Fachhochschule Köln
Cologne University of Applied Sciences

UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ

FACULTADES DE CIENCIAS QUÍMICAS, INGENIERÍA Y MEDICINA

PROGRAMAS MULTIDISCIPLINARIOS DE POSGRADO EN CIENCIAS AMBIENTALES

AND

COLOGNE UNIVERSITY OF APPLIED SCIENCES

INSTITUTE FOR TECHNOLOGY AND RESOURCES MANAGEMENT IN THE TROPICS AND SUBTROPICS

Assessment of the stream physical environment and study of its relation with water quality in the Guapi-Macacu watershed, Rio de Janeiro, Brazil

THESIS TO OBTAIN THE DEGREE OF

MAESTRÍA EN CIENCIAS AMBIENTALES

DEGREE AWARDED BY

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IN THE SPECIALIZATION: RESOURCES MANAGEMENT

DEGREE AWARDED BY COLOGNE UNIVERSITY OF APPLIED SCIENCES

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August 2012

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Dedication

I want to dedicate this work to my parents María Rosa and Ernesto. There is no amount of achievements I could dedicate to you, that would be enough to thank you for the way you guided me through life and for sharing your lives with me the way you did and do.

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Contents

Note: all included photographs were taken by the author during the field research carried out from April to May 2012.

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Acronyms

APA	*Área de Proteção Ambiental* (Environmental Protection Area)
APABRM	*Área de Proteção Ambiental da Bacia do Rio Macacu* (Macacu River Environmental Protection Area)
APP	*Área de Proteção Permanente* (Permanent Protection Area)
BAF	Brazilian Atlantic Forest
BRL	Brazilian Reais (legal currency)
CERHI-RJ	*Conselho Estadual de Recursos Hídricos* (Water Resources State Council)
COMPERJ	*Complexo Petroquímico do Rio de Janeiro* (Rio de Janeiro Petrochemical Complex)
DINARIO	Climate Change, Landscape dynamics, Land use and Natural Resources in the Atlantic Forest of Rio de Janeiro (Research project)
DNOS	*Departamento Nacional de Obras e Saneamiento* (National Department of Works and Sanitation)
EMBRAPA	*Empresa Brasileira de Pesquisa Agropecuária* (Brazilian Enterprise for Agricultural Research)
FMP	*Faixa Marginal de Proteção* (Lateral Strip of Protection)
GDP	Gross Domestic Product
GMB	Guapi-Macacu basin
IBGE	*Instituto Brasileiro de Geografia e Estatística* (Brazilian Institute of Geography and Statistics)
ICMBio	*Instituto Chico Mendes de Conservação da Biodiversidade* (Chico Mendes Institute for Biodiversity Conservation)
INEA	*Instituto Estadual do Ambiente* (State Institute of Environment)
NCRS	US Natural Resource Conservation Service
RAMs	Rapid Assessment Methods
REGUA	*Reserva Ecológica de Guapiaçu* (Guapiaçu Ecological Reserve)
RPE	River Physical Environment
SRJ	State of Rio de Janeiro
SVAP	Stream Visual Asessment Protocol
WQ	Water Quality

Abstract

In last decades, water resources around the world have been severely degraded as a consequence of the expansion of areas under human utilization and lack of adequate management. Simultaneously, awareness has increased about the interactions between the environmental condition of river basins and the quality of water resources they provide. Today, in the context of water resources management, the importance of monitoring the environmental condition of basins is fundamental. Among the several methodological approaches available with this purpose, the recent trend is the use of rapid assessment methods, based on a visual inspection of specific indicators of the health of fluvial ecosystems.

The Guapi-Macacu rivers basin (GMB), located northeast of the Guanabara Bay in the Brazilian State of Rio de Janeiro, is an area characterized by its abundant water resources. However, pressure over them is rising due to growing population and industrial activities. The area presents a heterogeneous mosaic of land uses, with increasing intensity from the upper zones to the lowlands.

The objective of this research was to study the river environment condition in the GMB and if it can be related to water quality of the rivers. Initially, an assessment of the river ecosystem was carried out. It was focused on the river’s physical environment (RPE), that is, the morphological and structural characteristics of the river ecosystems. For the field survey, an existent protocol was used, which was selected primarily according the group of elements from the RPE it proposes to evaluate, and how. The survey was carried out in 27 points distributed in the GMB with focus on three sub-basins with particular land use cover and for which water quality data was available. An indexed score was then obtained for each site expressing its RPE’s environmental condition. For the analysis of patterns from these scores, they were mapped to obtain a spatial overview. Also the correlation between scores and water quality data was calculated.

