compared to the pre-impact. A similar pattern of flows can be observed for the pre and post-impact during the dry season (see Figure 38).

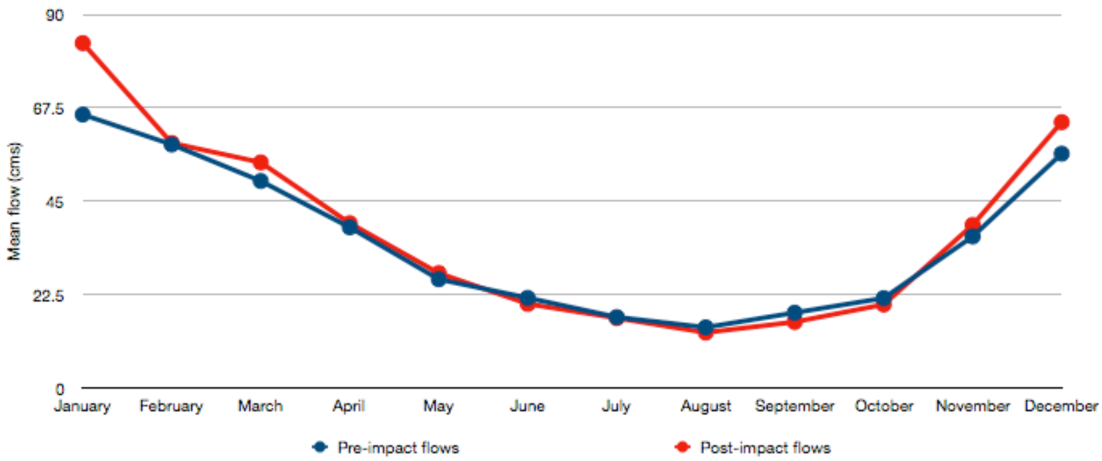

Figure 38: UHE Simplício Moura Brasil monthly flow alterations

Group 2 - Magnitude and duration of annual extreme water conditions:

The maximum flows rate increased in the post-impact period for the all the stations, but for the stations, Pedro do Rio, Fagundes and UHE Simplício Moura Brasil these changes were with a higher rate (see Figure 39 to 43).

Minimum flows increased compared to the pre-impact period for Fagundes station and mainly decreased for Moreli and UHE Simplício Moura in the post-impact period (see Figure 44 to 48).

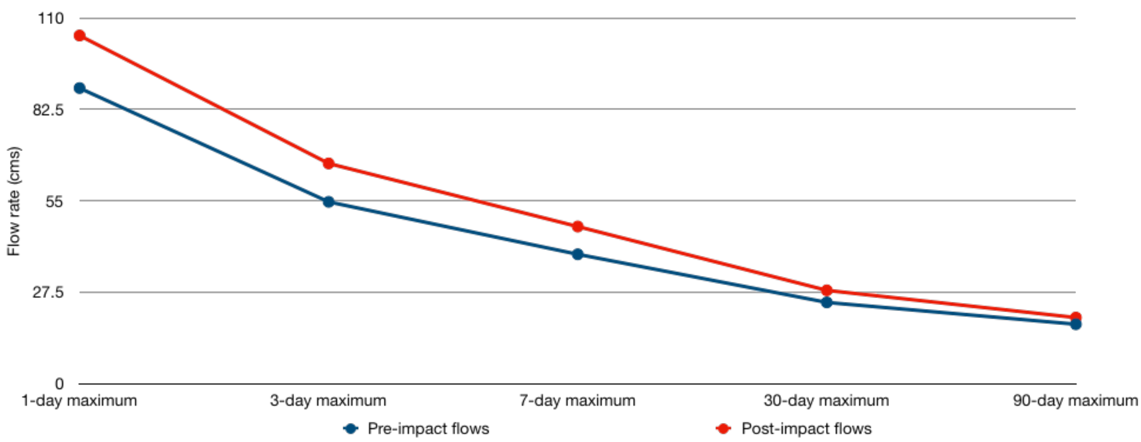

Figure 39: Pedro do Rio maximum flows

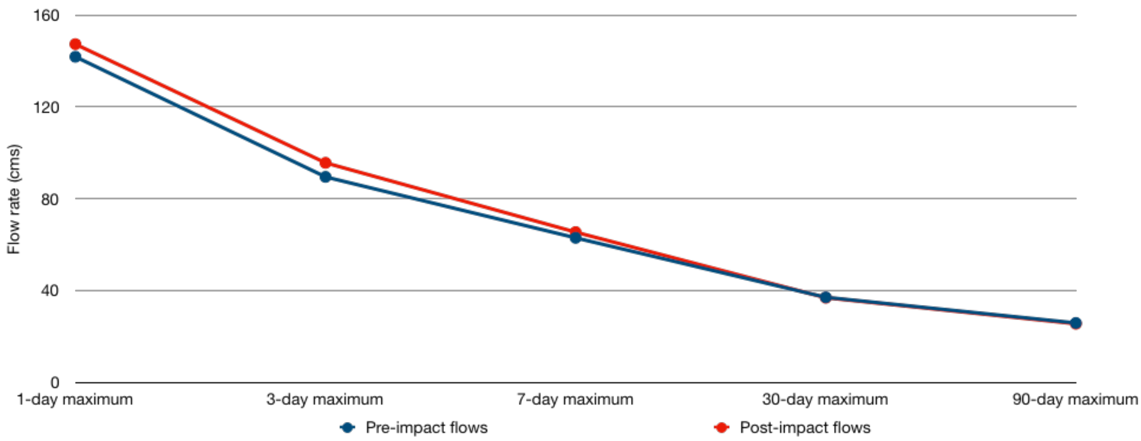

Figure 40: Fazenda Sobradinho maximum flows

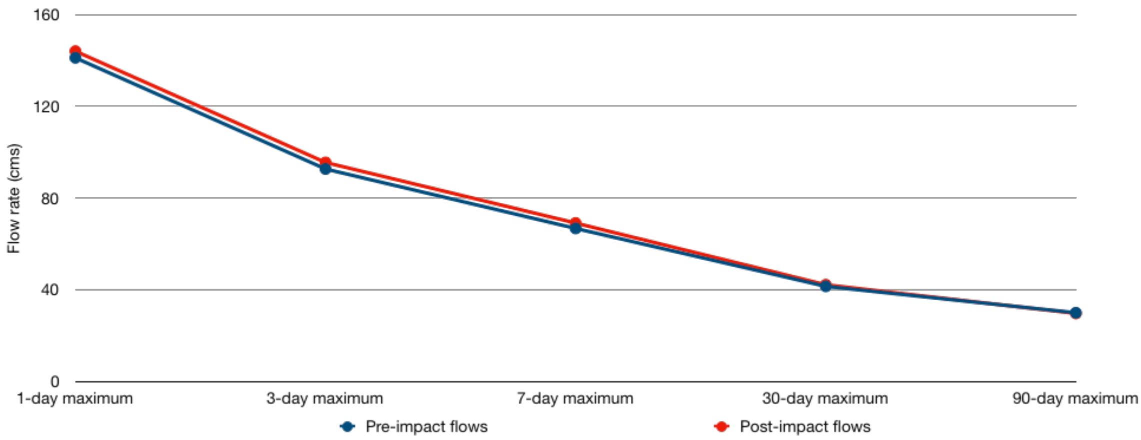

Figure 41: Moreli (Parada Moreli) maximum flows

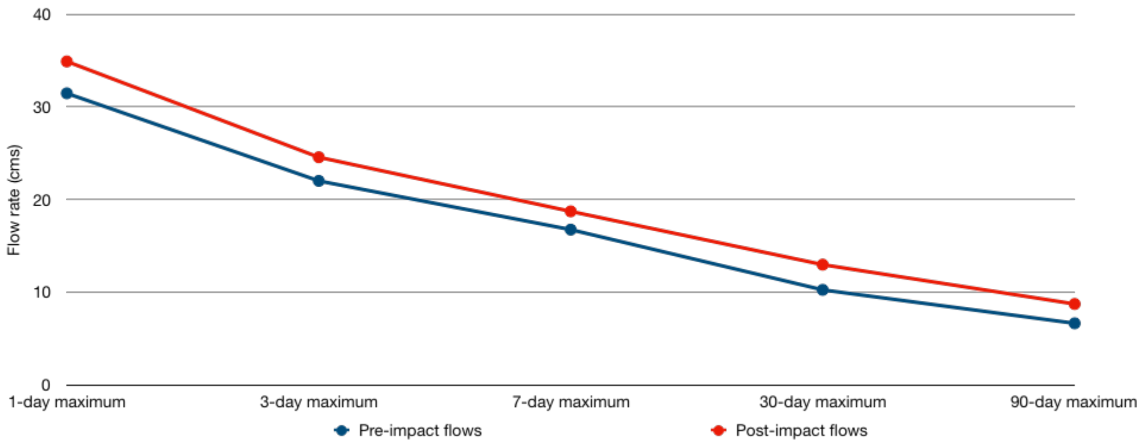

Figure 42: Fagundes maximum flows

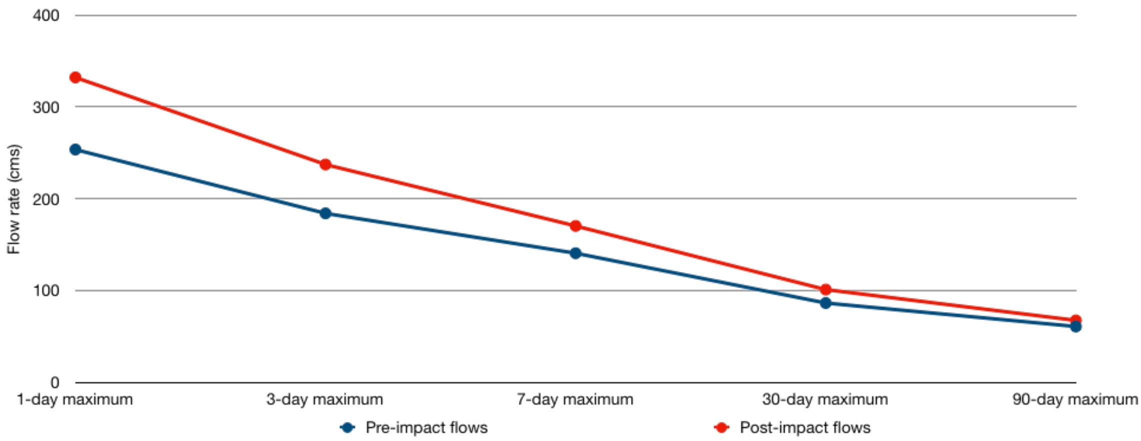

Figure 43: UHE Simplício Moura Brasil maximum flows

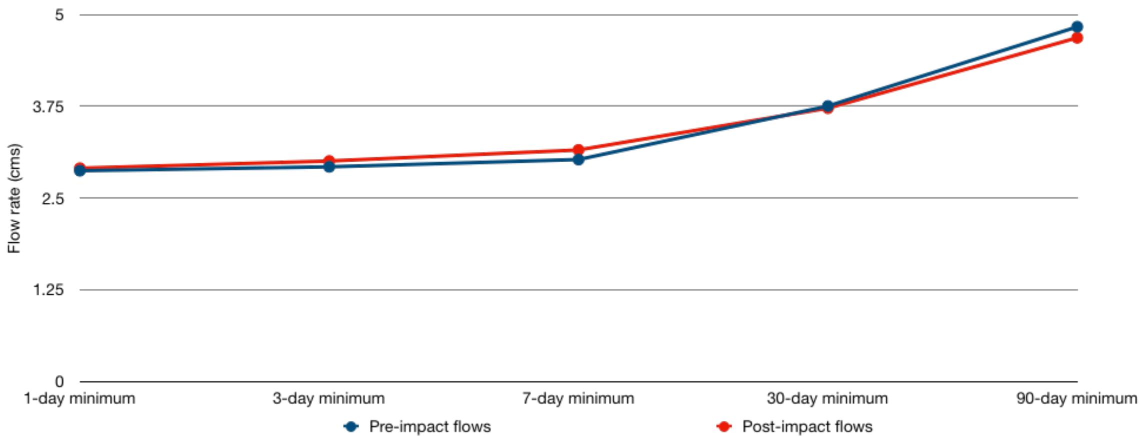

Figure 44: Pedro do Rio minimum flows

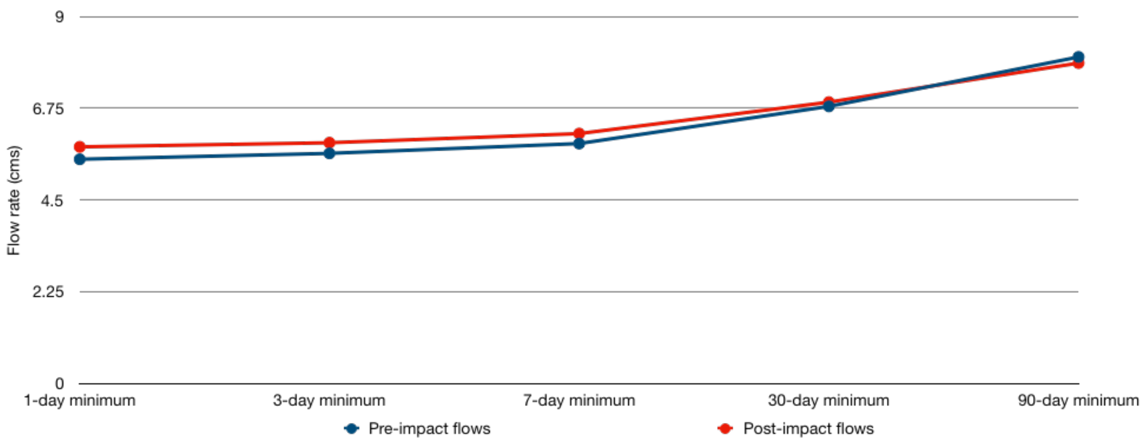

Figure 45: Fazenda Sobradinho minimum flows

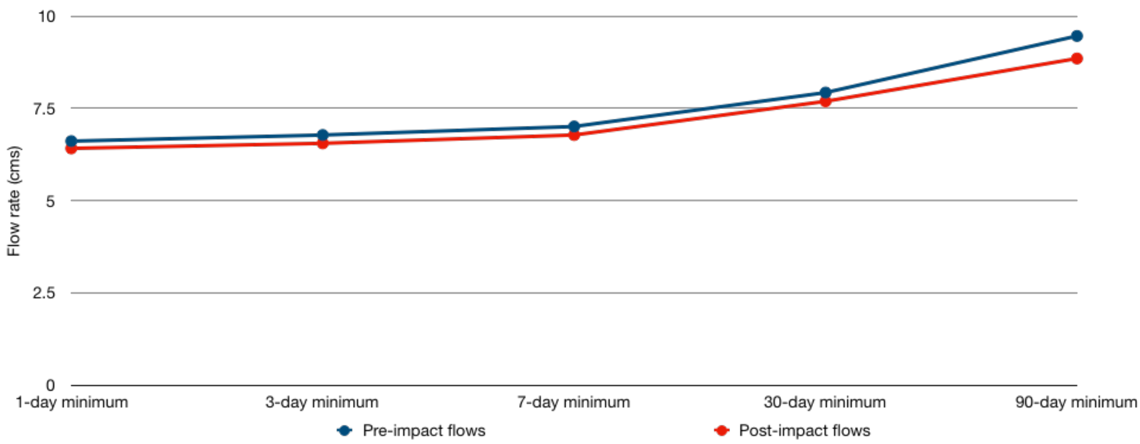

Figure 46: Moreli (Parada Moreli) minimum flows

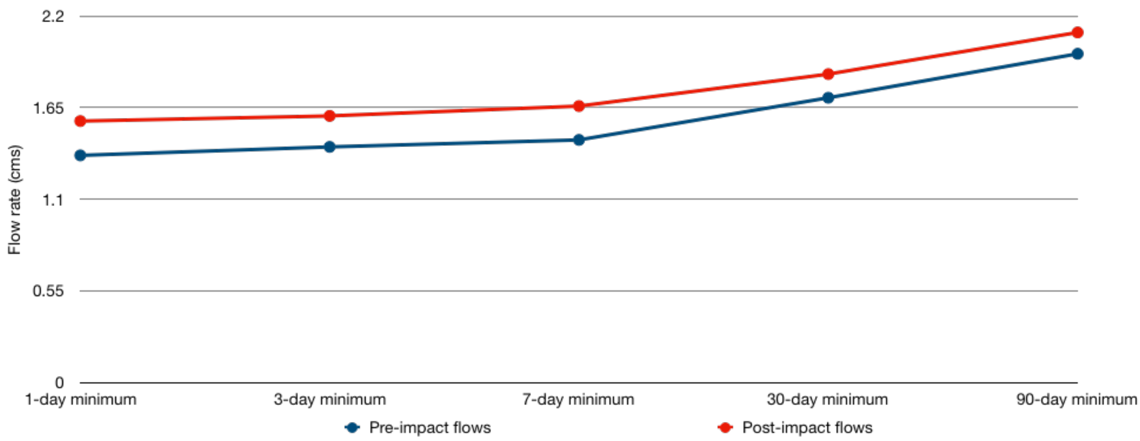

Figure 47: Fagundes minimum flows

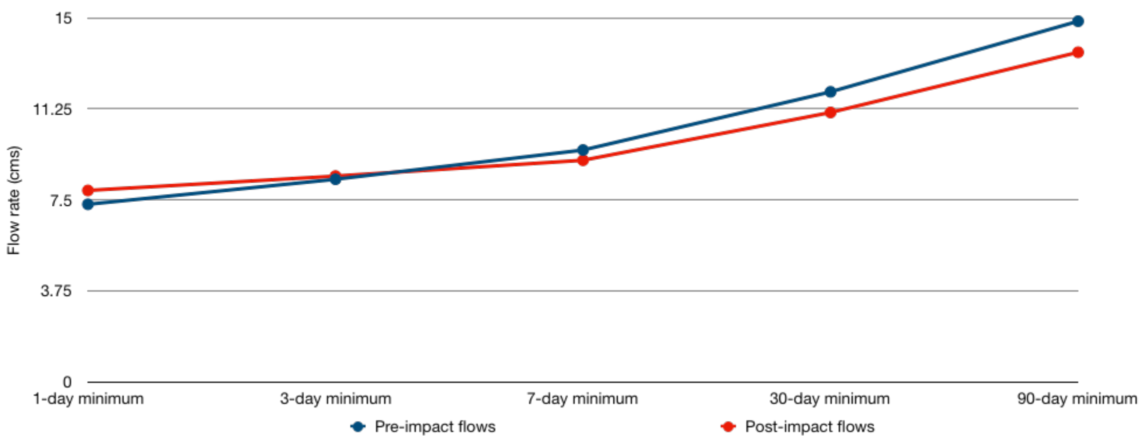

Figure 48: UHE Simplício Moura Brasil minimum flows

Group 3 - Timing of annual extreme water conditions:

All the stations had the date of the maximum altered, for UHE Simplício Moura Brasil this alteration was substantial (see Table 31).

Table 31: Alteration in the date of maximum and minimum flows

Gauge name	Pre-impact Julian date of each annual 1-day maximum	Post-impact Julian date of each annual 1-day maximum
Pedro do Rio	21.6	20.8
Fazenda Sobradinho	24.3	13.1
Moreli (Parada Moreli)	13.8	22.0
Fagundes	13.2	7.8
UHE Simplício Moura Brasil	20.1	349.6

Fazenda Sobradinho, Moreli (Parada Moreli) and Fagundes also had the date of the minimum and slightly altered (see Table 32).