The assessment method functioned well in order to describe the RPE’s conditions in the GMB, which deteriorate from up to downstream, together with increasing land use intensity. The correlation analysis showed interactions between scores and some water quality parameters. For other parameters, patterns resulted less clear due to the highly complex links between both elements.

Keywords: Brazilian Atlantic Forest, water resources management, water quality, river rapid assessment, SVAP.

Resumen

En las últimas décadas, los recursos hídricos a nivel global han sido objeto de una fuerte degradación como consecuencia de la expansión de las áreas bajo utilización humana y la falta de un manejo adecuado. Al mismo tiempo, han aumentado los conocimientos sobre los vínculos que existen entre la condición ambiental de las cuencas hídricas y la calidad de los recursos hídricos que proveen. En el marco de la gestión de los recursos hídricos, la importancia de monitorizar las condiciones ambientales de las cuencas es hoy en día indiscutida. Entre las diversas propuestas disponibles con este propósito, la tendencia reciente es el uso de métodos de evaluación rápida, basados en la inspección visual de indicadores específicos de la condición de los ecosistemas fluviales.

La cuenca del río Guapi-Macacu (GMB) se encuentra al noreste de la bahía de Guanabara, en el estado brasileño de Rio de Janeiro. Se caracteriza por su abundancia de recursos hídricos; sin embargo, éstos se encuentran amenazados por el crecimiento de la población y de las actividades industriales. El área presenta un diverso mosaico de usos del suelo, con un incremento en la intensidad de uso desde las zonas altas hacia los valles inferiores.

El objetivo de esta investigación fue estudiar la condición del ecosistema fluvial en la GMB y si existen relaciones entre esta y la calidad del agua en los ríos. Se realizó primero una evaluación del ecosistema fluvial enfocada en el ambiente físico de los ríos (RPE), o sea, el definido por las características morfológicas y estructurales. Para el relevamiento de campo, se utilizó un protocolo existente, seleccionado a partir de los elementos del RPE que proponía evaluar y como. El relevamiento fue realizado en 27 puntos, los cuales fueron distribuidos dentro de la GMB con énfasis en tres sub-cuencas de particulares condiciones de uso del suelo y para las cuales se contaba con datos de calidad del agua. Se obtuvo un valor indexado para cada sitio, el cual expresa la condición ambiental de su RPE. Para el análisis de los patrones espaciales de estos puntajes, se elaboraron mapas. También se calcularon las correlaciones entre los puntajes y los datos de calidad del agua.

El desempeño del método de evaluación fue adecuado en cuanto a la descripción de las condiciones del RPE en la GMB, las cuales muestran un deterioro progresivo desde las zonas altas hacia abajo, junto con el incremento de la intensidad de uso del suelo. El análisis de correlación verificó interacciones entre los puntajes y algunos de los parámetros de calidad del agua. Para otros parámetros, los patrones resultaron menos claros debido a la complejidad de los vínculos entre ambos elementos.

Palabras clave: Bosque Atlántico de Brasil, gestión de recursos hídricos, calidad de agua, evaluación rápida de ríos, SVAP.

Zusammenfassung

Als Folge der Ausbreitung von Gebieten unter menschlicher Nutzung und wegen Mangel an adäquatem Management sind Wasserressourcen auf der ganzen Welt in den letzten Jahrzehnten stark degradiert. Gleichzeitig hat sich das Bewusstsein über die Wechselwirkungen zwischen Umweltzuständen von Flusseinzugsgebieten und deren Qualität von Wasserressourcen erhöht. Heute, im Rahmen der Wasserressourcenwirtschaft, ist die Bedeutung der Überwachung des ökologischen Zustands dieser Becken grundlegend. Unter den zu diesem Zweck verfügbaren verschiedenen methodischen Ansätzen ist der jüngste Trend der Einsatz von Schnellbeurteilungs-Methoden, basierend auf einer visuellen Inspektion von spezifischen Indikatoren über die Intaktheit von fluviatilen Ökosystemen.

Das Guapi-Macacu Flussbecken (GMB), nordöstlich der Guanabara-Bucht im brasilianischen Bundesstaat Rio de Janeiro gelegen, ist ein Gebiet gekennzeichnet durch seine reichlich vorhandenen Wasserressourcen. Allerdings steigt der Druck auf ihnen aufgrund der wachsenden Bevölkerung und industrieller Aktivitäten. Das Gebiet stellt ein heterogenes Mosaik von verschiedenen Landnutzungen dar, mit steigender Intensität von den oberen Zonen in die Niederungen.

Das Ziel dieser Forschung war eine ökologische Zustandserhebung der Flüsse im GMB um deren Einfluss auf die Wasserqualität zu untersuchen. Zunächst wurde eine Bewertung des Flussökosystems durchgeführt. Der Fokus lag hierbei auf den physikalischen Fluss Umweltbedingungen (RPE), was die morphologischen und strukturellen Eigenschaften des Flussökosystems bedeutet.

Für die Feldforschung wurde ein vorhandenes Protokoll verwendet das vor allem nach den Elementgruppen gewählt wurde, welche die RPE vorschlägt zu bewerten. Die Aufnahmen wurden an 27 Punkten verteilt im GMB durchgeführt, mit dem Schwerpunkt auf Teileinzugsgebieten mit besonderer Landnutzung und für die Daten zur Wasserqualität zur Verfügung standen. Der Erhalt einer indizierten Punktzahl für jeden Standort stellt den ökologischen Zustand der RPEs dar. Für die Auswertung von Mustern aus diesen Ergebnissen wurden sie kartiert um einen räumlichen Überblick zu erhalten. Außerdem wurde eine Korrelation zwischen der Punktzahlen und der Daten zur Wasserqualität berechnet.

Die Beurteilungsmethode funktionierte gut um die Bedingungen der RPE im GMB zu beurteilen, die sich von oben nach unten verlaufend verschlechtern, zusammen mit zunehmender Intensität der Bodennutzung. Die Korrelationsanalyse zeigte Wechselwirkungen zwischen den resultierenden Punktzahlen und einigen Parameter der Wasserqualität, jedoch waren Muster wegen der komplexen Zusammenhänge zwischen den beiden Elementen weniger klar zu erkennen.

Stichworte: Brasilianisch-Atlantischer Wald, Wasserressourcenwirtschaft, Wasserqualität, Fluss-Schnellbeurteilung, SVAP.

1. Introduction

1.1 Degradation of the river environment

Rivers around the world have been subject to increasing deterioration. The population growth combined with a development paradigm focusing on technology rather than on ecology has resulted in a more intensive use of rivers and its floodplains (UNEP/GRID-Arendal, 2010). Modifications were in some cases direct, such as those made in search of improvement of particular river functions for the benefit of human society, e.g. discharge of wastewaters, shipping, irrigation. Other modifications were the result of the degradation of the river's drainage area (or basin): where forest land was converted to cropland, the river's characteristics also deteriorated as a result of soil erosion and nutrient load, among others (Lemmens & Menke, 2008).

Along with river and basin modification, different problems affecting society made appearance, which seemed at first not to be related to those modifications. Floods increased in frequency and intensity, in some areas steady water provision was no longer ensured, and the capability of waters to support further waste discharges was diminished, just to mention some examples. It was not until the last decades that these problems were associated to the ecological state of rivers and to the functions they fulfill when working properly. The recognition of the role of free floodplains to temporarily store water during floods is an example in this process where the river's natural functions began to be acknowledged as advantageous to society.

This process of knowledge accumulation was framed in a broader change of paradigm taking place worldwide during the second half of the 20^{th} century, from which one of the most important tenets is the recognition of the ecosystem's limits for the provision of goods and services. Particularly, the awareness of the services ecosystems are able to provide to human society has become one of the strongest arguments to intensify its protection and recovery (Sukhdev et al., 2010).

It has become clear that healthy river ecosystems are crucial to ensure ecosystem services that are essential to society, and even further, that these services are provided more efficiently by ecosystems than by human technological replacements (UNEP/GRID-Arendal, 2010).

In particular, river ecosystems have been probably among the first ones where the evidences of these relations were detected, as a consequence of their (1) high sensitivity to the degradation of the environment because they are highly dynamic and (2) important role as water providers to society.