Table 32: Alteration in the date of maximum and minimum flows

Gauge name	Pre-impact Julian date of each annual 1-day minimum	Post-impact Julian date of each annual 1-day minimum
Pedro do Rio	260.8	260.7
Fazenda Sobradinho	271.8	266.6
Moreli (Parada Moreli)	265.1	267.8
Fagundes	266.7	283.0
UHE Simplício Moura Brasil	254.8	255.7

Group 4 - Frequency and duration of high and low pulses:

Among the four stations, Fagundes present more impact in this group. Low pulse count and duration decreased for Fagundes station in the post-impact period (see Figure 49 and 50); high pulse count decreased in the post-impact period, and high pulse duration increased (see Figure 51 and 52).

For the other stations, high pulse count minimally increased for UHE Simplício Moura Brasil in the post-impact period, while for the other stations the count decreased; and high pulse duration increased for all the stations.

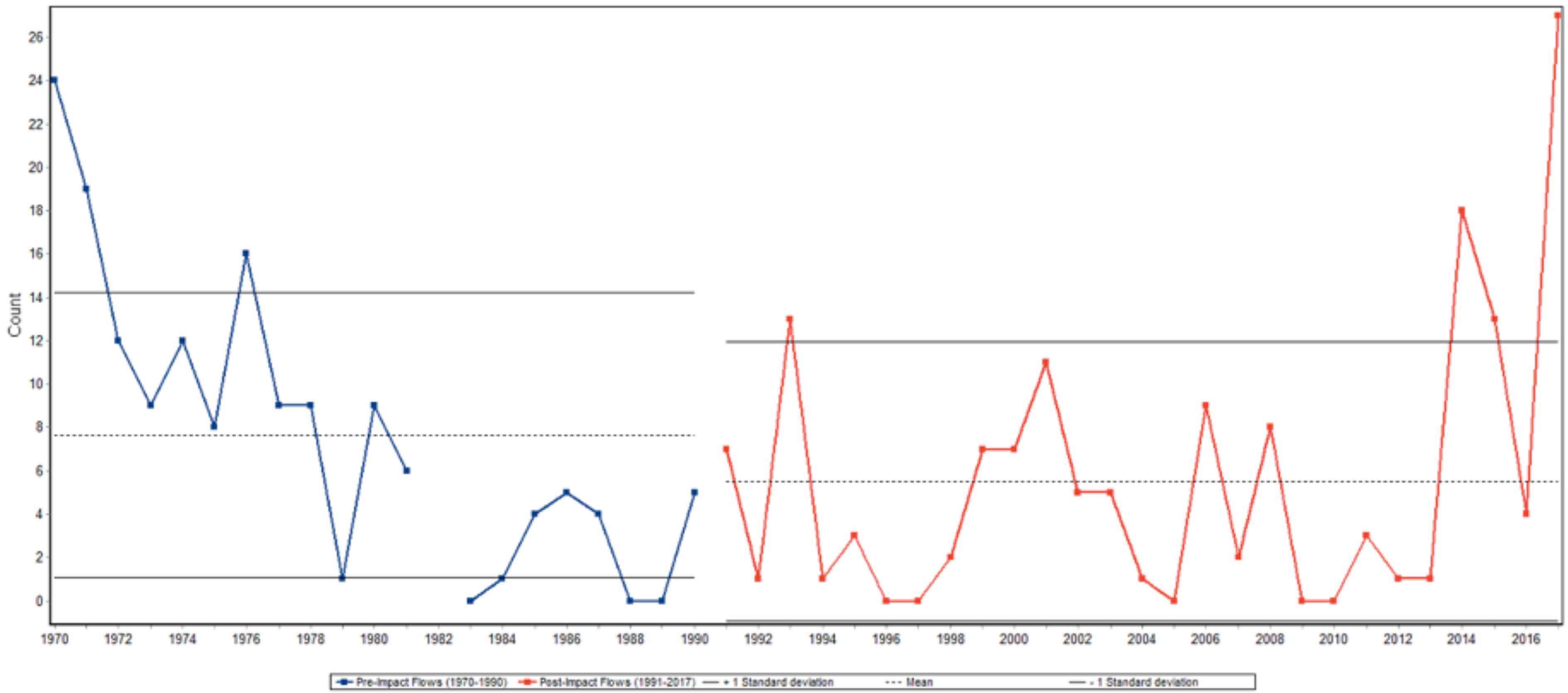

Figure 49: Low pulse count for Fagundes station

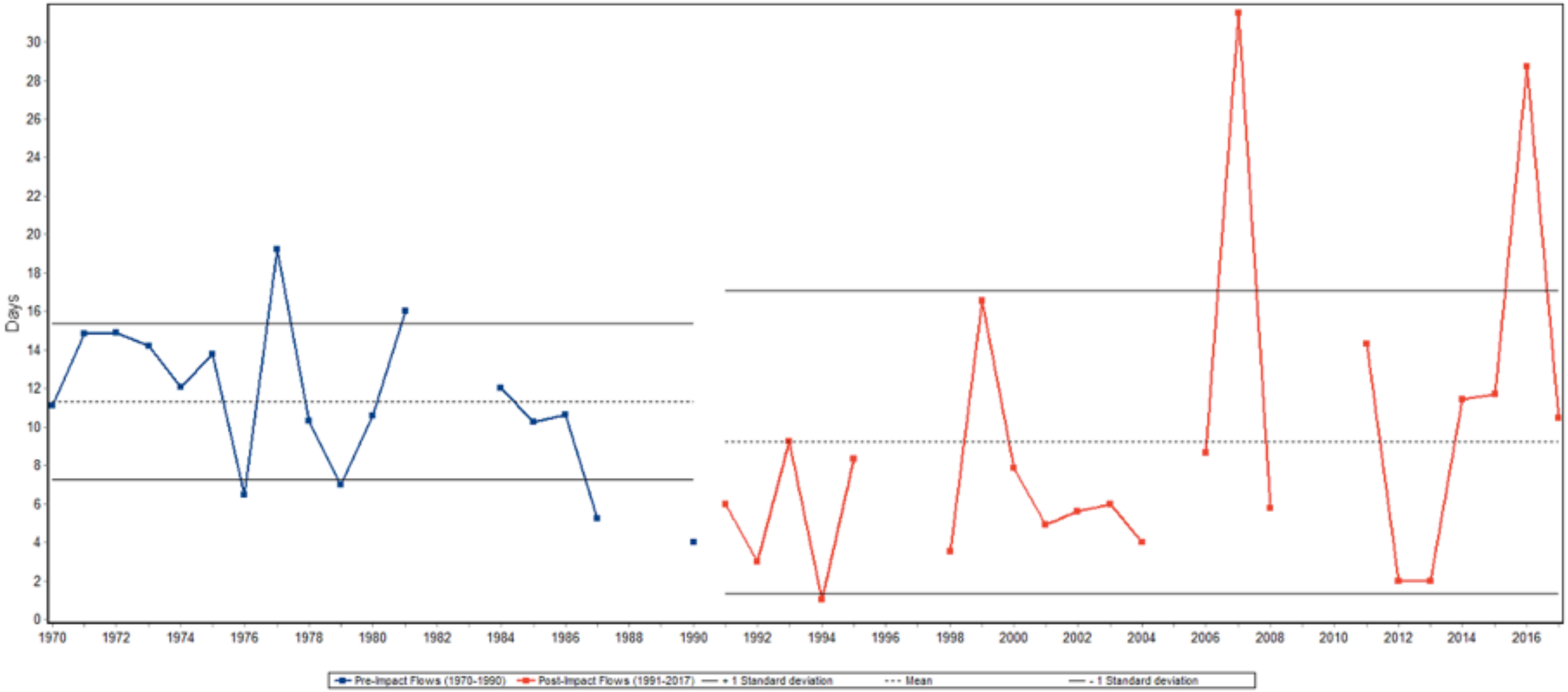

Figure 50: Low pulse duration for Fagundes station

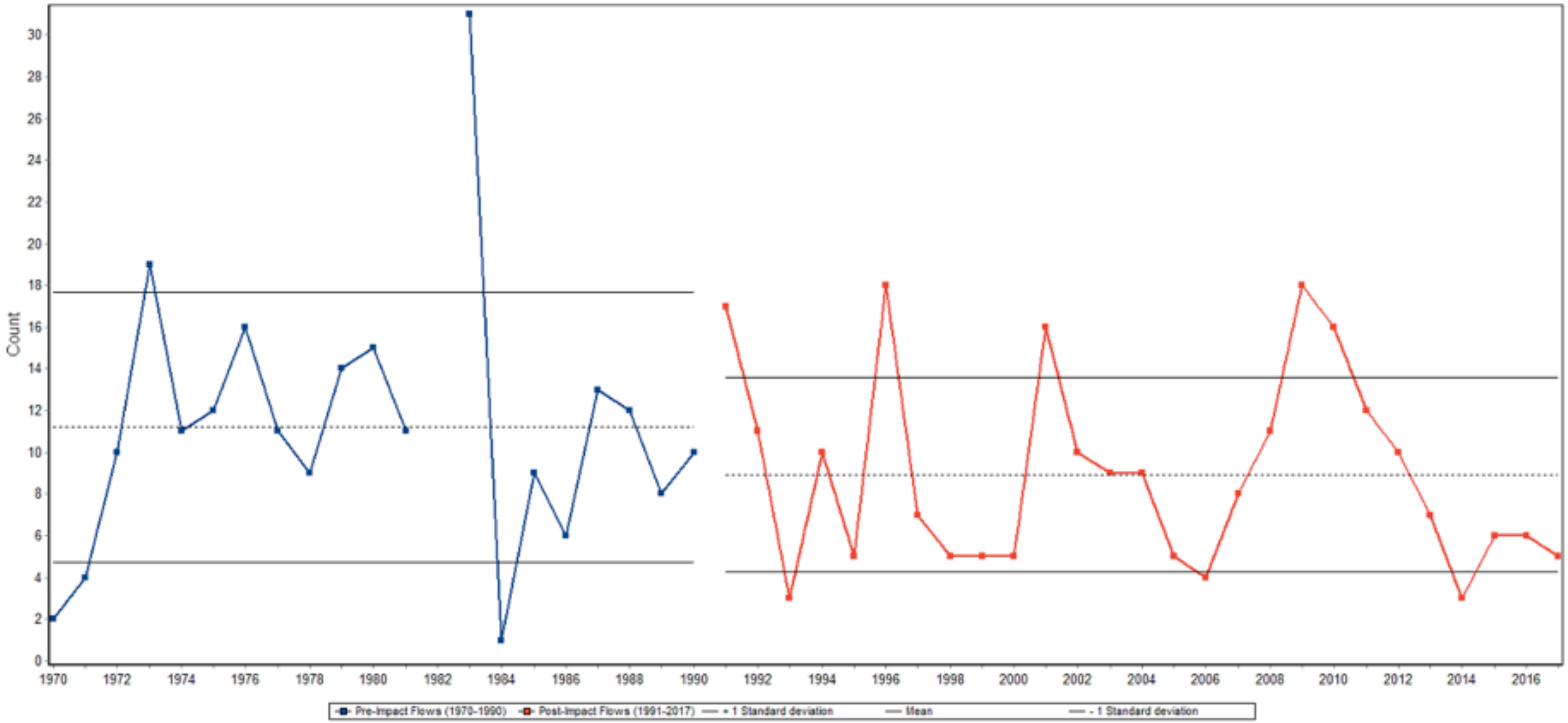

Figure 51: High pulse count for Fagundes station

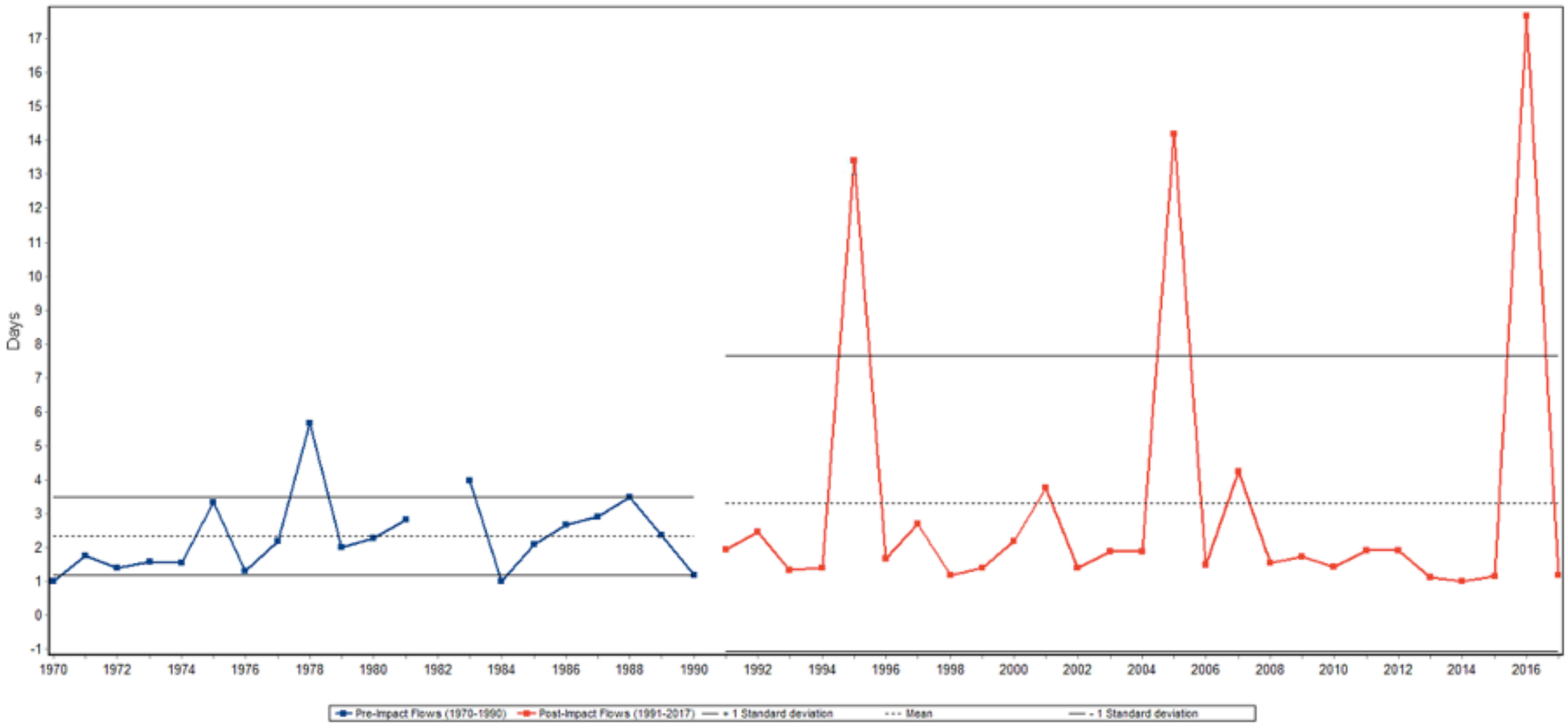

Figure 52: High duration for Fagundes station

Group 5 - Rate and frequency of water condition changes: Overall all the stations had the rising rate increased in the post-impact period (see Figure 53); the fall rate decreased for Moura Brasil but increased for all other stations in the post-impact period (see Figure 54); and the number of reversals increased for Pedro do Rio and Moreli (Parada Moreli) in the post-impact period and decreased for Fazenda Sobradinho, Fagundes and UHE Simplício Moura Brasil (see Figure 55).

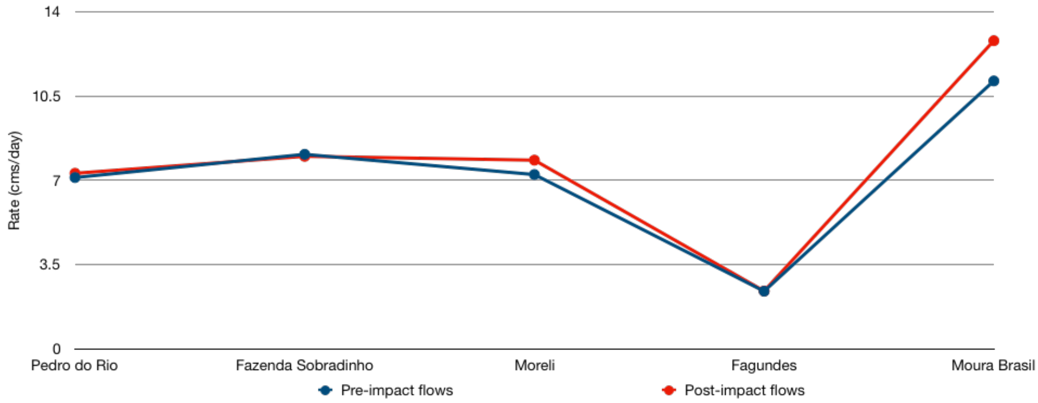

Figure 53: Rise rate among the stations

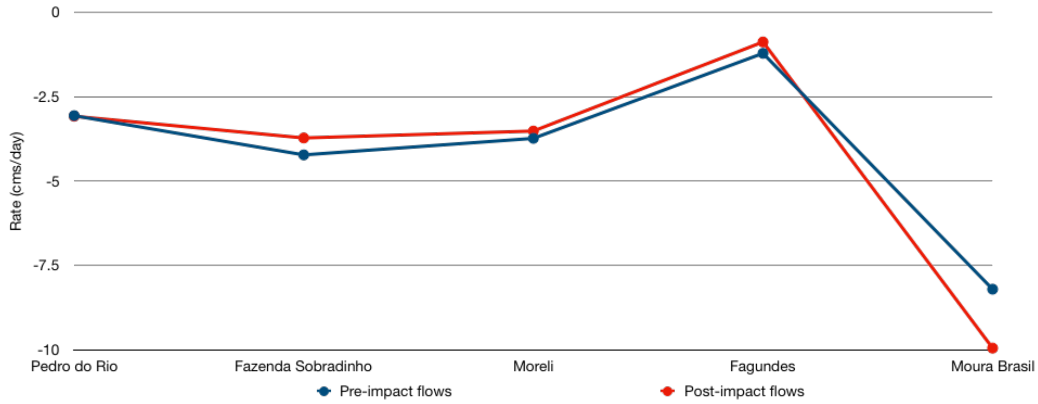

Figure 54: Fall rate among the stations

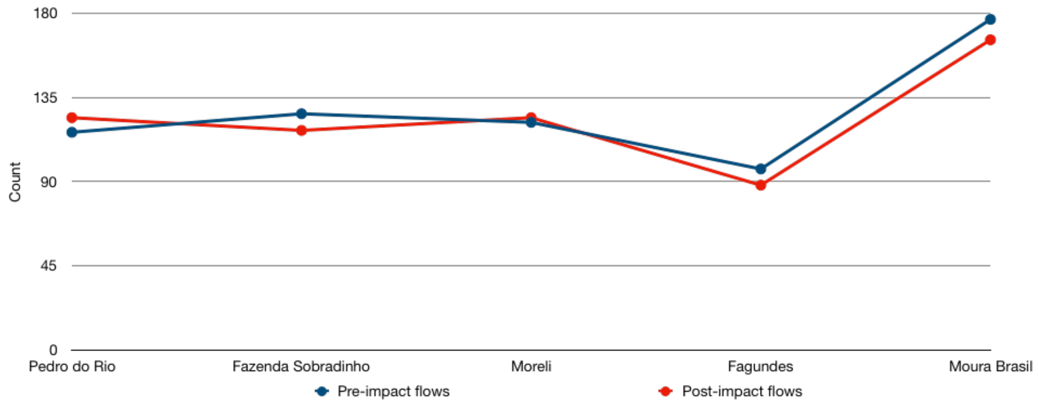

Figure 55: Number of reversals among the stations

4.3.2. Application of the Indicators of the Dundee Hydrological Regime Alteration Method

After the previous step, the data generated was used to classify the hydrological alterations. Among the five stations analyzed three of them were classified as Class 2 (Low risk of impact), while two of them as Class 1 (Un-impacted condition) see Table 33 and Figure 56.

Table 33: Final classification of the hydrological alterations DHRAM scores and stream classes

Gauge name	IHA indicator altered	Points range	Class	Description
Pedro do Rio	3	1	2	Low risk of impact
Fazenda Sobradinho	-	0	1	Un-impacted condition
Moreli (Parada Moreli)	-	0	1	Un-impacted condition
Fagundes	1, 4	3	2	Low risk of impact
UHE Simplício Moura Brasil	3	4	2	Low risk of impact

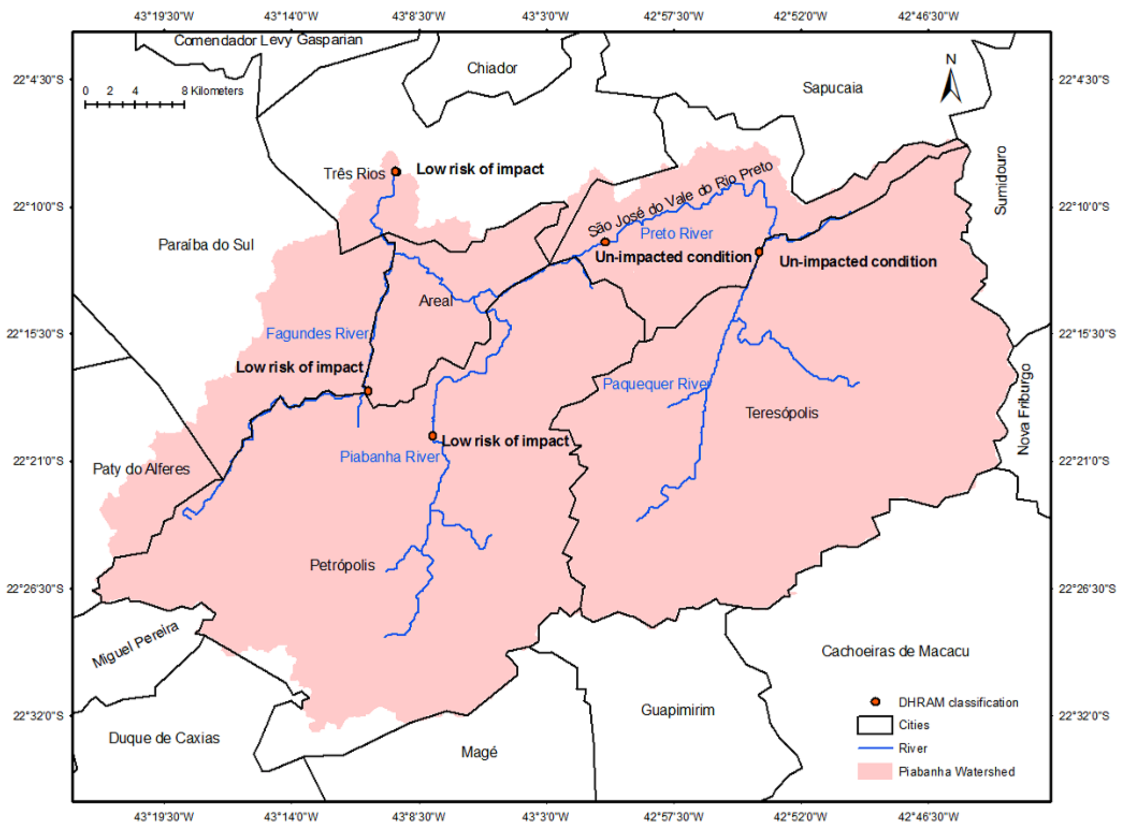

Figure 56: DHRAM classification distribution within the Piabanha watershed committee

Overall the final classifications show that the basin did not suffer significant impacts, mainly due to the fact that its rivers mostly are un-regulated. Two stations classified as Class 2 are within the city of Petrópolis and one is at Três Rios.

As mentioned before Petrópolis is one of the cities within the basin that was more affected by the growth of population and urbanization, while the station in Três Rios is under the influence of a small hydropower plant.

The main groups impacted the stations classified as low risk of impact are:

(1) Group 1 (magnitude of monthly water conditions);

(2) Group 3 (timing of annual extreme water) for Pedro do Rio and UHE Simplício Moura Brasil; and

(3) Group 4 (frequency and duration of high and low pulses) for Fagundes (see Table 34).

Fazenda Sobradinho and Moreli (Parada Moreli) were classified as the un-impacted condition and have not received any score from any of the IHA groups.

Table 34: Pedro do Rio DHRAM scores and stream classes

Station	**Summary indicator points**										**Total Points**	**DHRAM class**
	1a	**1b**	**2a**	**2b**	**3a**	**3b**	**4a**	**4b**	**5a**	**5b**		
Pedro do Rio	7.1	15.7	9.1	20.5	0.2	43.4	13.6	6.4	3.2	11.3	1	2
Fazenda Sobradinho	5.9	20.2	3.8	24.5	4.5	19	15.5	16.1	6.7	18.4	0	1
Moreli	5.3	15.6	2.8	19.7	3	16.4	10.4	7.1	5.4	10.7	0	1
Fagundes	16.4	63.7	14.8	54.9	5.9	20.6	27.2	87.9	12.3	19.9	3	2
UHE Simplício Moura Brasil	8.4	18.4	13.4	20.2	10.2	78.8	14.4	20.8	14.2	38.9	4	2

4.4. Ecological foundation

There was no long-term ecological data that could represent the entire timeline used for the hydrological foundation as a baseline and developed condition, so this approach considered the data available as development condition and in the future can be considered as a baseline if a long-term monitoring program start.

Based on the local database available, among the 10 ecological stations monitored by Caramaschi *et al.* (2016) between 2012-2014, only four were close to a streamflow station.

As mentioned on the analyzes criteria, the stations selected had to be connected with streamflow data. After this filter, the remaining stations were:

(1) Fagundes (close to Fagundes streamflow station);

(2) Pedro (close to Pedro do Rio streamflow station);

(3) Moura Brasil (close to UHE Simplício Moura Brasil streamflow station); and

(4) Preto (close to Moreli streamflow station).

From 51 species the database was reduced to 44 species. The list of the species together with their spatial distribution among the four stations can be seen in Table 35.

Among the four monitoring stations. Preto station has a higher number of species, followed by Moura Brasil, Pedro, and Fagundes.

8 species had a high level of spatial distribution (all 4 sites or at least 3 sites), and three of them are considered resilient to environmental flow disturbance, see Table 36.

Fish species with a high level of spatial distribution and resilient to environmental disturbance can be used as an ecological indicator of major changes in the system in the future if they disappear of the river. A big range of species with the small spatial distribution and that are not resilient do environmental disturbances could be an indicator of a health ecosystem.

Table 35: Species distribution among the four stations

Specie	Fagundes	Pedro	Moura Brasil	Preto
Ancistrus multispinis		X		
Apareiodon piracicabae			X	
Astyanax giton			X	X
Astyanax gr. bimaculatus	X		X	X
Astyanax hastatus	X		X	X
Astyanax janeiroensis				X
Astyanax parahybae			X	
Australoheros facetus	X			X
Bryconamericus microcephalus			X	X
Bryconamericus tenuis				X
Cyphocharax gilbert				X
Corydoras nattereri				X
Crenicichla lepidota			X	
Geophagus brasiliensis	X	X	X	X
Gymnotus gr. carapo		X	X	X
Gymnotus sylvius				X
Glanidium melanopterus			X	
Hisonotus notatus				X
Hyphessobrycon bifasciatus				X
Hyphessobrycon luetkeni				X
Hypostomus punctatus	X	X	X	X
Hoplias malabaricus				X
Imparfinis minutus		X		X
Leporinus copelandii			X	X
Mimagoniates microlepis			X	X
Oligosarcus hepsetus		X	X	X
Oreochromis niloticus		X		X
Otocinclus affinis			X	X
Phalloceros harpagos		X		
Phalloceros leptokeras				X

Table 35: Continued

Specie	Fagundes	Pedro	Moura Brasil	Preto
Pimelodella lateristriga				X
Pimelodus fur			X	
Pimelodus maculatus			X	
Poecilia reticulata	X	X		
Poecilia vivipara				X
Prochilodus lineatus			X	
Rhamdia quelen	X	X		X
Rineloricaria sp.	X	X		X
Schizolecis guntheri		X		
Scleromystax barbatus			X	X
Synbranchus marmoratus			X	
Trachelyopterus striatulus				X
Trichomycterus gr. travessosi	X			
Xiphophorus hellerii		X		

Table 36: Species that compose the ecological foundation

Specie	**How many sites monitored have this species?**	**Resilient to environmental disturbance (Caramaschi *et al.*, 2016)**
Astyanax gr. bimaculatus	3	No
Astyanax hastatus	3	No
Geophagus brasiliensis	4	Yes
Gymnotus gr. carapo	3	No
Hypostomus punctatus	4	Yes
Oligosarcus hepsetus	3	No
Rhamdia quelen	4	Yes
Rineloricaria sp.	4	No

4.5. Flow-ecology linkages

4.5.1. Flow-ecology hypothesis

According to the first hypothesis if the hydrological alteration increased over time in a certain river, then we would observe a reduction in species richness (S). To verify this, the results of the hydrological classification with the ecological station's species richness were compared (see Table 37).

Table 37: Species Richness (S) vs. DHRAM score

Station	N	S	DHRAM total points	DHRAM class
Pedro (Pedro do Rio)	203	12	1	Low risk of impact
Fagundes	92	9	3	Low risk of impact
Preto (Moreli)	301	31	0	Un-impacted condition
Moura Brasil	86	24	4	Low risk of impact

Among the four stations analyzed, only Moreli streamflow station was classified as un-impacted condition (0 total points of impact) and when compared with Preto ecological station displayed the higher number of species richness (S=31).

Pedro do Rio and Fagundes streamflow stations were also classified as low risk of impact with the score of 1 and 3 points respectively and the higher the points the species richness (S) decreased from 12 for Pedro do Rio e 9 for Fagundes.

Expert consultation indicates that at Fagundes station the fish community may be reflecting the homogenization of the substrate, loss of vegetation due agriculture activities that destroy the habitat of the species.

Although Moura Brasil streamflow station was classified as low risk of impact and presented the higher score of points for DHRAM (4 points of impact) among the stations it has the second higher number of species richness (S=24). This fact could be due to: (1) the influence of the Paraiba do Sul river. Moura Brasil outlet is connected to it and there is a possible species migration, and (2) the species-area relationship as suggested by Caramaschi *et al.* (2016).

According to Curtin & Tabor (2016), one of the most fundamental relationships in conservation and ecology is the species-area curve. Rosenzweig (1995) demonstrated that species diversity, as well as population size, are largely a function of the area.

Overall, a pattern between the overall hydrological alteration increase over time in and a reduction in species richness for fish was observed in the basin.

4.5.2. Vulnerability to extinction

A total of 70% of species were categorized as having a low vulnerability to extinction, and 18% ranged from low to moderate vulnerability, 9% as moderate and only 2% as high (see Figure 57).

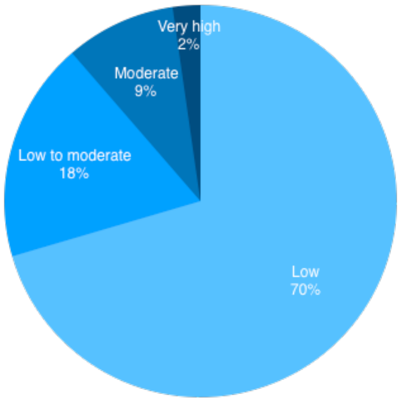

Figure 57: Overall species vulnerability distribution

Among the nine species in Fagundes station, the classification ranged from low and low to moderate, Figure 58 contains the % distribution.

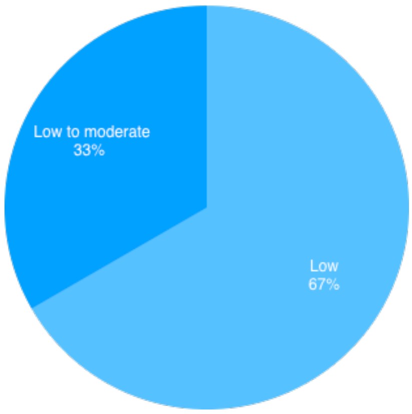

Figure 58: Species vulnerability distribution in Fagundes station

Pedro and Preto stations had tree classifications among their species, low, low to moderate and moderate. Although Preto station has almost double the number of species of Pedro station the percental distribution of the classification was very similar and can be seen in Figure 59 and 60.

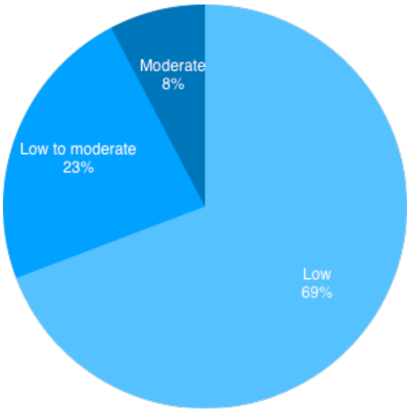

Figure 59: Species vulnerability distribution in Pedro station

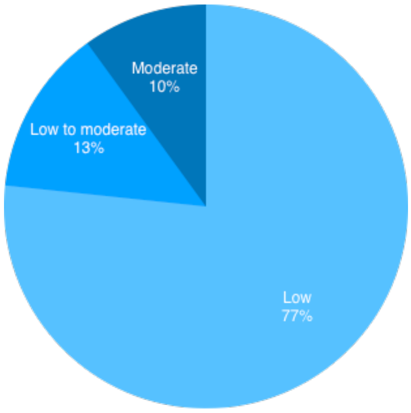

Figure 60: Species vulnerability distribution in Preto station

Moura Brasil station had four classifications among their species, low, low to moderate, moderate and very high see in Figure 61. It was the only station with very high species classification.

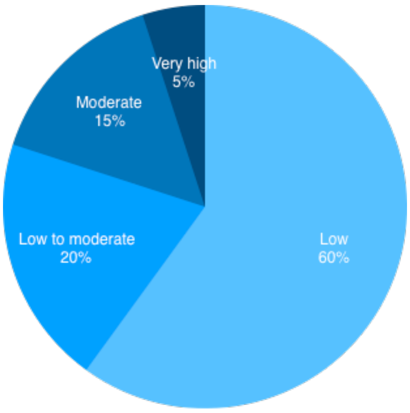

Figure 61: Species vulnerability distribution in Moura Brasil station

Although in Moura Brasil, the specie *Synbranchus marmoratus* was classified as very high vulnerability to extinction (according to FishBase database), local experts disagree with this classification. Local expert consultation points out that this species is very hard to be captured because it stays at the bottom of the river, but during the monitoring time as it was a dry period, it was possible to catch it.

Other highlights made by local expert consultation when it comes to the use of FishBase data is that:

(1) *Apareiodon piracicabae* should not be considered moderate vulnerability to extinction within the Piabanha basin because this species in the region can be considered as introduced species. The species classification within the Piabanha basin could be changed to low vulnerability to extinction.

(2) *Geophagus brasiliensis* should not be considered as low to moderate vulnerability to extinction, as it was classified by studies within the basin as resilient to environmental disturbance (Caramaschi *et al*., 2016). The species classification within the Piabanha basin could be changed to low vulnerability to extinction.

(3) *Mimagoniates microlepis* classification based on FishBase was low vulnerability to extinction but for experts, this species can be considered almost at risk. The species classification within the Piabanha basin could be changed from low vulnerability to extinction to high to very high or very high.

(4) *Poecilia reticulate* should not be considered low to moderate vulnerability to extinction within the Piabanha basin because this species can be considered as foreign species within the basin. The species classification within the Piabanha basin could be changed to low vulnerability to extinction.

The classification per species can be seen in and Table 38, where the green color represents low vulnerability, yellow represents low to moderate, orange represents moderate and red represents very high.

The usage of the global database was able to point for the most part of the species its low risk of vulnerability, but expert consultation should always be taken into account when it comes to evaluation of the overall classification. As it was pointed out after local experts analyze the classification, some exceptions of underestimation or overestimation of the classification with the global database can occur.

Table 38: Species vulnerability of extinction

Specie	Fagundes	Pedro	Moura Brasil	Preto	Vulnerability (FishBase)
Ancistrus multispinis		X			Low
Apareiodon piracicabae			X		Moderate
Astyanax giton			X	X	Low
Astyanax gr. bimaculatus	X		X	X	Low
Astyanax hastatus	X		X	X	Low
Astyanax janeiroensis				X	Low
Astyanax parahybae			X		Low
Australoheros facetus	X			X	Low to moderate
Bryconamericus microcephalus			X	X	Low
Bryconamericus tenuis				X	Low
Cyphocharax gilbert				X	Low
Corydoras nattereri				X	Low
Crenicichla lepidota			X		Low
Geophagus brasiliensis	X	X	X	X	Low to moderate
Gymnotus gr. carapo		X	X	X	Moderate
Gymnotus sylvius				X	Low
Glanidium melanopterus			X		Low to moderate
Hisonotus notatus				X	Low
Hyphessobrycon bifasciatus				X	Low
Hyphessobrycon luetkeni				X	Low
Hypostomus punctatus	X	X	X	X	Low
Hoplias malabaricus				X	Moderate
Imparfinis minutus		X		X	Low
Leporinus copelandii			X	X	Moderate
Mimagoniates microlepis			X	X	Low
Oligosarcus hepsetus		X	X	X	Low
Oreochromis niloticus		X		X	Low to moderate
Otocinclus affinis			X	X	Low
Phalloceros harpagos		X			Low
Phalloceros leptokeras				X	Low

Table 38: Continued

Specie	Fagundes	Pedro	Moura Brasil	Preto	Vulnerability (FishBase)
Pimelodella lateristriga				X	Low
Pimelodus fur			X		Low
Pimelodus maculatus			X		Low to moderate
Poecilia reticulata	X	X			Low to moderate
Poecilia vivipara				X	Low
Prochilodus lineatus			X		Low to moderate
Rhamdia quelen	X	X		X	Low
Rineloricaria sp.	X	X		X	Low
Schizolecis guntheri		X			Low
Scleromystax barbatus			X	X	Low
Synbranchus marmoratus			X		Very high
Trachelyopterus striatulus				X	Low to moderate
Trichomycterus gr. travessosi	X				Low
Xiphophorus hellerii		X			Low

4.5.3. Factors/ feature that put fish species in danger

After the fish expert was consulted regarding direct or indirect response to flow alteration, habitat requirements or any morphological, behavioral, life-history adaptations that could put it at risk in future if the streamflow conditions or the land use in the watershed changed, 24 fish species were classified into eight factors/features. Table 39 contains the factor/feature with its respective ecological indicator and Table 40 contains the classification per species.

Table 39: Link between the selected factors/ features and ecological indicators

Factor/feature	Ecological indicators
Cryptic	Habitat requirements and guilds
Rare	Endangered species (could be in the future)
Rheophilic	Direct response to flow, e.g. spawning or migration Morphological, behavioral, life-history adaptations (e.g. short-lived versus long-lived, reproductive guilds)
Scrapers	Habitat requirements and guilds
Pelagic	Habitat requirements and guilds Morphological, behavioral, life-history adaptations (e.g. short-lived versus long-lived, reproductive guilds)
Needs rapids	Indirect response to flow, e.g. habitat-mediated Habitat requirements and guilds
Needs tree shading	Habitat requirements and guilds
Needs marginal plants with roots	Habitat requirements and guilds

Rheophilic fish, live in an environment with current and need to migrate in order to reproduce. The migration consists of traveling long distances along rivers, swimming against the current (Dalmass *et al*., 2016). Expert consultation points that rheophilic fish depends on river current but do not always migrate. Periphyton scrapers feed primarily on the periphyton, which is a biofilm matrix of algae and bacteria growing on inorganic benthic surfaces (Smith, 2016). Although Rajan (2018) define pelagic fish as highly migratory and generally show shoaling behavior, expert consultation defined it as species that occupy the water column in rivers or lakes, and that are not particularly rheophilic, much less migratory.