Indeed, water flux in rivers acts as a matter and energy conveyor, and changes occurring in a given section of its path affect rapidly the downstream sections as explained by means of the “river continuum” concept by Vannote et al. (1980) (Allan, 2004; Ataroff & Rada, 2000). The area adjacent to rivers is also subject to this dynamic, especially in cases with intense seasonal hydrological cycles, what generates “flood pulses” (Junk, Bayley, & Sparks, 1989).

River ecosystem is composed primarily by physical, chemical and biological elements being all subject to landscape-scale hydrological processes and to a minor extent, to ecological processes (Arizpe, Mendes, & Rabaça, 2008).

From the result of those interactions, river physical environment (RPE) is, that defined by morphological and structural features, roughly, the shape of the river ecosystem. Two main zones compose the RPE: the river channel and the riparian zone, being the latter the area adjacent to the river that is influenced by the river’s hydrological processes, from the bank and upland. Riparian zones are highly productive ecosystems: they accommodate for instance forests in areas where the usual plant formation is grazing lands or even in deserts. They affect the river’s characteristics in a synergetic process, altering water chemistry and influencing the mentioned hydrologic processes (Eubanks & Meadows, 2002).

In consequence, relevance of the river environment is disproportionately high in terms of the ecosystem services provided per area unit. For this reason, water resources management practices need to be carefully studied and defined for this particular component of basins (Hruby, 2009).

1.2 Regional context

The Brazilian Atlantic Forest (BAF) is one of the largest bioregions of Brazil, located southeast of its territory along the shore of the Atlantic Ocean and occupies a strip of land parallel to the shore, reaching in some cases up to 800 km inland (Galindo-Leal & Câmara, 2003).

Given the combination of factors such as its rate of endemism and high environmental degradation, BAF is considered one of the world’s biodiversity hotspots. From the five

South American hotspots, BAF is listed second in terms of biodiversity (Myers, et al., 2000).

After the European Colonization in the 16th century, the development showed an increasingly rapid deterioration of the forest cover, along with the degradation of other resources such as soil and water. The main factors which favored degradation were initially expansion of pastures, later of croplands and lastly of urban areas (Nehren, Alfonso de Nehren, & Heinrich, 2009). The extension of the current pristine areas is stated to be less than a 10% of its assumed original extension (Ribeiro, et al., 2009). Today, even though development patterns have changed and protection measures have been taken, the rate of forest loss still threatens the sustainability of the bioregion (Colombo & Joly, 2010; Galindo-Leal & Câmara, 2003).

This study was focused on Guapiaçu and Macacu rivers basin (Guapi-Macacu river basin, RMB), located northeast of the Guanabara Bay in the State of Rio de Janeiro.

1.3 Hypothesis

The working hypothesis is that a deteriorated physical environment in streams or rivers could be related to poorer water quality conditions.

1.4 Objectives

1.4.1 General objective

The objective of this study was to analyze the existence of relations between the river physical environment in the Guapi-Macacu basin and the quality of the water resources it provides.

1.4.2 Specific objectives

- Review and collect existing data and information about water quality.
- Review methodologies for rapid river assessment, select one and adapt it to the local conditions of the study area.
- Conduct a survey in the study area using the selected methodology and considerate its applicability to local conditions.
- Elaborate a geo-referenced database about river physical environment and water quality.

- Establish relations between the parameters describing the status of the river physical environment and water quality data.

2 State of the art

2.1 River ecosystem

2.1.1 Composition

The basic component of river ecosystem is a set of physical and chemical features, which determine the abiotic medium. It supports, in turn, biological communities, the second element. Finally, the third element is composed of the interactions among the first two elements and with themselves, that affect the whole composition (Allan, 1995).

From the first element, the physical and chemical features, the following are the most important characteristics (Allan, 1995; Faria & Soares Marques, 1999):

- Geophysical characteristics: related to underlying geologic composition and geomorphic processes.
- Sediment dynamics, which is a result of the water movement downstream and determines many of the characteristics of the stream's substrate.
- Climate controls the river environment via the effects of temperature and precipitation, the latter being the determinant factor of the stream's hydrology.

These characteristics control the diversity of habitat types available for the establishment of organisms. They operate in a wide range of time and space scales (Arizpe et al., 2008).