Overall most part of the species in the list was described either way as pelagic or scrapers (29% and 25% respectively). The overall % per factor/ feature can be seen in Figure 62, its distribution along the basin can be seen in a map in Figure 63.

Table 40: Factors/ feature that put fish species in danger

Specie	Fagundes	Pedro	Moura Brasil	Preto	Factor, feature, and risks (expert consultation)
Ancistrus multispinis		X			Land use change with riparian forest removal can cause silting as a consequence, loss of substrate for the periphyton scrapers (detritivores)
Astyanax giton			X	X	Pelagic fish - sensitive to reduction of water column and habitat
Astyanax gr. bimaculatus	X		X	X	Pelagic fish - sensitive to reduction of water column and habitat
Astyanax hastatus	X		X	X	Pelagic fish - sensitive to reduction of water column and habitat
Astyanax janeiroensis				X	Pelagic fish - sensitive to reduction of water column and habitat
Astyanax parahybae			X		Pelagic fish - sensitive to reduction of water column and habitat
Bryconamericus microcephalus			X	X	Land use changes and deforestation - can cause the reduction of tree shading required by this species
Bryconamericus tenuis				X	Land use changes and deforestation - can cause the reduction of tree shading required by this species
Cyphocharax gilbert				X	Pelagic fish - sensitive to reduction of water column and habitat
Gymnotus gr. carapo		X	X	X	Land use changes and decrease of marginal plants with roots can cause reduction of habitat for this species
Gymnotus sylvius				X	Land use changes and decrease of marginal plants with roots can cause reduction of habitat for this species
Glanidium melanopterus			X		Rare - has to be observed
Hisonotus notatus				X	Land use change with riparian forest removal can cause silting as a consequence, loss of substrate for the periphyton scrapers (detritivores)
Hypostomus punctatus	X	X	X	X	Land use change with riparian forest removal can cause silting as a consequence, loss of substrate for the periphyton scrapers (detritivores)
Imparfinis minutus		X		X	Fish that lives in rapids - a violent reduction of flow threatens this species
Leporinus copelandii			X	X	Rheophilic and pelagic - strong flow reduction can decrease the water column, rapids and current
Mimagoniates microlepis			X	X	Land use changes and deforestation - can cause the reduction of tree shading required by this species
Oligosarcus hepsetus		X	X	X	Pelagic fish - sensitive to reduction of water column and habitat
Otocinclus affinis			X	X	Land use change with riparian forest removal can cause silting as a consequence, loss of substrate for the periphyton scrapers (detritivores)
Prochilodus lineatus			X		Rheophilic and migrate - flow reduction can affect the reproduction and decrease the population

Table 40: Continued

Specie	Fagundes	Pedro	Moura Brasil	Preto	Factor, feature, and risks (expert consultation)
Rineloricaria sp.	X	X		X	Land use change with riparian forest removal can cause silting as a consequence, loss of substrate for the periphyton scrapers (detritivores)
Schizolecis guntheri		X			Land use change with riparian forest removal can cause silting as a consequence, loss of substrate for the periphyton scrapers (detritivores)
Scleromystax barbatus			X	X	Rheophilic - flow reduction can affect the reproduction and decrease the population
Trichomycterus gr. travessosi	X				Cryptic fish - depends on the rocky river bottom

It is possible to identify that Moura Brasil and Preto stations have a higher range of factor/features compared to other stations (6 different types among 8). The species that with factors/features linked to flow were selected to compose the breeding calendar.

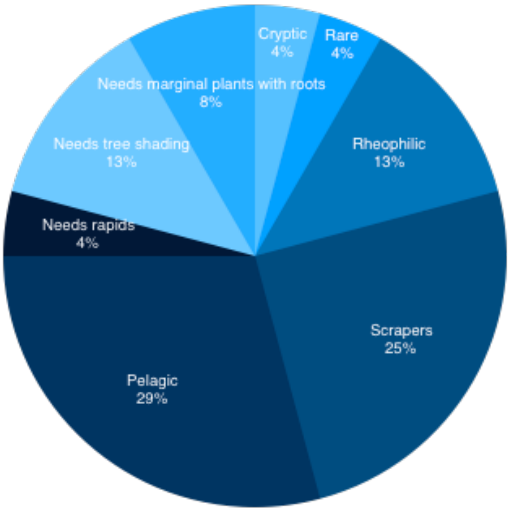

Figure 62: % distribution of the factors/feature that put fish species in danger

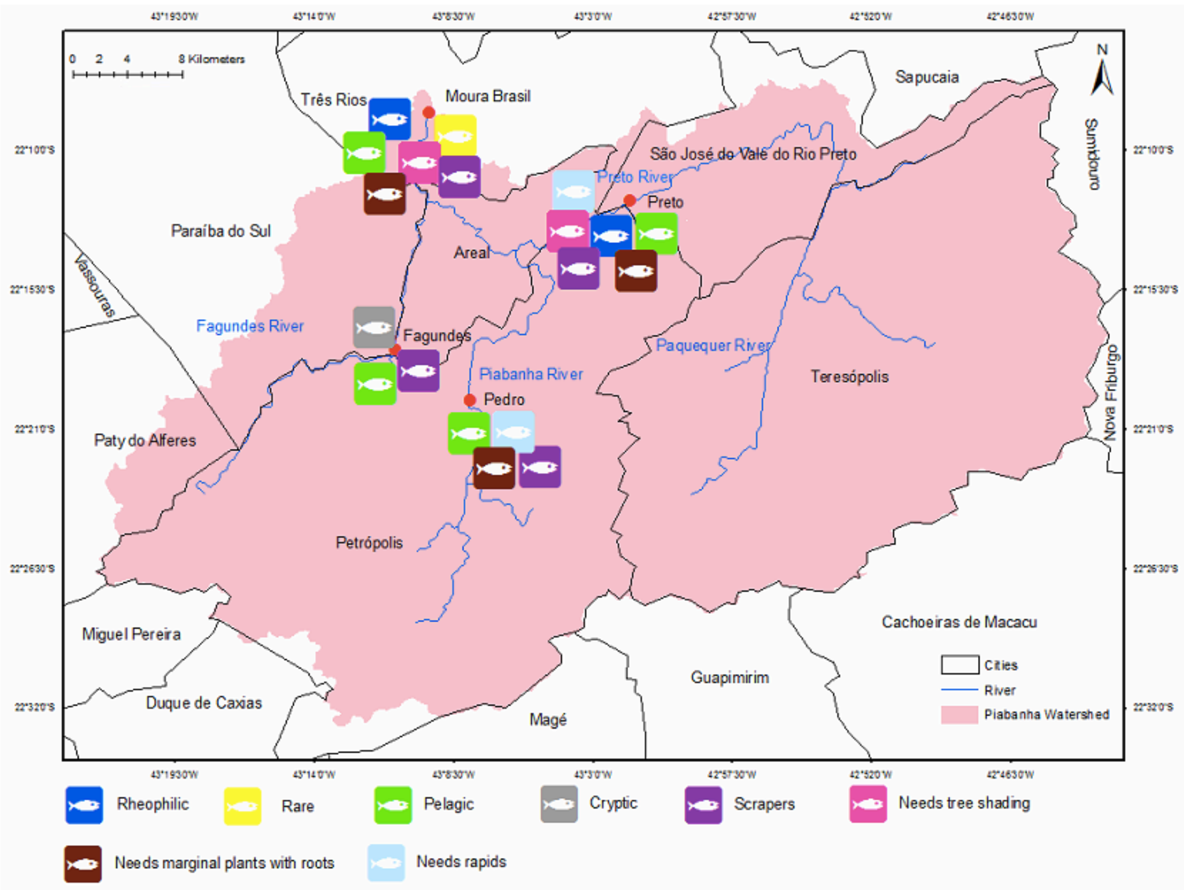

Figure 63: Factors/feature that put fish species in danger distribution within Piabanha basin

4.5.4. Functional groups description

Based on the expert input 8 species were selected based on their high level of spatial distribution (all 4 sites or at least 3 sites). For each species, the functional groups (movement, feeding, and breeding) information was accessed based on literature review and expert consultation.

75% of the species presented small movement (see Table 41), only *Astyanax* genus migrate small distances (500-600m), this match their pelagic feature. This species is distributed among 3 stations, Fagundes, Moura, and Preto.

Table 41: Movement data for the selected species

Specie	Type of movement	Reference
Astyanax gr. bimaculatus	Can migrate small distances (500-600m)	Uieda, 1984; Garutti, 1988 (cited by Paiva *et al*., 2006); Expert consultation;
Astyanax hastatus	Can migrate small distances (500-600m)	Mazzoni & Iglesias-Rios, 2012; Expert consultation
Geophagus brasiliensis	Small	Mazzoni & Iglesias-Rios, 2012
Gymnotus gr. carapo	Small	Davis & Hopkins, 1988
Hypostomus punctatus	Small (<150 m)	Mazzoni *et al.*, 2018
Oligosarcus hepsetus	Small	Agostinho *et al*., 2007 (cited by Paiva *et al*., 2006)
Rhamdia quelen	Small	Mazzoni & Iglesias-Rios, 2012
Rineloricaria sp.	Small (< 150 m)	Mazzoni *et al*., 2018

50% of the species is Omnivorous (feeds on the food of both plant and animal origin), 25% is Detritivorous (feeds on dead plant or animal matte) and the other 25% Insectivorous (Feeding on insects) and Piscivorous (feeds on fish), see Table 42.

Two different sources of the trophic level were analyzed, one from local data (Berriel *et al*., 2018) and another one from global data (Fishbase, 2019). This was made with the intention to check if there is a lack of local data the global data could be used.

Table 42: Feeding information for the selected species ranked by trophic level

Specie	Classification	Reference	Trophic Level (Berriel *et al.*, 2018)	Trophic Level (Fishbase, 2019)
Hypostomus punctatus	Detritivorous	Mazzoni *et al*., 2010	1	2.0 ±0.00 se; Based on food items
Geophagus brasiliensis	Omnivorous	Mazzoni & Costa, 2007	1.25	2.6 ±0.26 se; Based on food items
Astyanax hastatus	Omnivorous	Portella *et al*, 2016	1.59	2.9 ±0.4 se; Based on size and trophs of closest relatives
Astyanax gr. bimaculatus	Omnivorous	Costa & Braga, 1993 (cited by Paiva *et al*., 2006); Esteves & Galetti, 1995; Vilella *et al*., 2002	1.65	2.4 ±0.1 se; Based on diet studies
Rineloricaria sp.	Detritivorous	Silva *et al*., 2012	1.8	2.6 ±0.2 se; Based on size and trophs of closest relatives
Rhamdia quelen	Omnivorous	Gomiero *et al*., 2007	1.84	3.9 ±0.3 se; Based on diet studies
Oligosarcus hepsetus	Insectivorous (juvenile) Piscivorous (adult)	Botelho *et al*., 2007	2.35	4.2 ±0.73 se; Based on food items
Gymnotus gr carapo	Insectivorous	Prejs, 1987; Ferreira & Cassati, 2006	2.89	3.6 ±0.56 se; Based on food items

As the studies use a different scale, in order to compare them is necessary to decrease 1 unit from the global data. After this conversion, it is possible to see that global and local data had similar trophic level classification. The only species that the range is not the same is *Oligosarcus hepsetus*, but this could be due to the fact that the species has an insectivorous behave when juvenile and piscivores when adult.

Breeding data was collected for the 8 species based on expert consultation and literature review (see Table 43). October and November demonstrated the highest breeding activity months for the most part of the species, as seen in Figure 64 and 65. Five species have parceled spawning and the other three have partial, multiple and periodic spawning.

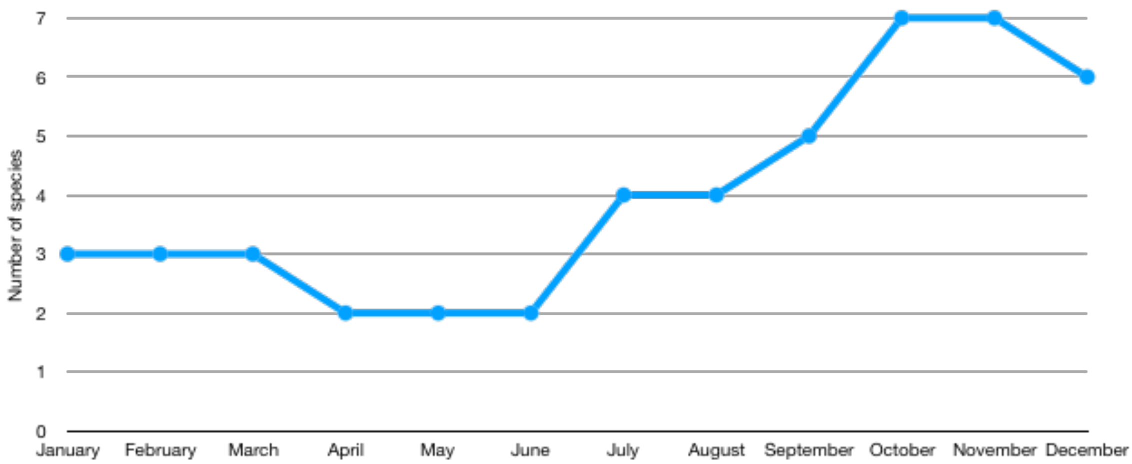

Figure 64: Reproductive calendar frequency per month for species with the high spatial distribution

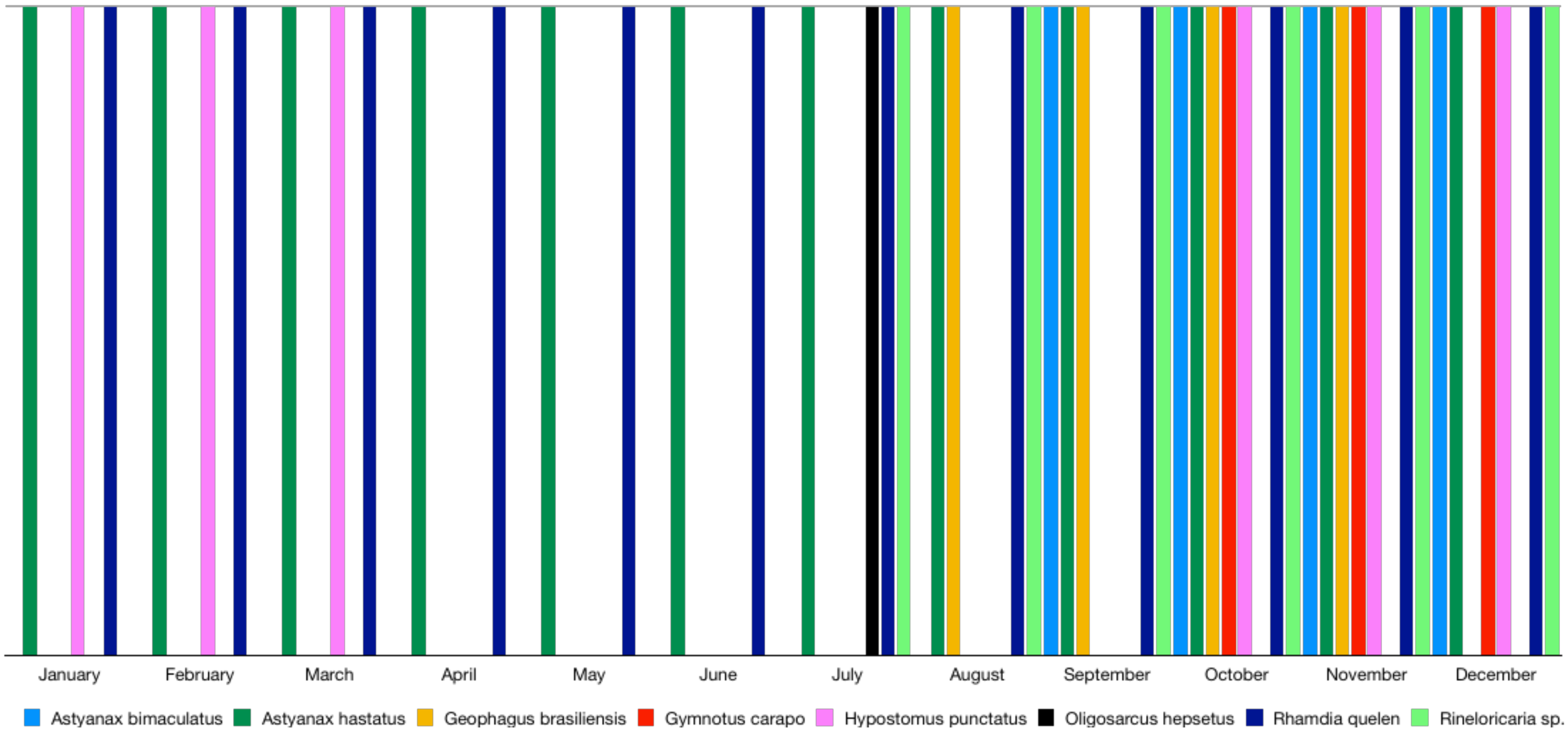

Figure 65: Reproductive calendar for the fish species with the high spatial distribution

Table 43: Breeding data for species with the high spatial distribution

Specie	Season	Spawning Period	Reference	Type	Reference
Astyanax gr. bimaculatus	Dry/Wet	September to December	Berriel *et al*., 2018	Partial spawning reproductive regime and adhesive eggs	Bazzoli *et al.,* 1991 (Cited by Paiva *et al*., 2006)
Astyanax hastatus	Dry/ Wet	All year (peak in March, May, August, and October)	Mazzoni & Petito, 1999; Mazzoni & Iglesias-Rios, 2007	Total (individual) Multiple spawning (population, non-synchronic population)	Mazzoni & Iglesias-Rios, 2007; Araujo 2009; Fish expert consultation
Geophagus brasiliensis	Dry/ Wet	August to November	Silva, 2017	Multiple (parceled) spawning with parental care and nesting site	Barbieri *et al.,* 1981 (cited by Silva 2017); Cappi 2006; Mazzoni *et al*., 2018
Gymnotus gr. carapo	Wet	October to December	Barbieri & Barbieri, 1983 (cited by Giora & Fialho, 2009)	Periodic spawns	Cognato & Fialho, 2006
Hypostomus punctatus	Wet	October to March	Menezes & Caramaschi, 1994; Agostinho *et al*., 2007 (cited by Paiva *et al*., 2006)	Parceled spawning with parental care and nesting site	Menezes & Caramaschi, 1994; Mazzoni *et al.,* 2018
Oligosarcus hepsetus	Dry	July	Berriel *et al*., 2018	Parceled spawning	Gomiero *et al.,* 2008
Rhamdia quelen	Dry/ Wet	All year	Gomiero *et al.,* 2007	Parceled spawning	Gomes *et al.,* 2000
Rineloricaria sp.	Dry/ Wet	July to December (peak in September to October)	Barbieri, 1994	Parceled spawning with parental care and nesting site	Barbieri, 1994; Mazzoni *et al.,* 2018

4.5.5. Breeding calendar for Piabanha watershed species

13 species compose the breeding calendar, species with a high level of spatial distribution, species considered pelagic, rheophilic and that needs rapids by expert consultation (see Table 44). Although *Glanidium melanopterus* was also selected to be part of the breeding calendar but no reproduction data was found.

For the most part of the species, the spawning period occurs during the wet season (see Figure 66 and 67). October, November, and December demonstrated the highest breeding activity months, this behave was expect for the rheophilic species.

According to Agostinho *et al.* (2004), despite the existence of several triggers to migration species, one of the most important in the Neotropical region is the increase in water flow during the rainy season. Severe flow alterations caused by human activities in the wet period could interrupt the reproduction of rheophilic species or even lead them to extinction.

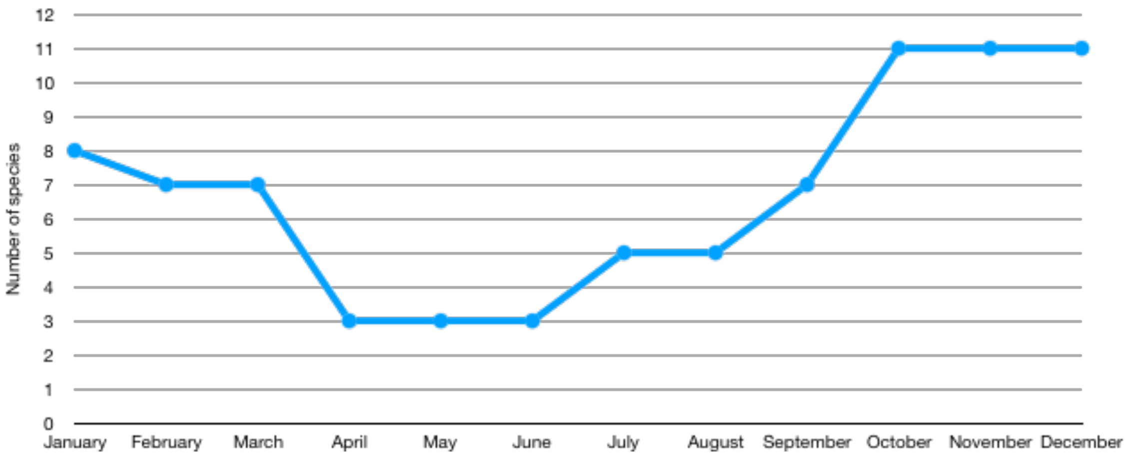

Figure 66: Reproductive calendar frequency per month for 13 species

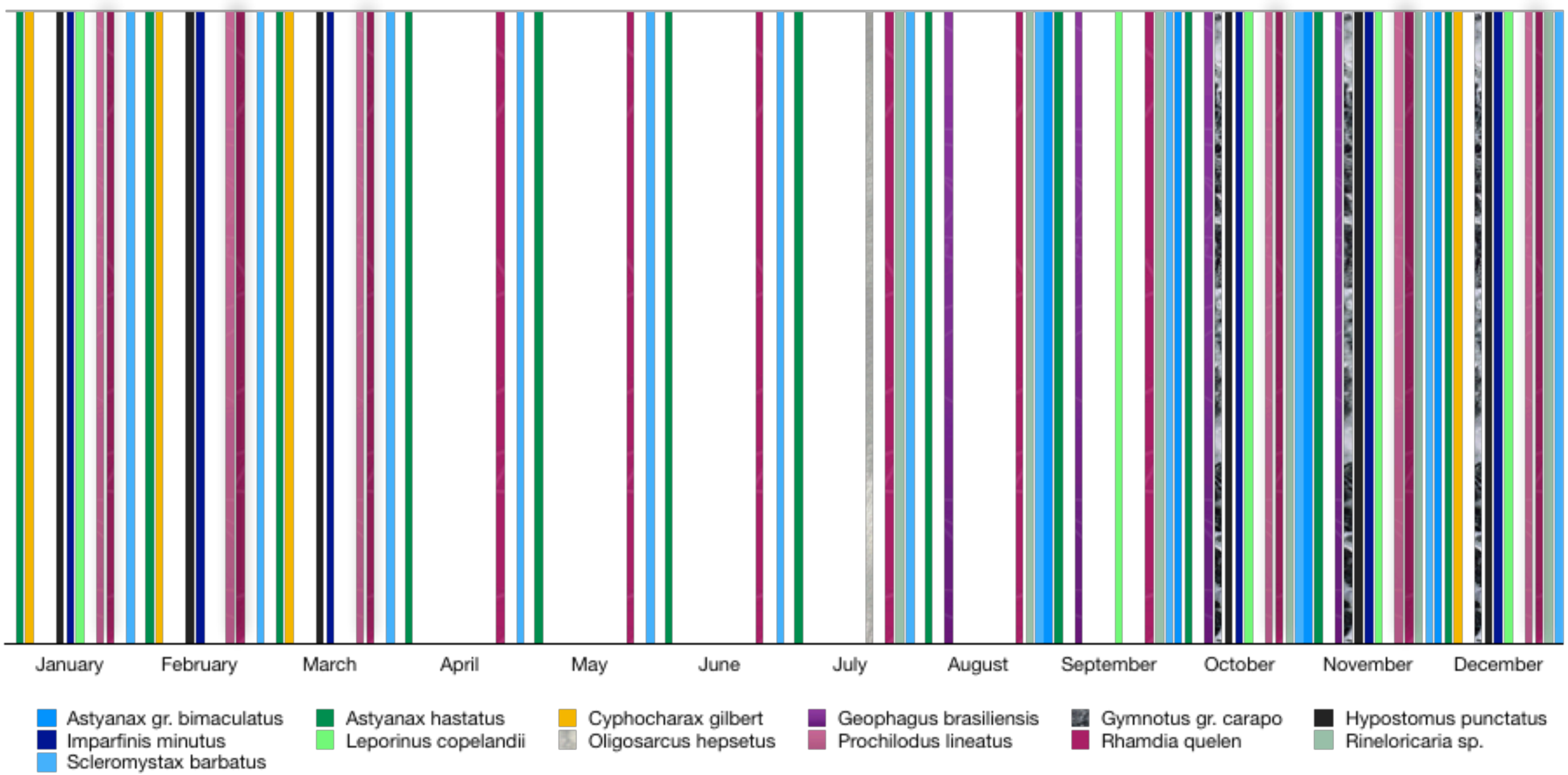

Figure 67: Reproductive calendar including 13 fish species

Table 44: Breeding data for the selected species

Specie	Season	Spawning Period	Reference	Reason
Astyanax gr. bimaculatus	Dry/Wet	September to December	Berriel *et al*., 2018	High spatial distribution Pelagic Small migrator
Astyanax hastatus	Dry/ Wet	All year (peak in March, May, August, and October)	Mazzoni & Petito, 1999; Mazzoni & Iglesias-Rios, 2007	High spatial distribution Pelagic Small migrator
Cyphocharax gilbert	Rain season	December to March (summer)	Perez, 2014; Hashiguti *et al*., 2017	Pelagic
Geophagus brasiliensis	Dry/ Wet	August to November	Silva, 2017	High spatial distribution
Glanidium melanopterus	No data	No data	No data	Rare
Gymnotus gr. carapo	Wet	October to December	Barbieri & Barbieri, 1983 (cited by Giora & Fialho, 2009)	High spatial distribution
Hypostomus punctatus	Wet	October to March	Menezes & Caramaschi, 1994; Agostinho *et al*., 2007 (cited by Paiva *et al*., 2006)	High spatial distribution
Imparfinis minutus	Wet	October to January (peak in November and December); October to March (peak in December)	Moraes & Braga, 2011	Needs rapids

Table 44: Continued

Specie	Season	Spawning Period	Reference	Reason
Leporinus copelandii	Dry/ Wet	September to January	Costa *et al*., 2005; Pereira *et al*., 2007; Andrade *et al*., 2013	Rheophilic
Oligosarcus hepsetus	Dry	July	Berriel *et al*., 2018	High spatial distribution Pelagic
Prochilodus lineatus	Wet	October to December (peak in November and December); October to March (peak in December)	Ramos *et al*., 2010; Lizama *et al*., 2006	Rheophilic
Rhamdia quelen	Dry/ Wet	All year	Gomiero *et al.,* 2007	High spatial distribution
Rineloricaria sp.	Dry/ Wet	July to December (peak in September to October)	Barbieri, 1994	High spatial distribution
Scleromystax barbatus	Dry/Wet	All year (peak in the wet season)	Moraes, 2012	Rheophilic

4.6. Proposed environmental flows

4.6.1. Tennant Method for Piabanha basin

For this method, the mean annual flow for the post-impact period was used for each station as the base value metric (100%). Based on the mean annual flow, the other variations in % for the recommended flow regime (200%, 60%, 50%, 40%, 30%, 20% and 10%) were calculated for each station (see Table 45).

Table 45: Recommended flow regime in % values for the Tennant method (m^3/s)

Station	200%	100%	60%	50%	40%	30%	20%	10%
Pedro do Rio	23.240	11.620	6.972	5.810	4.648	3.486	2.324	1.162
Fazenda Sobradinho	31.520	15.760	9.456	7.880	6.304	4.728	3.152	1.576
Moreli (Parada Moreli)	36.90	18.450	11.070	9.225	7.380	5.535	3.690	1.845
Fagundes	8.940	4.470	2.682	2.235	1.788	1.341	0.894	0.447
UHE Simplício Moura Brasil	75.660	37.830	22.698	18.915	15.132	11.349	7.566	3.783

Furthermore, each station has a table with the final recommended flow regime based on the Tennant method (see Table 46 to Table 50 and Figure 68 to 72).

Table 46: Flow recommendations as per the Tennant method in Pedro do Rio

Description of flows	Recommended flow regime (m^3/s)	
	May-October (low flows)	November - April (high flows)
Flushing or maximum	23.240	
Optimum range	6.972-11.620	
Outstanding	4.648	6.972
Excellent	3.486	5.810
Good	2.324	4.648
Fair or degrading	1.162	3.486
Poor or minimum	1.162	1.162
Severe degradation	<1.162	

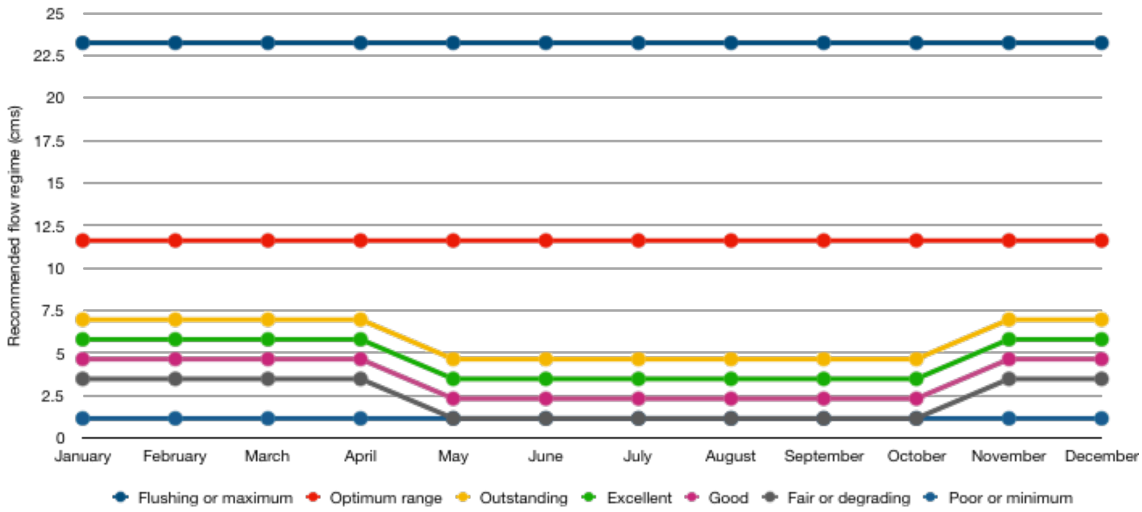

Figure 68: Flow recommendations plots as per the Tennant method in Pedro do Rio

Table 47: Flow recommendations as per the Tennant method in Fazenda Sobradinho

Description of flows	**Recommended flow regime (m³/s)**	
	May-October (low flows)	**November - April (high flows)**
Flushing or maximum	31.520	
Optimum range	9.456-15.760	
Outstanding	6.304	9.456
Excellent	4.728	7.880
Good	3.152	6.304
Fair or degrading	1.576	4.728
Poor or minimum	1.576	1.576
Severe degradation	<1.576	

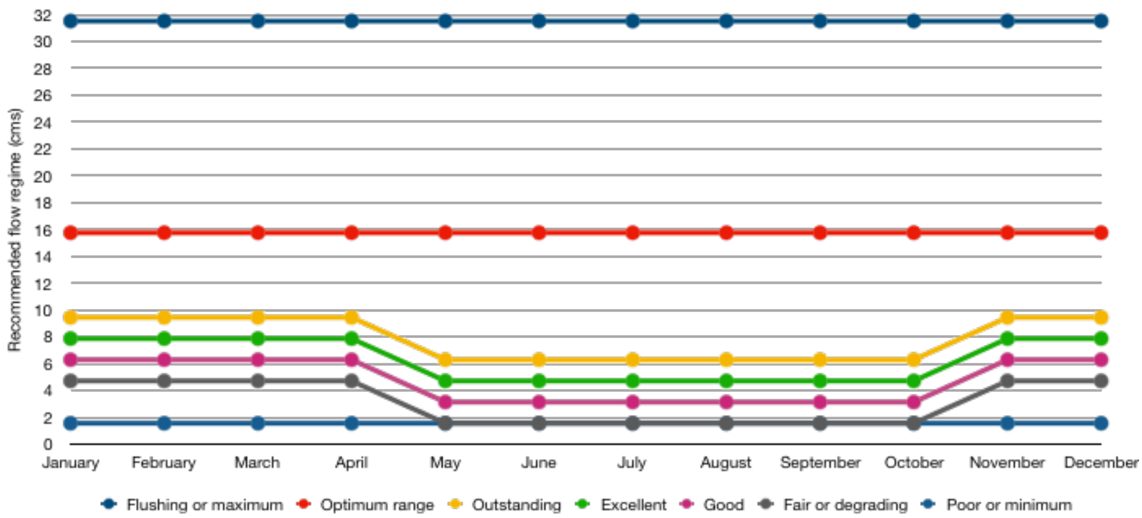

Figure 69: Flow recommendations plots as per the Tennant method in Fazenda Sobradinho

Table 48: Flow recommendations as per the Tennant method in Moreli (Parada Moreli)

Description of flows	Recommended flow regime (m^3/s)	
	May-October (low flows)	**November - April (high flows)**
Flushing or maximum	36.90	
Optimum range	11.070 - 18.450	
Outstanding	7.380	11.070
Excellent	5.535	9.225
Good	3.690	7.380
Fair or degrading	1.845	5.535
Poor or minimum	1.845	1.845
Severe degradation	<1.845	

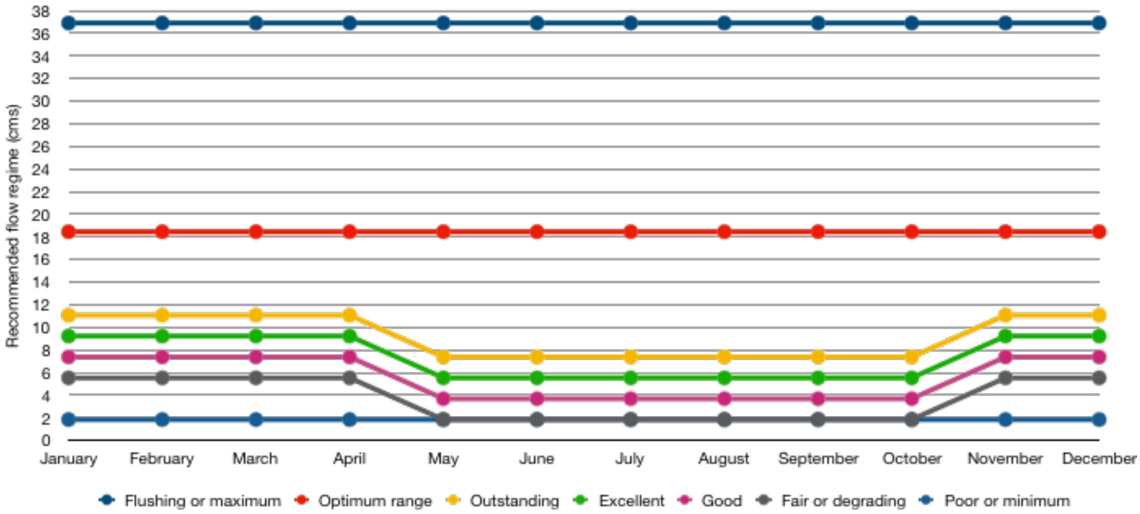

Figure 70: Flow recommendations plots as per the Tennant method in Moreli (Parada Moreli)

Table 49: Flow recommendations as per the Tennant method in Fagundes

Description of flows	Recommended flow regime (m^3/s)	
	May-October (low flows)	**November - April (high flows)**
Flushing or maximum	8.940	
Optimum range	2.682 - 4.470	
Outstanding	1.788	2.682
Excellent	1.341	2.235
Good	0.894	1.788
Fair or degrading	0.447	1.341
Poor or minimum	0.447	0.447
Severe degradation	<0.447	

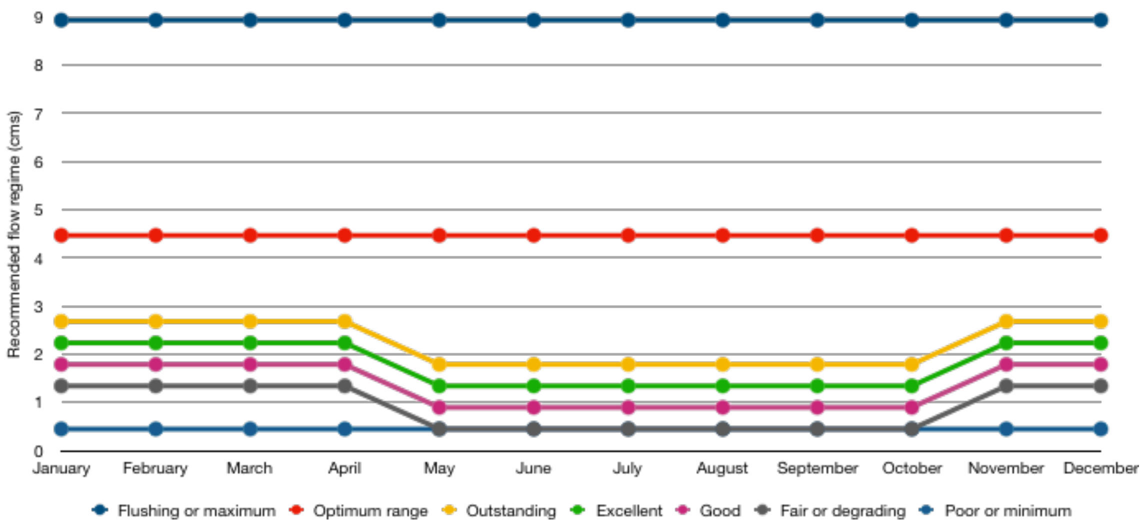

Figure 71: Flow recommendations plots as per the Tennant method in Fagundes

Table 50: Flow recommendations as per the Tennant method in UHE Simplício Moura Brasil

Description of flows	**Recommended flow regime (m^3/s)**	
	May-October (low flows)	**November - April (high flows)**
Flushing or maximum	75.660	
Optimum range	22.698-37.830	
Outstanding	15.132	22.698
Excellent	11.349	18.915
Good	7.566	15.132
Fair or degrading	3.783	11.349
Poor or minimum	3.783	3.783
Severe degradation	<3.783	

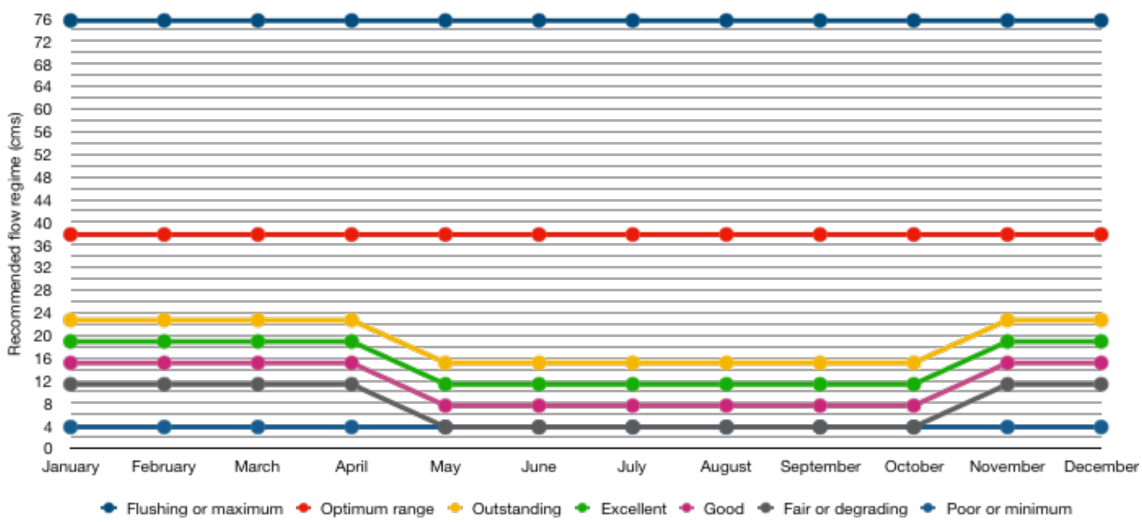

Figure 72: Flow recommendations plots as per the Tennant method in UHE Simplício Moura Brasil

4.6.2. Flow-duration curve for Piabanha basin

Pedro do Rio, Fazenda Sobradinho, Fagundes and Moura Brasil flow-duration curve values increased in the post-impact, while Moreli flow-duration curve values decreased in the post-impact (see Table 51).