The second element, biological communities, determines the river's biological environment. It is characterized by a high variability in terms of life forms and population density. Usually, plant diversity in the riparian zone is higher in the middle course of rivers, where the occurrence of disturbances is more frequent and therefore a larger habitat diversity is available (Tabacchi et al., 1998). Regarding aquatic flora, high-gradient streams support smaller communities because the shade from trees limits energy input and the high water speed limits habitat availability. Aquatic plants are either macrophytes (vascular plants and bryophytes) or algae that have the ability to attach to substrate in order to survive in the rapidly moving water. Phytoplankton communities are present mostly in high order rivers where water speed is slower (Allan, 1995).

Aquatic animal diversity is also highly variable. The streams in higher zones may offer more habitat diversity than downstream, showing the opposite scenario to plant communities. Elevation and stream size are here the main factors determining diversity of animal communities (Allan, 1995).

In small high-mountain streams, shade and harsh environment for plants imply that aquatic animals living in the stream depend on allochthonous production entering the river channel for surviving (e.g. litter and seeds falling from riverbanks). In low gradient streams and rivers with higher plant diversity and productivity, the animal food webs may however be based on authochtonous plant production (E. Carvalho & Uieda, 2010).

The third element of river ecosystems is composed by the interactions between the previous two elements. Thus their characteristics will determine the number and intensity of the interactions. For instance, climate will determine vegetation, which in turn affects river channel shape due to bank stabilization. Some of the main interactions are shown in Fig. 1.

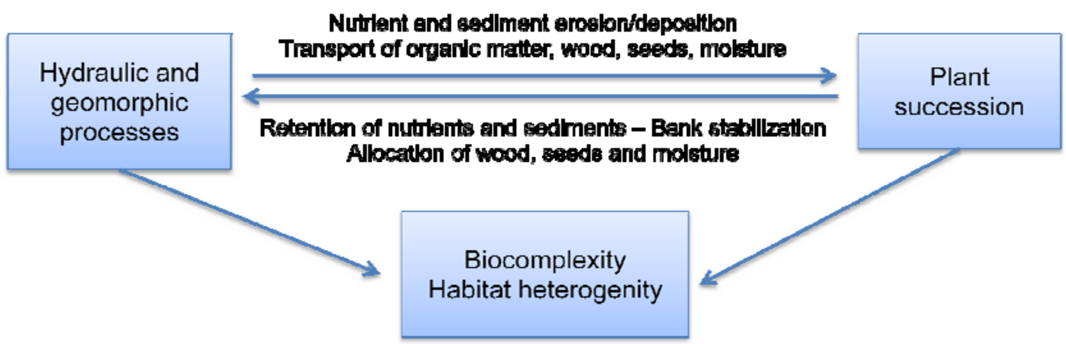

Figure 1: Dynamic relationships among hydrologic, geomorphic and ecological processes of river ecosystems, all deriving in “biocomplexity” (Arizpe et al., 2008).

2.1.2 Main characteristics

One of the main characteristics of this composition is its high variability. Sources of variability include short- and long-term patterns of climate, alterations in runoff and sediment transference patterns, and changing hydrological and geomorphologic responses to these patterns. Dependence of biota on these physical processes is reflected in the temporally variable composition of both plant and animal communities living in riparian zones and in-stream environments (Arizpe et al., 2008; Lemmens & Menke, 2008). As result, rivers are complex mosaics of habitat types and environmental gradients (Allan, 2004).

But also this heterogeneous composition is characterized by a high connectivity, since water moves along the river carrying not only materials but also physical properties such as temperature and chemical properties such as acidity (Allan, 2004). This led to the development of the concept of river continuum (Vannote et al., 1980) which refers to the longitudinal connectivity in a river not only regarding physical and chemical aspects, but also biological, since water transports also living and dead organisms, seeds, and organic matter in general.

In this sense, rivers may be thought to be ecological axis of basins. Almost every characteristic of a basin is reflected on the rivers draining through it. From geology to relief, climate, and biome, all these factors influence the river's parameters.

Another related study proposed the existence of "lateral" connectivity, that is, between the river and its floodplain horizontally by means of the "flood pulse" concept (Junk et al., 1989). The hydrologic cycle plays a determining role in this influence since it determines the frequency of flooding, an event which unleashes a considerable amount of biological processes especially on the riverbanks.

Ward (1989) described the linkages among basins, rivers and its composing elements as a multidimensional network: "longitudinal (upstream to downstream), lateral (floodplains to uplands), vertical (subsurface to riparian canopy), and temporal (because the other three dimensions are dynamic over time).

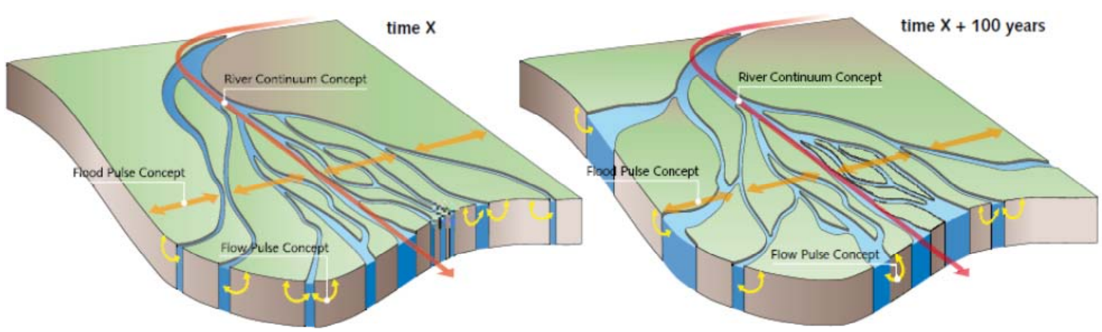

Figure 2: Representation of the processes connecting a river's different zones and its basin (Lemmens & Menke, 2008).

This degree of interconnectivity explains why human land use, both at basin as at river ecosystem scale, affect the characteristics of rivers located at great distances (L. Carvalho, Cortes, & Bordalo, 2011; Neill, et al., 2001).

How the condition of upstream reaches affects the rest of the river (the "upstream effect") is a consequence of this multi-dimensional connectivity (Kail & Hering, 2009). However, a large quantity of factors determines the intensity this effect will have downstream (e.g. the longitude). Those factors depend in turn on the particular conditions of every river system.

2.1.3 River physical environment

The river physical environment (RPE) is that determined by the morphological and structural features of the river ecosystems as result of the interaction of its composing elements as described above. These features vary differently depending on the zone of the river ecosystem under consideration: the channel or the riparian zone.

At channel scale, morphological features depend mostly of the channel's shape. It determines the availability of in-stream habitat diversity and is the result of large scale processes such as hydrology, geology and relief. These in turn derive in fluvial processes such as erosion and sediment transport and deposition which govern the dynamics of riffles and pools, two of the basic habitat types in streams (Pedersen, 2003).

Riparian zones (from the Latin word *riparius*, of or belonging to the riverbank) are the areas encompassing the stream channel between the low and high water marks, and that portion of the terrestrial landscape further away from the high water mark toward the upland, where vegetation may be influenced by elevated water tables or flooding and by the ability of the soil to hold water (Naiman & Décamps, 1997).

Given their nature as an interface zone between land and water ecosystems, riparian zones are some of the most diverse, dynamic and complex biophysical habitats on the terrestrial portion of the planet (Décamps et al., 2004; Naiman & Décamps, 1997).

As described by several investigators (Dosskey et al., 2010; Hefting et al., 2005; Naiman & Décamps, 1997), riparian zones and the vegetation growing on them perform several functions within a river ecosystem:

- Physical functions:
    - Regulation of mass movement of materials, as result of its influence on soil structure –by means of roots– and floor roughness in riverbeds and riverbanks during floods, a key factor determining how hydrology affects river morphology.
    - Provision of woody debris, which plays an important biophysical role in the stream channel: piles of large woody debris dissipate and modify water flow energy, diversifying the channel's habitat availability. They also are a source of energy for organisms.
    - Forests growing on riparian zones exert strong controls on the microclimate of streams, mainly by shading and altering local water balance through evapotranspiration.
- Ecological functions:
    - Source of nourishment: litter falling from riparian zones is an allochthonous source of energy for aquatic organisms (the main in low order streams).
    - Filtering of nutrients, through physical trapping of sediment-bound substances being moved by sheet flow runoff, and biologically through plant uptake.
    - Refuge and corridor habitat for regional diversity of plant and animals.