Table 51: Flow-duration curve values for each station

Station	Pre-impact period			Post-impact period		
	90%	95%	98%	90%	95%	98%
Pedro do Rio	3.557	3.064	2.600	3.563	3.139	2.816
Fazenda Sobradinho	6.303	5.613	4.970	6.698	5.862	5.008
Moreli (Parada Moreli)	7.601	6.671	5.882	7.224	6.139	5.121
Fagundes	1.399	1.079	0.908	1.745	1.459	1.168
Moura Brasil	9.326	7.753	6.596	9.503	8.068	6.833

For each station it was estimated:

(1) 90% percentile streamflow (Q90% – m^3/s) variations of flow recommendation values per station (see Table 52);

(2) 95% percentile streamflow (Q95% – m^3/s) variations of flow recommendation values per station (see Table 53);

(3) 98% percentile streamflow (Q98% – m^3/s) variations of flow recommendation values per station (see Table 54);

(4) monthly 90% percentile streamflow (Q90% – m^3/s) variations of flow recommendation values per station (see Table 55 to 60);

(5) monthly 95% percentile streamflow (Q95% – m^3/s) variations of flow recommendation values per station (see Table 61 to 64); and

(6) monthly 98% percentile streamflow (Q98% – m^3/s) variations of flow recommendation values per station (see Table 65 and 66).

Besides the tables, graphs were created per station with a comparison of the flow recommendation based on Q90%, Q95% and Q98% variations (see Figure 73 to 77).

Table 52: 90% percentile streamflow (Q90% – m^3/s) variations of flow recommendation values per station

Station	90%				
	100%	10%	20%	25%	80%
Pedro do Rio	3.563	0.356	0.713	0.891	2.850
Fazenda Sobradinho	6.698	0.670	1.340	1.675	5.358
Moreli (Parada Moreli)	7.224	0.722	1.445	1.806	5.779
Fagundes	1.745	0.175	0.349	0.436	1.396
Moura Brasil	9.503	0.950	1.901	2.376	7.602

Table 53: 95% percentile streamflow (Q95% – m^3/s) variations of flow recommendation values per station

Station	95%			
	100%	20%	30%	50%
Pedro do Rio	3.139	0.628	0.942	1.570
Fazenda Sobradinho	5.862	1.172	1.759	2.931
Moreli (Parada Moreli)	6.139	1.228	1.842	3.070
Fagundes	1.459	0.292	0.438	0.730
Moura Brasil	8.068	1.614	2.420	4.034

Table 54: 98% percentile streamflow (Q98% – m^3/s) variations of flow recommendation values per station

Station	98%	
	100%	50%
Pedro do Rio	2.816	1.408
Fazenda Sobradinho	5.008	2.504
Moreli (Parada Moreli)	5.121	2.560
Fagundes	1.168	0.584
Moura Brasil	6.833	3.416

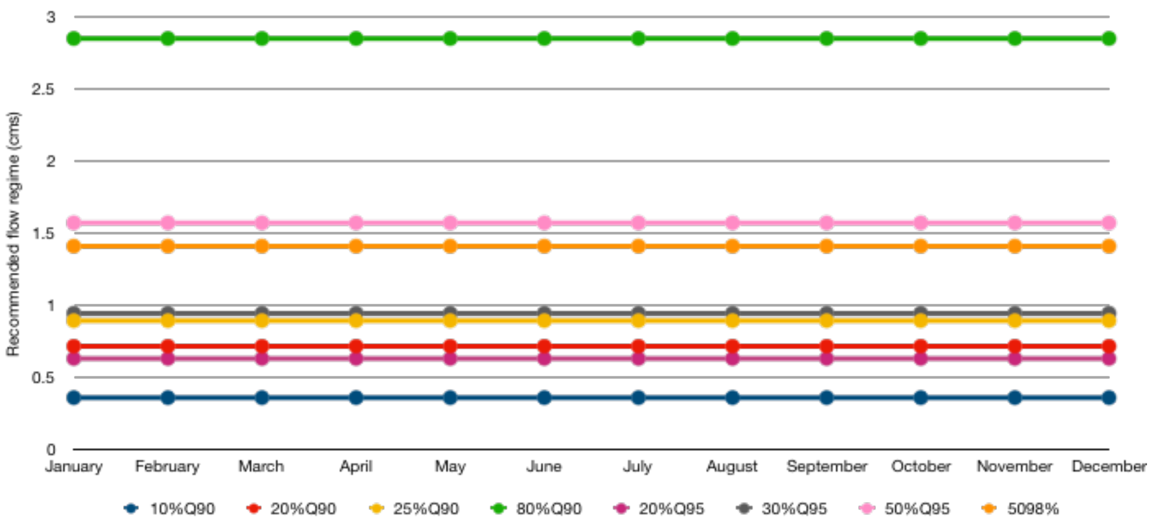

Figure 73: Flow recommendations plots as per the flow-duration curve method in Pedro do Rio

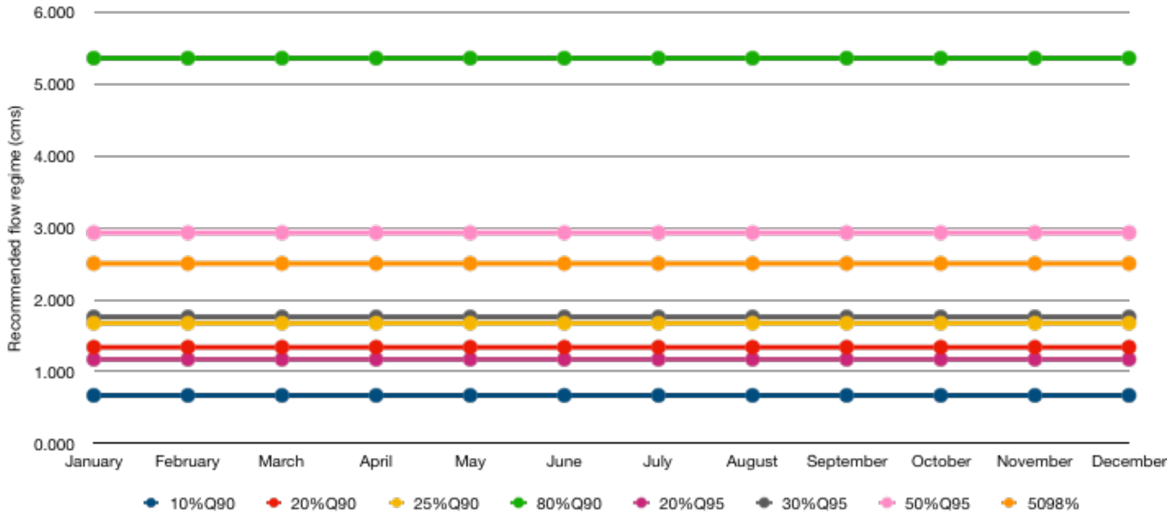

Figure 74: Flow recommendations plots as per the flow-duration curve method in Fazenda Sobradinho

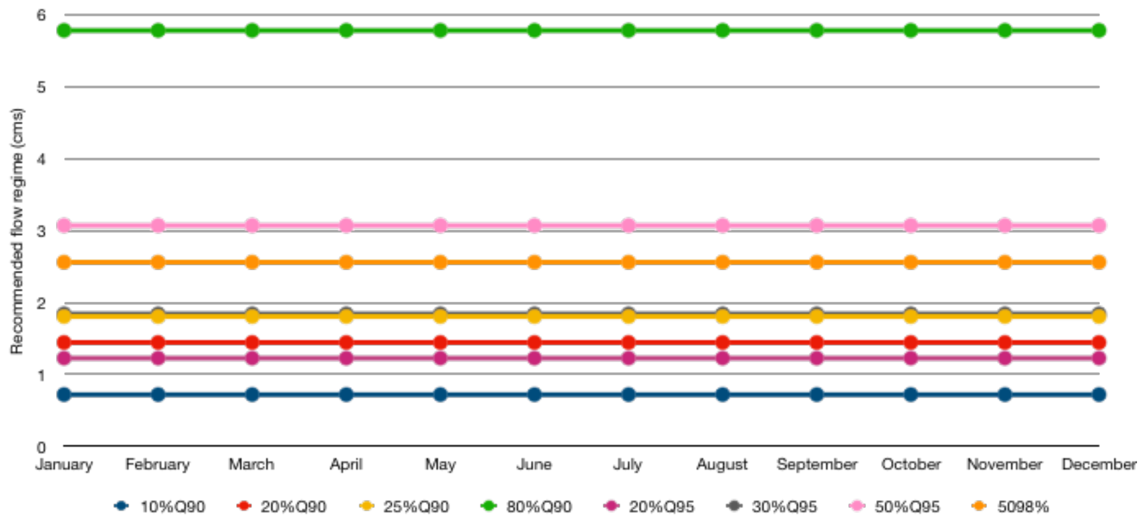

Figure 75: Flow recommendations plots as per the flow-duration curve method in Moreli

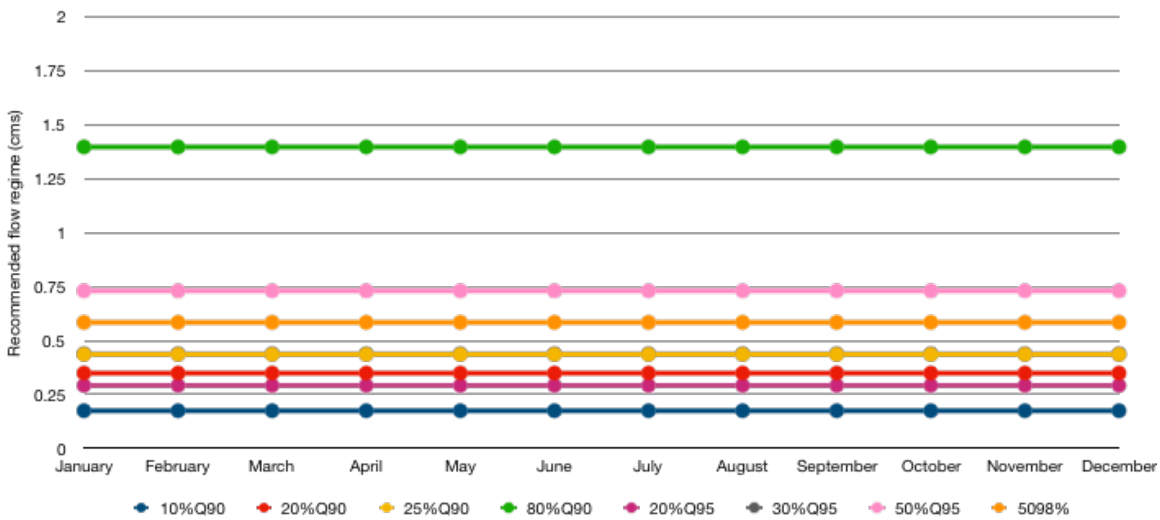

Figure 76: Flow recommendations plots as per the flow-duration curve method in Fagundes

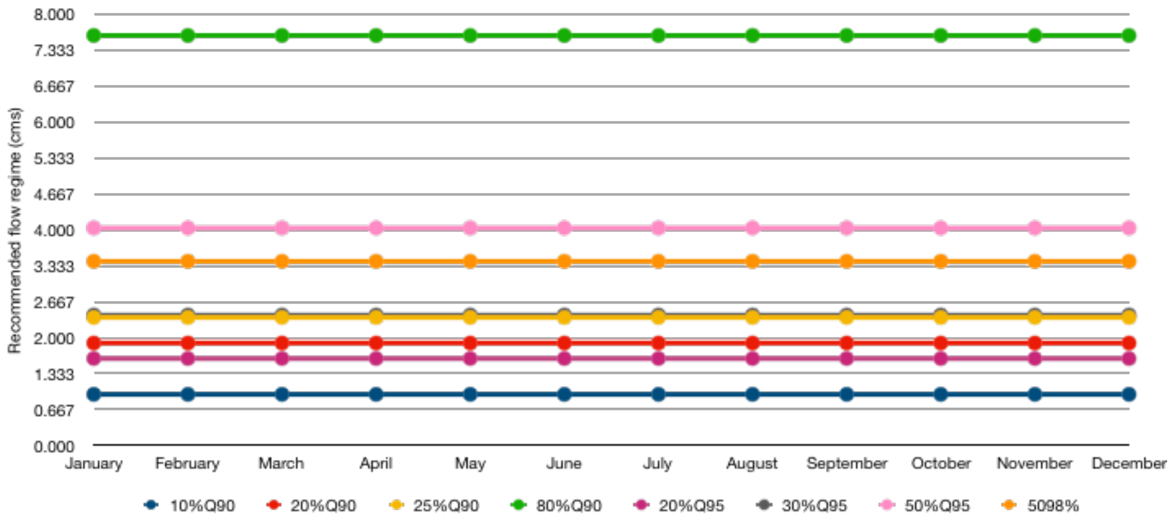

Figure 77: Flow recommendations plots as per the flow-duration curve method in Moura Brasil

Table 55: 90% percentile streamflow (Q90% – m^3/s) values per month

Gauge name	January	February	March	April	May	June	July	August	September	October	November	December
Pedro do Rio	7.552	7.390	8.590	6.755	5.388	4.322	3.473	2.834	2.834	2.834	3.690	5.949
Fazenda Sobradinho	10.955	10.211	10.994	10.098	8.697	7.419	6.515	5.536	5.379	5.379	6.913	10.301
Moreli (Parada Moreli)	12.227	11.08	12.882	11.3	9.588	8.375	6.944	5.792	5.315	5.465	7.039	11.609
Fagundes	2.582	2.468	2.684	2.358	2.087	1.903	1.679	1.391	1.389	1.279	1.745	2.217
UHE Simplício Moura Brasil	26.17	22.765	21.997	18.291	12.829	9.673	8.528	7.332	7.419	7.847	11.543	21.411

Table 56: Recommended flows based on 10% of the 90% percentile streamflow values per month

Gauge name	January	February	March	April	May	June	July	August	September	October	November	December
Pedro do Rio	0.7552	0.739	0.859	0.6755	0.5388	0.4322	0.3473	0.2834	0.2834	0.2834	0.369	0.5949
Fazenda Sobradinho	1.0955	1.0211	1.0994	1.0098	0.8697	0.7419	0.6515	0.5536	0.5379	0.5379	0.6913	1.0301
Moreli (Parada Moreli)	1.2227	1.108	1.2882	1.13	0.9588	0.8375	0.6944	0.5792	0.5315	0.5465	0.7039	1.1609
Fagundes	0.2582	0.2468	0.2684	0.2358	0.2087	0.1903	0.1679	0.1391	0.1389	0.1279	0.1745	0.2217
UHE Simplício Moura Brasil	2.617	2.2765	2.1997	1.8291	1.2829	0.9673	0.8528	0.7332	0.7419	0.7847	1.1543	2.1411

Table 57: Recommended flows based on 20% of the 90% percentile streamflow values per month

Gauge name	January	February	March	April	May	June	July	August	September	October	November	December
Pedro do Rio	1.5104	1.478	1.718	1.351	1.0776	0.8644	0.6946	0.5668	0.5668	0.5668	0.738	1.1898
Fazenda Sobradinho	2.191	2.0422	2.1988	2.0196	1.7394	1.4838	1.303	1.1072	1.0758	1.0758	1.3826	2.0602
Moreli (Parada Moreli)	2.4454	2.216	2.5764	2.26	1.9176	1.675	1.3888	1.1584	1.063	1.093	1.4078	2.3218
Fagundes	0.5164	0.4936	0.5368	0.4716	0.4174	0.3806	0.3358	0.2782	0.2778	0.2558	0.349	0.4434
UHE Simplício Moura Brasil	5.234	4.553	4.3994	3.6582	2.5658	1.9346	1.7056	1.4664	1.4838	1.5694	2.3086	4.2822

Table 58: Recommended flows based on 25% of the 90% percentile streamflow values per month

Gauge name	January	February	March	April	May	June	July	August	September	October	November	December
Pedro do Rio	1.888	1.848	2.148	1.689	1.347	1.081	0.868	0.709	0.709	0.709	0.923	1.487
Fazenda Sobradinho	2.739	2.553	2.749	2.525	2.174	1.855	1.629	1.384	1.345	1.345	1.728	2.575
Moreli (Parada Moreli)	3.057	2.770	3.221	2.825	2.397	2.094	1.736	1.448	1.329	1.366	1.760	2.902
Fagundes	0.646	0.617	0.671	0.590	0.522	0.476	0.420	0.348	0.347	0.320	0.436	0.554
UHE Simplício Moura Brasil	6.543	5.691	5.499	4.573	3.207	2.418	2.132	1.833	1.855	1.962	2.886	5.353

Table 59: Recommended flows based on 50% of the 90% percentile streamflow values per month

Gauge name	January	February	March	April	May	June	July	August	September	October	November	December
Pedro do Rio	3.776	3.695	4.295	3.3775	2.694	2.161	1.7365	1.417	1.417	1.417	1.845	2.9745
Fazenda Sobradinho	5.4775	5.1055	5.497	5.049	4.3485	3.7095	3.2575	2.768	2.6895	2.6895	3.4565	5.1505
Moreli (Parada Moreli)	6.1135	5.54	6.441	5.65	4.794	4.1875	3.472	2.896	2.6575	2.7325	3.5195	5.8045
Fagundes	1.291	1.234	1.342	1.179	1.0435	0.9515	0.8395	0.6955	0.6945	0.6395	0.8725	1.1085
UHE Simplício Moura Brasil	13.085	11.3825	10.9985	9.1455	6.4145	4.8365	4.264	3.666	3.7095	3.9235	5.7715	10.7055

Table 60: Recommended flows based on 80% of the 90% percentile streamflow values per month

Gauge name	January	February	March	April	May	June	July	August	September	October	November	December
Pedro do Rio	6.042	5.912	6.872	5.404	4.310	3.458	2.778	2.267	2.267	2.267	2.952	4.759
Fazenda Sobradinho	8.764	8.169	8.795	8.078	6.958	5.935	5.212	4.429	4.303	4.303	5.530	8.241
Moreli (Parada Moreli)	9.782	8.864	10.306	9.040	7.670	6.700	5.555	4.634	4.252	4.372	5.631	9.287
Fagundes	2.066	1.974	2.147	1.886	1.670	1.522	1.343	1.113	1.111	1.023	1.396	1.774
UHE Simplício Moura Brasil	20.936	18.212	17.598	14.633	10.263	7.738	6.822	5.866	5.935	6.278	9.234	17.129

Table 61: 95% percentile streamflow (Q95% – m^3/s) values per month

Gauge name	January	February	March	April	May	June	July	August	September	October	November	December
Pedro do Rio	6.127	4.912	6.735	6.127	4.796	4.026	3.313	2.612	2.605	2.605	3.07	4.767
Fazenda Sobradinho	8.707	8.062	10.010	9.433	8.244	7.214	6.234	5.152	4.814	4.795	5.921	8.59
Moreli (Parada Moreli)	10.218	9.338	11.521	10.308	8.618	7.819	6.238	5.094	4.876	4.639	6.139	9.354
Fagundes	2.143	2.035	2.306	2.093	1.872	1.695	1.46	1.252	1.261	1.074	1.375	1.745
UHE Simplício Moura Brasil	22.134	17.322	18.163	15.359	10.819	8.479	7.966	6.506	6.432	6.697	9.693	16.776

Table 62: Recommended flows based on 20% of the 95% percentile streamflow values per month

Gauge name	January	February	March	April	May	June	July	August	September	October	November	December
Pedro do Rio	1.225	0.982	1.347	1.225	0.959	0.805	0.663	0.522	0.521	0.521	0.614	0.953
Fazenda Sobradinho	1.741	1.612	2.002	1.887	1.649	1.443	1.247	1.030	0.963	0.959	1.184	1.718
Moreli (Parada Moreli)	2.044	1.868	2.304	2.062	1.724	1.564	1.248	1.019	0.975	0.928	1.228	1.871
Fagundes	0.429	0.407	0.461	0.419	0.374	0.339	0.292	0.250	0.252	0.215	0.275	0.349
UHE Simplício Moura Brasil	4.427	3.464	3.633	3.072	2.164	1.696	1.593	1.301	1.286	1.339	1.939	3.355

Table 63: Recommended flows based on 30% of the 95% percentile streamflow values per month

Gauge name	January	February	March	April	May	June	July	August	September	October	November	December
Pedro do Rio	1.838	1.474	2.021	1.838	1.439	1.208	0.994	0.784	0.782	0.782	0.921	1.430
Fazenda Sobradinho	2.612	2.419	3.003	2.830	2.473	2.164	1.870	1.546	1.444	1.439	1.776	2.577
Moreli (Parada Moreli)	3.065	2.801	3.456	3.092	2.585	2.346	1.871	1.528	1.463	1.392	1.842	2.806
Fagundes	0.643	0.611	0.692	0.628	0.562	0.509	0.438	0.376	0.378	0.322	0.413	0.524
UHE Simplício Moura Brasil	6.640	5.197	5.449	4.608	3.246	2.544	2.390	1.952	1.930	2.009	2.908	5.033

Table 64: Recommended flows based on 50% of the 95% percentile streamflow values per month

Gauge name	January	February	March	April	May	June	July	August	September	October	November	December
Pedro do Rio	3.0635	2.456	3.3675	3.0635	2.398	2.013	1.6565	1.306	1.3025	1.3025	1.535	2.3835
Fazenda Sobradinho	4.3535	4.031	5.005	4.7165	4.122	3.607	3.117	2.576	2.407	2.3975	2.9605	4.295
Moreli (Parada Moreli)	5.109	4.669	5.7605	5.154	4.309	3.9095	3.119	2.547	2.438	2.3195	3.0695	4.677
Fagundes	1.0715	1.0175	1.153	1.0465	0.936	0.8475	0.73	0.626	0.6305	0.537	0.6875	0.8725
UHE Simplício Moura Brasil	11.067	8.661	9.0815	7.6795	5.4095	4.2395	3.983	3.253	3.216	3.3485	4.8465	8.388

Table 65: 98% percentile streamflow (Q98% – m^3/s) values per month

Gauge name	January	February	March	April	May	June	July	August	September	October	November	December
Pedro do Rio	3.73	3.778	4.615	4.959	3.874	3.73	3.185	2.383	2.383	2.383	2.605	3.948
Fazenda Sobradinho	5.363	6.944	7.439	8.266	7.09	6.495	5.599	4.103	4.357	4.108	5.152	6.792
Moreli (Parada Moreli)	6.08	7.624	8.528	8.618	7.56	6.886	5.315	4.123	4.315	4.179	5.241	7.263
Fagundes	1.539	1.767	1.819	1.362	1.261	1.165	0.905	0.828	1.168	0.803	0.981	1.361
UHE Simplício Moura Brasil	18.263	14.464	15.854	12.623	9.151	7.254	6.971	5.687	5.57	5.341	8.528	11.09

Table 66: Recommended flows based on 50% of the 98% percentile streamflow values per month

Gauge name	January	February	March	April	May	June	July	August	September	October	November	December
Pedro do Rio	1.865	1.889	2.3075	2.4795	1.937	1.865	1.5925	1.1915	1.1915	1.1915	1.3025	1.974
Fazenda Sobradinho	2.6815	3.472	3.7195	4.133	3.545	3.2475	2.7995	2.0515	2.1785	2.054	2.576	3.396
Moreli (Parada Moreli)	3.04	3.812	4.264	4.309	3.78	3.443	2.6575	2.0615	2.1575	2.0895	2.6205	3.6315
Fagundes	0.7695	0.8835	0.9095	0.681	0.6305	0.5825	0.4525	0.414	0.584	0.4015	0.4905	0.6805
UHE Simplício Moura Brasil	9.1315	7.232	7.927	6.3115	4.5755	3.627	3.4855	2.8435	2.785	2.6705	4.264	5.545

4.6.3. 7Q10 for Piabanha basin

The values of the 7Q10 (minimum flow with 7 days duration within a 10-year recurrence time) were obtained in the literature and computed for each station based on the full streamflow series (1970-2017/ 1970-2014). The flow recommendations based on this method can be seen in Table 67.

Table 67: 7Q10 per station (m^3/s)

Location	7Q10	10% 7Q10	20% 7Q10	50% 7Q10
Entire watershed AGEVAP (2017)	7.10	0.71	1.42	3.55
Pedro do Rio	2.24	0.22	0.45	1.12
Fazenda Sobradinho	4.36	0.44	0.87	2.18
Moreli (Parada Moreli)	4.79	0.48	0.96	2.40
Fagundes	0.93	0.09	0.19	0.47
UHE Simplício Moura Brasil	5.88	0.59	1.18	2.94

7Q10 value proposed by AGEVAP (2017) to represent the entire basin do not match with the values found for each station, it is higher (see Figure 78). The best e-flow value was based on 50% 7Q10, followed by 20% 7Q10 and 10% 7Q10.

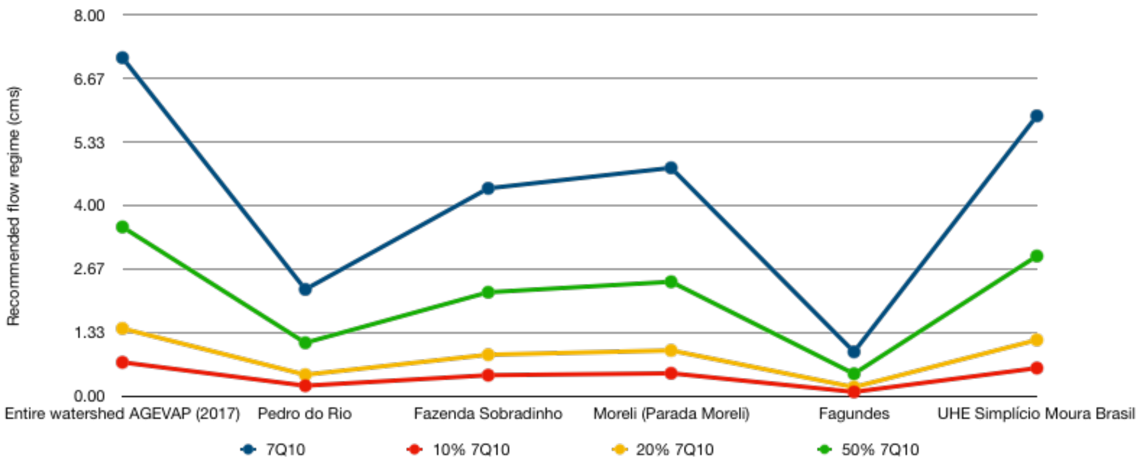

Figure 78: Flow recommendations plots as per the 7Q10 method

4.6.4. Comparison of different flow recommendations in Piabanha basin

Overall the condition “Outstanding” from the adapted Tennant method presented the highest values for instream flow protection when compared with other methods, followed by “Excellent” condition also from the adapted Tennant method. Other methods that presented high water volumes to the environment were: 80% Q90, 7Q10 proposed by AGEVAP (2017), Good (Tennant adaptation), 50% Q90 and 50% Q95 (see Figure 79 to 83). The only exception was for Fagundes station because the value 50% 7Q10 proposed by AGEVAP (2017) exceeds any e-flow proposed (see Figure 83).

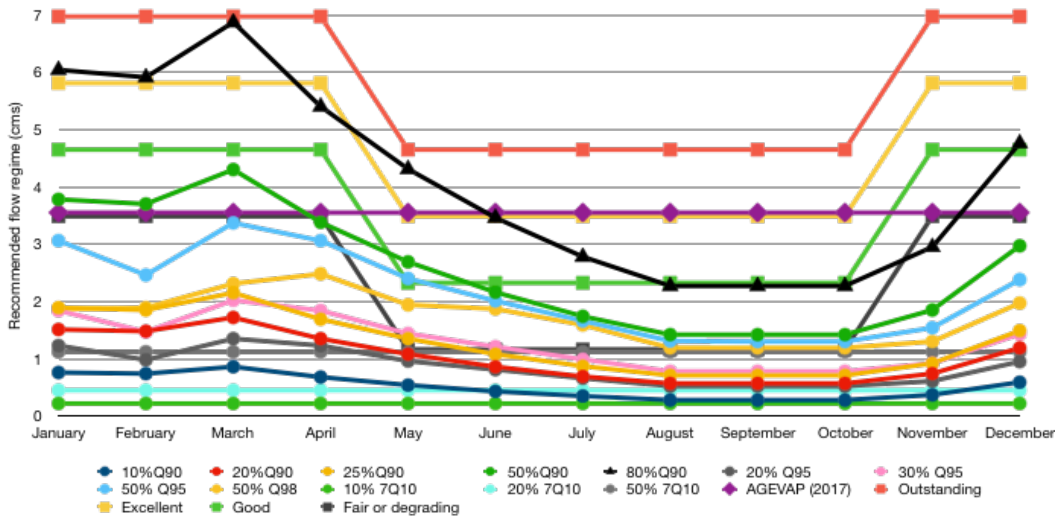

Figure 79: Flow recommendations from different methods in Pedro do Rio

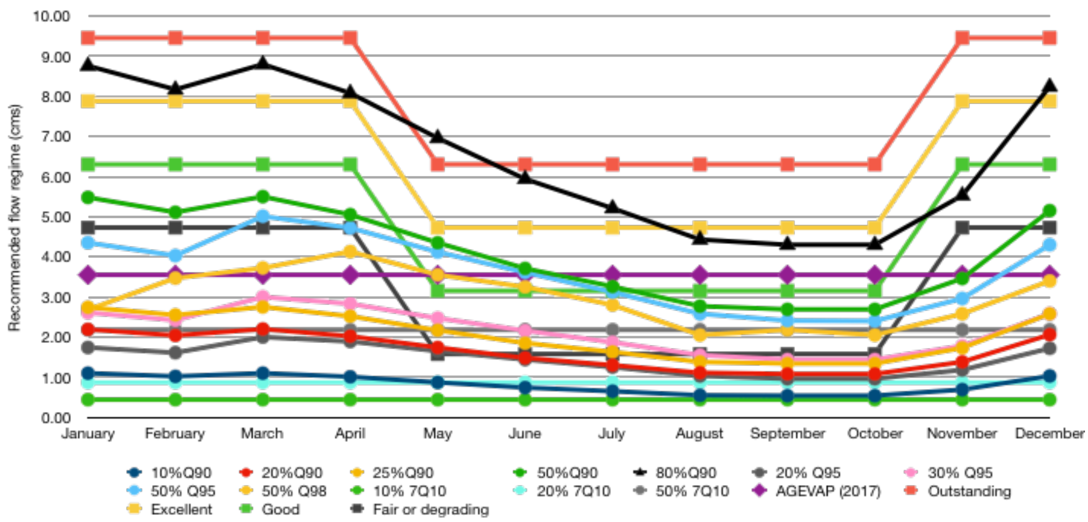

Figure 80: Flow recommendations from different methods in Fazenda Sobradinho

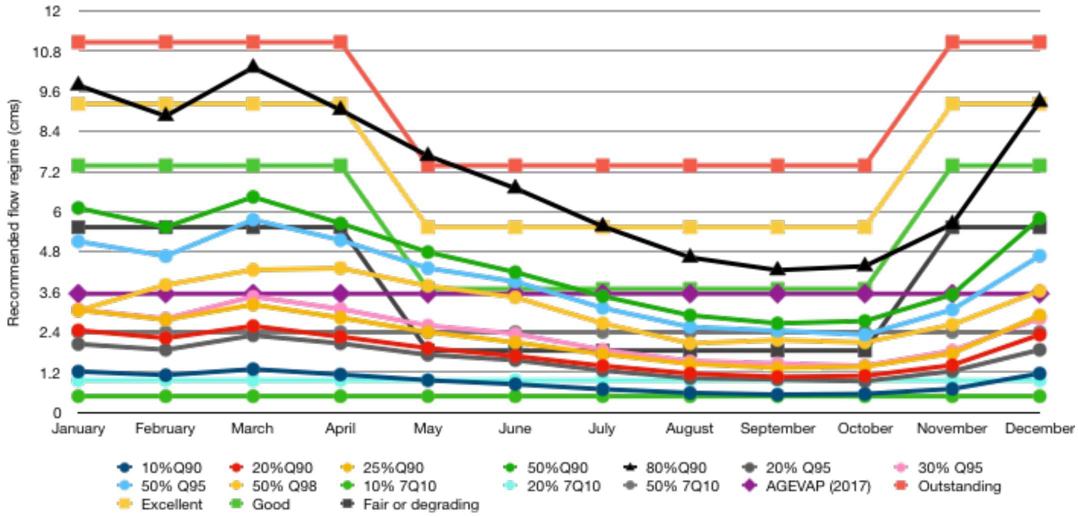

Figure 81: Flow recommendations from different methods in Moreli

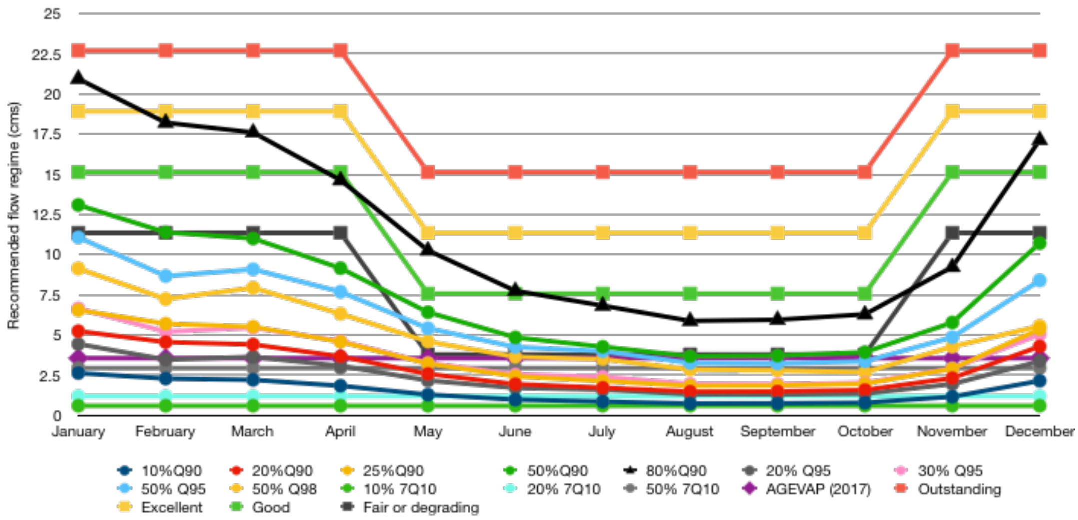

Figure 82: Flow recommendations from different methods in Moura Brasil

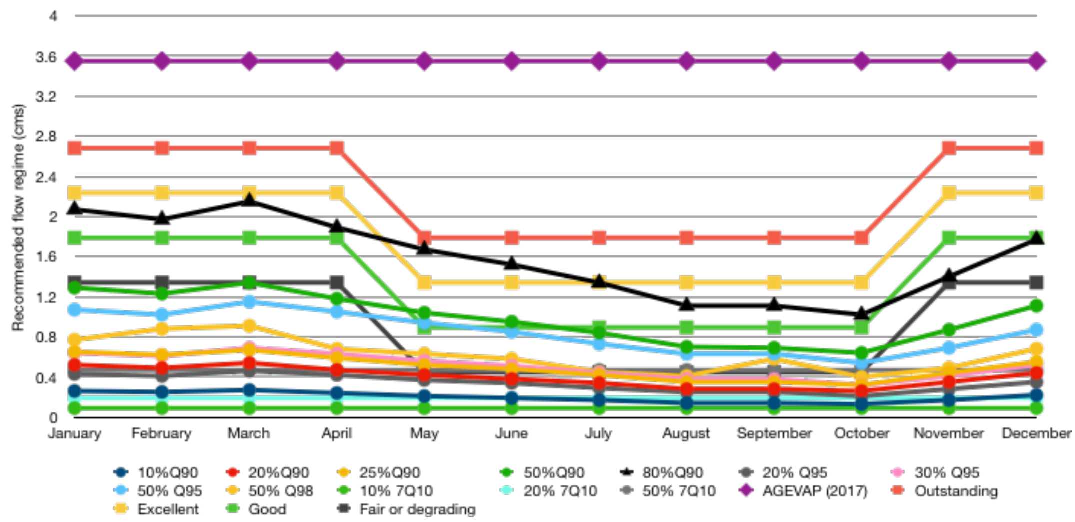

Figure 83: Flow recommendations from different methods in Fagundes

4.6.5. Conceptual model for Piabanha watershed fish species

Based on key flow components identified through expert consultation and literature review for some of the fish species and groups present in the Piabanha basin some conceptual model for the link between the hydrological and ecological system was proposed based on Shenton *et al.* (2011).

For the rheophilic and pelagic species, it's proposed that the volume and timing (during summer) components will influence the instream habitat and pre-spawning conditions (see Figure 84). The selection of timing factor was due to the spawning period.

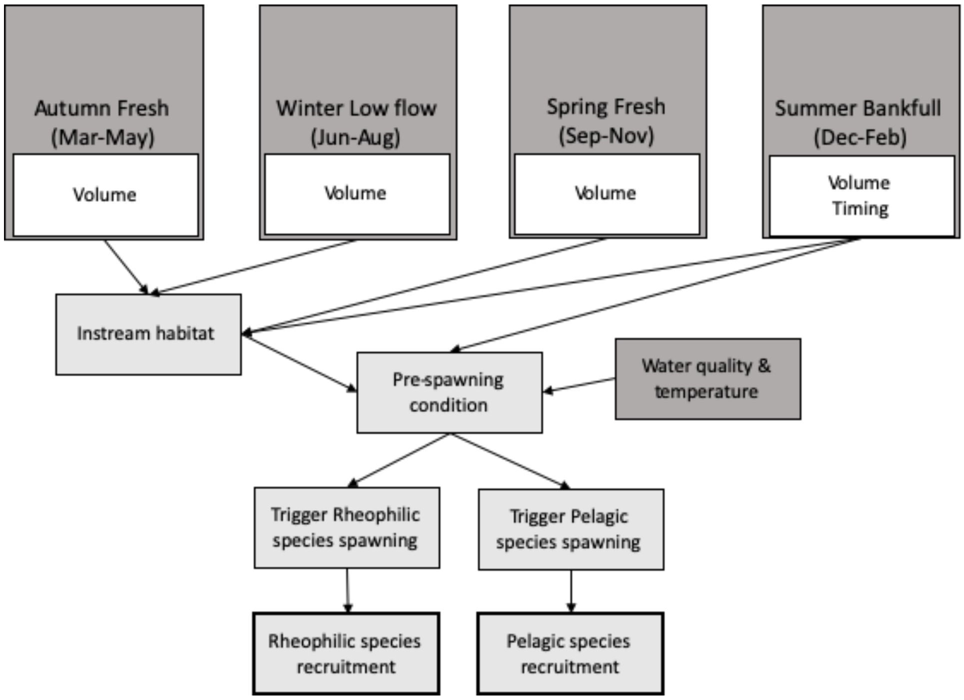

Figure 84: E-flow conceptual model for the rheophilic and pelagic species showing the linked between the hydrological and ecological systems (modified from Shenton *et al*., 2011)

For the *Oligosarcus hepsetus*, it's proposed that the volume and timing (during winter) components will influence the instream habitat and trigger the spawning see Figure 85). The selection of timing factor was due to the spawning period.