2.2 River environment and water quality

In natural rivers, factors such as geology and climate are responsible for the basic properties of running waters. But riparian zones play also a disproportionately important role in controlling water and chemical exchange between surrounding lands and stream systems (Dosskey et al., 2010).

Particularly, riparian vegetation is the main component in charge of a series of processes controlling the interaction of running waters with soil in the banks. Some of these processes are nutrient uptake by roots, stimulation of biogeochemical processes in soil, control of channel physical stability and regulation of physical conditions, as explained above and shown in Fig. 3.

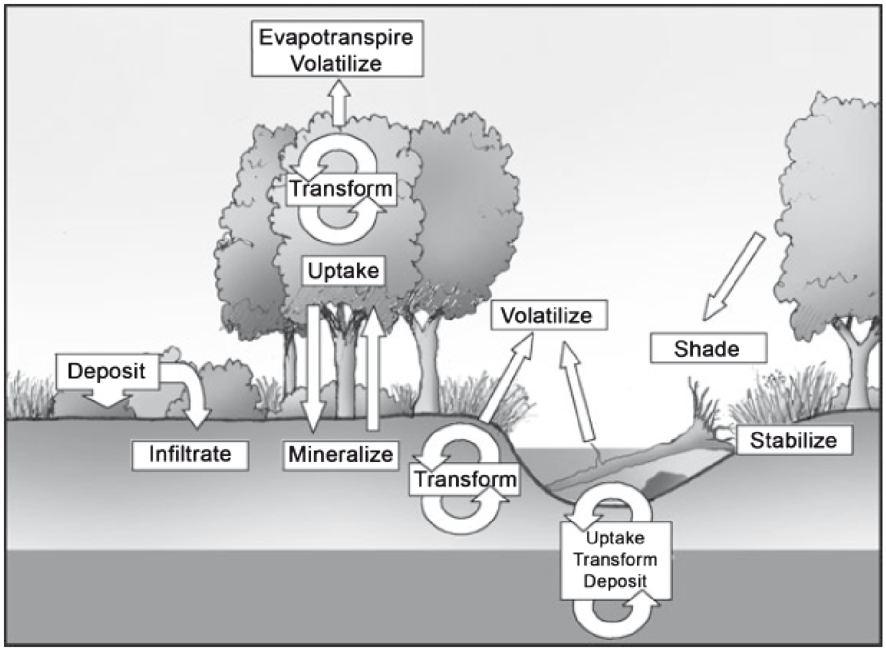

Figure 3: Processes through which the major components of vegetation in riparian and channel systems influence stream water chemistry (Dosskey et al., 2010).

All these processes have an effect on the chemical properties of the river's water. For instance, nutrient uptake by plants reduces its concentration in water. Nutrients do not leave the system, they are returned in form of organic matter. Soil stabilization modifies how water moves along the river channel, frequently reducing flow speed and consequently decreasing erosion rate. Also riparian vegetation increases surface roughness, what increases deposition of sediments entering the riparian zone via lateral water runoff (Blanco & Lal, 2008). Decreased erosion and sediment deposition on riparian zones prevent soil particles from entering water flow, thus reducing the amount of suspended solids and turbidity (Donadio, Galbiatti, & De Paula, 2005; Dosskey et al., 2010).

2.3 <u>River environment assessment</u>

2.3.1 Water resources management

Today, river environment assessment is a discipline of great interest and intense development for two main reasons: the scientific study of river ecosystems processes and functions, and the water resources management (González del Tánago, et al., 2006). In Europe, for example, the implementation of the Water Framework Directive has been a major impulse to the environmental monitoring as it proposes the achievement of a “good ecological status” in most water bodies. This ambitious objective requires a highly detailed evaluation and monitoring of water resources in order to establish conservation strategies and/ restoration measures.

Bjorkland, Pringle, & Newton (2001) state that the main reasons for conducing stream assessments are: (1) the detection of changes in stream conditions following a disturbance or project implementation, (2) the characterization of stream conditions for resource utilization, (3) the development of status reports as part of resource inventories, and (4) the establishment of reference sites.