For the *Imparfinis minutus*, it's proposed that the volume, magnitude, and timing (during summer) components will influence the instream habitat and act as a pre-spawning condition see Figure 86. The selection of timing factor was due to the spawning period and the component magnitude was selected because this species depends on rapids.

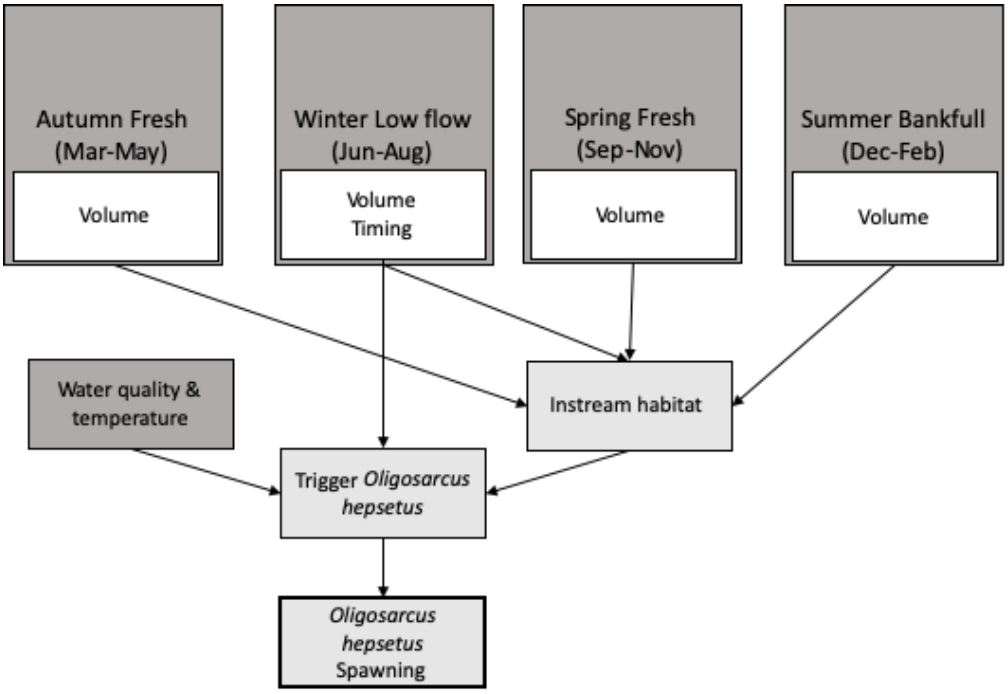

Figure 85: E-flow conceptual model for the *Oligosarcus hepsetus* showing the linked between the hydrological and ecological systems (modified from Shenton *et al*., 2011)

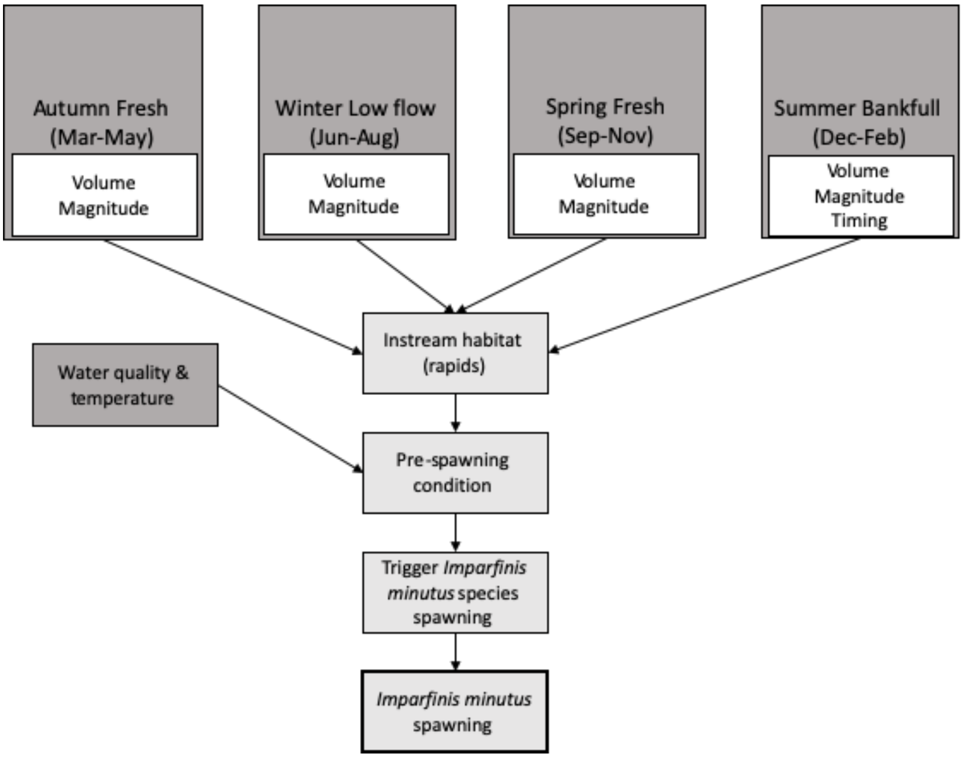

Figure 86: E-flow conceptual model for the *Imparfinis minutus* showing the linked between the hydrological and ecological systems (modified from Shenton *et al*., 2011)

4.6.6. Environmental flow policy and implementation strategy

In this study, different values of environmental flows were proposed based on different hydrological methods and the awareness of the use of ecosystem services and ecological data to flow-ecology relationships were proposed to support environmental flows in a holistic approach.

Yet, e-flows implementation in Brazil needs to evolve and move forward from a fixed value of remaining minimum flows related to the maximum flow % of water resources permit legislation, to hydrological regimes that are compatible with the needs for ecosystem maintenance along with the human needs.

There is great potential for the watershed committees to embrace this type of studies under their Water Resources Plans. They hold the keys to understand flow-ecology-social relationships and provide support for the implementation of e-flows. To do so, investments into long-term monitoring the ecosystem sensitivity, resilience needs to be done so that these key points can be incorporated into decision making.

A source of funding for this movement could come from the water tariffs. According to the Brazilian National Water Policy law (Brasil, 1999), their goal is to obtain funds for the recovery of the Brazilian watersheds, to stimulate the investment in pollution control, to give the user a suggestion of the real value of water and to encourage the use of clean and water-saving technologies. The laws related to the use of this money could be changed to include e-flow studies.

This study used fish species in the flow-ecology linkages but there are plenty indicators that could be used to draft these relationships as presented in the methodology chapter. After financial investment in monitoring the Piabanha basin in a long term, stronger links between water quality (future water allocation scenario defined as priority), hydrological alterations and species response can be better drafted and validated with this research proposed conceptual models and relationships.

5. CONCLUSION

The proposition and implementation of environmental flows in Brazil is still a challenge to be further developed, but this research proposed steps that are adapted to the Brazilian reality and can be replicated in other watershed committees at state and federal level.

During this adaptation, a few steps were designed and applied to engage members of a watershed committee. Those steps include workshops, surveys and preposition of maps using participatory mapping. They were successfully made in a way that facilitates the members to participate and communicate their needs.

Despite the fact that in the first moment the members of the watershed committee were fond of participatory mapping and engaged in the research, one of the main barriers found in the first workshop was the lack of participation of the water users. In the second workshop more confidentiality steps were developed in order to make water users more confident to give their input without compromise the company/ institution that they represent. As a consequence, the amount of water user's participation increased.

Another highlight is that the watershed committee engagement increased over time, the survey participation increased from 14 members in 2015 to 21 in 2018. In 2018, 5 water users participated in the survey that validated the future scenarios of water allocation.

The maps created in the first workshop taking into account the watershed member's participation were able to provide a social based diagnosis and prognosis of the basin in a participatory way that was consistent with the reality of previous scientific researches. Their prognosis took into account not only the maintenance of the ecosystem services but also the human needs.

Likert scale survey validated the future scenarios for water allocation based on the input of the government, water users and civil society. Treatment of domestic sewage was selected as the top the priority, followed by expanding water abstraction and distribution, expand farm activities and expand industries.

When it comes to the hydrological alteration within the Piabanha basin, currently it does not have significant hydrological alteration on its rivers. Once the impact was accessed and the rivers were classified, they fall in the category of un-impacted (two stations) and low impact condition (three stations). The impacted systems classified as "low impact condition" are possibly related to urbanization causing changes in the water balance together with population growth within the city of Petrópolis and the operation of a small hydropower plant. This aspects of Petrópolis city has to be further investigated. Although now the basin is no severely impacted, environmental flows could be used to protect the health of the rivers in the future.

The construction of an ecological foundation is as much important as the hydrological. This work aims to highlight the importance of monitoring ecological data. Without a good ecological database flow-ecology, links are limited. Based on the local data, 44 fish species were selected to be analyzed and compose the ecological foundation. Among those, it was possible to identify that species resilient to environmental disturbances had a high level of spatial distribution (occurrence in 4 monitoring points).

Among the flow-ecology linkages proposed, the flow-ecology hypothesis proposal matches the data, where overall when hydrological alteration increased over time a reduction in species richness (based on fish) was observed in the basin. Other influences in the fish richness (e.g. species-area relationship, water quality, dams, etc) need to be further investigated.

Most parts of the fish species within the basin were classified as low vulnerability to extinction (more than 70%). Only four species were classified as moderate vulnerability (*Apareiodon piracicabae*, *Gymnotus gr. carapo*, *Hoplias malabaricus,* and *Leporinus copelandii*) and one (*Synbranchus marmoratus*) was as high (at Moura Brasil station). According to expert consultation *Gymnotus gr. carapo* is not classified as resilient to environmental disturbance.

Among the 51 fish species present in the basin at least 24 were classified into eight factors/features that put fish species in danger and some of them were directly or indirectly linked to flow. Moura Brasil and Preto stations had the highest number of different features among the four stations. This classification along with functional groups data (e.g. breeding, feeding, and movement) helped propose the first draft of an e-flow conceptual model for some fish features and species within the Piabanha basin.

Most parts of the fish species selected for the analyses have their spawning period occurs during the wet season and October, November and December. Such evaluation demonstrated the highest breeding activity months (pattern presented also for rheophilic species). Severe alterations of flow in this period of the year, high level of water abstractions or impoundment could lead to the extinction of species, especially the ones that migrate.

The Tenant method condition “Outstanding” and “Excellent” presented the highest values for instream flow protection when compared with the current Brazilian state methods. Among the Brazilian state methods 80% Q90 had the highest values for instream flow protection, this method is only applied to the state of Maranhão.

This study was able to introduce the topic of environmental flows to the watershed committee and show different ways to collect and create data to support it. It was done without any funding. Robust environmental flows studies would require financial investments in ecological data monitoring, water quality monitoring, streamflow monitoring, hydraulic data surveys, further social/economic information surveys, experts consultation, an interdisciplinary team to analyze the data and revise the Water Resources Plans and support from the stakeholders to keep these proposals as a long-term project.

Once investment that e-flows require is provided, perhaps the Brazilian National Water Agency could support a national/ state/ municipality level change in water permits and environmental flows (minimum flows) policies. The traditional methodologies currently used (7Q10, Q95 and Q90), which are not classified as environmental flow methods for many authors (e.g. Caissie & El-Jabi 1995; Tharme, 2003; Annear *et al.,* 2004; Caissie *et al.,* 2007; Richter *et al.,* 2012; Armstrong & Nislow, 2012; Gopal, 2013), could be replaced by holistic approaches that could take into account climate adaptation and global change, poverty alleviation, socio-ecological sustainability, pollution and physical destruction of habitat.

There may be some possible limitations in this study. Some of them are:

(1) due to lack of financial support to conduct field trips and surveys, a small amount of social studies was conducted and no hydraulic nor habitat information was collected;

(2) due lack of long-term water quality and ecological data, the flow-ecology linkages were limited, the data available did not cover time frame used for the hydrological data as pre-development and developed condition (1970-2017);

(3) the ecological data available was not designed to answer the goal of this study; in future surveys, it would be important to design the monitoring based on the goal of the study;

(4) regarding breeding data, there is a lack of analysis of eggs and larvae and juveniles, this information would support a more robust breeding calendar;

(5) due to the lack of migration pattern studies for Piabanha species in the basin and the fact that many species are endemic and there is no study of their reproduction at all, understand migration patterns and other flow-ecology relationships were affected.

Future environmental flow studies in the Piabanha basin will have to overcome some challenges, some of the opportunities for future works include:

(1) survey hydraulic features across the basin (e.g. river depth, vegetation, bank erosion, and sand deposits) to use as input for habitat and hydraulic modeling;

(2) modeling past, current and future physical destruction of habitat;

(3) modeling past, current, and future water quality;

(4) modeling future scenarios of water allocations based on the participatory mapping and Likert scale validation of scenarios;

(5) modeling climate changes;

(6) further study the relationship of the anthropogenic effect in the hydrological system;

(7) study breeding patterns among the fish species based on analysis of eggs and larvae and juveniles;

(8) for a better understanding of the flow-ecology relationships long-term monitoring of fish and other ecological data program needs to be started, if possible, the field trips to collect data should follow the hydrological low flows (June-August) and high flows period (November to April);

(9) survey and study functional group relationships (how they feed, breed and move) for fish and other species in the region;

(10) usage of applications on mobiles as a tool of gamification to obtain ecological data from civil society.

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APPENDIX

APPENDIX A

COMITÊ DA BACIA HIDROGRÁFICA DO
RIO PIABANHA E DAS SUB-BACIAS HIDROGRÁFICAS DOS RIOS PAQUEQUER E PRETO

Carta Circular nº 047/2015/CBH-PIABANHA Petrópolis, 10 de agosto de 2015

Aos Srs. Membros do COMITÊ PIABANHA

CONVOCATÓRIA

Prezados Senhores,

Vimos através desta, convocá-los a participar da **48ª Reunião Ordinária do Comitê Piabanha**, a ser realizada no dia **18 de agosto de 2015 (terça-feira).**

Horário: 9h30m - 1ª convocatória / **9h45** - 2ª convocatória

Local: Paraíba do Sul/RJ – Teatro Municipal Mariano Aranha (ao lado da linha férrea).

Av. Ayrton Senna, 238 – Centro, Paraíba do Sul.

Pauta:

1. Aprovação da ata da 47ª Reunião Ordinária;
2. Adequação da composição da Câmara Técnica Institucional ao novo Regimento Interno;
3. Apresentação dos Grupos de Trabalho PSA Hídrico, Rural, Saneamento e Educomunicação e suas atividades;
4. Renovação do Contrato de Gestão da AGEVAP;
5. Apresentação sobre CAR e CNARH (INEA-GESEF);
6. Apresentação Projeto Rios da Serra (ONG Viva Rio);
7. PSA Hídrico – Convênios, Grupo de Trabalho;
8. Informes: **1)** Andamento da campanha de divulgação; **2)** III ECOB; **3)** Seminário de SIG e o BDE; **4)** Plano de Aplicação Plurianual; **5)** Apresentação do Projeto Vazão Ambiental na Região Hidrográfica IV (Camila Hellen Lima, doutoranda COPPE-UFRJ);
9. Assuntos Gerais.

Atenciosamente,

Paulo Sergio Oliveira de Souza Leite
Presidente do Comitê Piabanha

Sérgio de Siqueira Bertoche
Secretário Executivo do Comitê Piabanha

Secretaria Executiva – AGEVAP UD 2
Av. Barão do Rio Branco, 1003 Centro - Petrópolis/RJ
CEP: 25680-120 Tel: (24) 2237-9913
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APPENDIX B

COMITÊ DA BACIA HIDROGRÁFICA DO
RIO PIABANHA E DAS SUB-BACIAS HIDROGRÁFICAS DOS RIOS PAQUEQUER E PRETO

Carta Circular nº 095/2018/CBH-PIABANHA Petrópolis, 26 de novembro de 2018.

Aos Srs. Membros do Comitê Piabanha

C O N V O C A T Ó R I A

Prezados Senhores,

Venho, por meio desta convocá-los (as) a participar da **68ª Reunião Ordinária do Comitê Piabanha**, a ser realizada no dia **03 de dezembro de 2018 (segunda-feira).**

Horário: 09:30h.
Local: Secretaria de Serviços, Segurança e Ordem Pública de Petrópolis (Parque Municipal de Petrópolis) End.: Estrada União Industria, 10.000, Itaipava – Petrópolis.

Pauta:

1. 9:30 - Aprovação das atas da 67ª Reunião Ordinária e de 15ª Reunião Extraordinária;
2. 9:40 - Aprovação do Calendário de Reuniões de 2019;
3. 10:00 - Minuta de Resolução - critérios para apoio para projetos e eventos solicitados por outras instituições ao Comitê;
4. 10:30 - Apresentação - PCH Poço Fundo e Plano de Educação Ambiental;
5. 11:00 - Apresentação - Vazões ambientais como ferramenta de apoio à gestão de recursos hídricos de forma participativa com o comitê de bacia hidrográfica Piabanha;
6. 11:30 - Informes:
   a. Andamento da elaboração do Atlas da RH-IV;
   b. Publicação do Ato Convocatório - Monitoramento de Rios na RH IV;
   c. Andamento do Edital para Manifestação de interesse em projetos e obras de sistemas alternativos de saneamento ambiental para coleta e tratamento de efluentes sanitários domésticos urbanos;
   d. Atualização do PPU na RH IV aprovado no CERHI.

Atenciosamente,

Rafaela dos Santos Facchetti Vinhaes Assumpção
Presidente do Comitê Piabanha

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APPENDIX C

Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test

Test interpretation:

H_0: The series is stationary.

H_a: The series is not stationary.

For all the stations, as the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H_0. Test results point that the series are stationary.

Table C1: P-value (one-tailed) for level and trend approach

Station	Level p-value	Trend p-value
Pedro do Rio	0.270	0.289
Fazenda Sobradinho	0.623	0.206
Moreli (Parada Moreli)	0.497	0.112
Fagundes	0.228	0.594
UHE Simplício Moura Brasil	0.130	0.080

APPENDIX D

Student's t-test

Test interpretation:

H_0: The difference between the means is equal to 0.

H_a: The difference between the means is different from 0.

For all the stations, as the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H_0. Test results point that the pre and post development streamflow series when compared follow a normal distribution.

Table D1: t (observed value), |t| (critical value) and p-value (two-tailed)

Station	t	|t|	p-value
Pedro do Rio	-0.758	2.013	0.453
Fazenda Sobradinho	0.427	2.013	0.672
Moreli (Parada Moreli)	0.296	2.013	0.769
Fagundes	-0.815	2.025	0.420
UHE Simplício Moura Brasil	-0.744	2.017	0.461

APPENDIX E

Pettit's test

Test interpretation:

H_0: Data are homogeneous

H_a: There is a date at which there is a change in the data

For all the stations, as the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H_0. Test results point that the data are homogeneous.

Table E1: Pettit's test K and p-value (two-tailed)

Station	**K**	**p-value**
Pedro do Rio	192.000	0.392
Fazenda Sobradinho	150.000	0.928
Moreli (Parada Moreli)	170.000	0.642
Fagundes	184.000	0.409
UHE Simplício Moura Brasil	232.000	0.066