2.3.2 Emergence of rapid assessment methods

Rivers located in the upper portions of watersheds, near to the river’s origin, are classified as of low order. In these areas, higher gradient determines steep, “v” shaped valleys where space for interactions between the river and the riparian zones is small. Low order rivers have also smaller flow fluctuations because they drain smaller areas. As result, riparian zones in low order rivers are usually very small in terms of area. Despite this fact, their accumulated length is much larger than that of high order rivers. For instance in the United States, first and second order streams sum up more than 73% of the country’s total river length. Therefore, riparian zone of the small rivers (first and second order) is comparable by the same order of magnitude to that of larger rivers (Arizpe et al., 2008).

In a context of high demand of information describing the state of water resources, and limited economic resources for carrying out detailed surveys, a trade-off solution was found in the adoption of tiered evaluation methods (Barbour, et al., 1999; Bjorkland et al., 2001) being the recent trend to move away from strictly quantitative approaches towards qualitative evaluations. “Tiered” refers to the division of the assessment process into different steps of progressive complexity.

In this scheme, traditional methods based on sampling and analysis of numerous metrics have been replaced partially by rapid assessment methods (RAMs) (Bjorkland et al., 2001), which emerged as the optimal tool for the basic tier of assessment. By focusing on simple, yet appropriate, measurements and avoiding the use of specialized equipment, these protocols can be completed in a relatively short time and applied to many different stream reaches in a wide area, a critical requirement for large-scale survey programs. The more extended application offers a wider outlook of the river's status. Results of an assessment using RAMs feeds the next level of evaluation in the mentioned frame of a tiered evaluation process, where more detailed surveys are carried out.

The main advantages of RAMs noted by Barbour et al. (1999) are (1) a cost-effective, yet scientifically valid procedure, (2) the provision of multiple site investigation in a field season, (3) quick turn-around of results for management decisions, (4) easy translation of scientific reports to management authorities and the public and (5) environmental-benign procedures.

Stacey et al. (2006) stress also the advantages RAMs provide as a consequence of their easiness of use: the possibility of analyzing time trends to monitor management strategies and restoration progress. Finally, they noted that these methods can usually be performed by almost any interested individual who has been properly trained and whose work is overseen by an expert. Thus, with proper training, RAMs may prove to be useful for educational purposes and furthermore generate citizen involvement in land management issues as well.

2.4 Types of RAMs

Many different protocols have been developed to directly or indirectly assess the condition of river ecosystems in general or riparian zones specifically. Some of them focus on a particular component or process within the overall river system (e.g. channel geomorphology, riparian vegetation, flow regime patterns, aquatic habitat quality, water quality and aquatic invertebrate community composition) (Parsons, Thoms, & Norris, 2002). Another approach of the assessment is the examination of a broader array of variables that encompass the entire ecosystem. Each variable then works as an indicator for one or more important components or processes (Hruby, 2009; Stacey et al., 2006).

Some examples of RAMs considered for this research are detailed in table 1. The river environment parameters they evaluate are also detailed.

Table 1: Examples of RAMs, showing the main features from the river environment on which they are focused.

Methodology	**River environment component (number of evaluated parameters)**						**Total no. of parameters**
	Physical structure	**Hydrology**	**Water quality**	**Riparian zone vegetation**	**Aquatic habitat quality**	**Terrestrial habitat quality**	
SVAP (Bjorkland et al., 2001)	3	1	4	1	6	0	15
Índice de Avaliação Visual (IAV) - Plano Manejo APA Macacu (Instituto BioAtlântica, 2009)	6	0	0	2	2	0	10
RFV (Magdaleno, Martínez, & Roch, 2010)	0	0	0	4	0	0	4
RQI (González del Tánago et al., 2006)	3	0	0	4	0	0	7
QBR (Munné, Prat, Solá, Bonada, & Rieradevall, 2003)	1	0	0	3	0	0	4
USEPA RBP for streams and wadeable rivers (Barbour et al., 1999)	8	0	0	2	3	0	13
RSRA (Stacey et al., 2006)	4	0	2	6	6	3	21

3 Study area

3.1 Guapi-Macacu basin

The Guapi-Macacu basin (GMB) lies on the southern central area of the Brazilian State of Rio de Janeiro. Its main rivers are Macacu and Guapiaçu, and covers an area of 1266,34 km^2 (Instituto BioAtlântica, 2009). It is the largest basin draining to the Guanabara Bay from which is located at Northeast (Fig. 4).

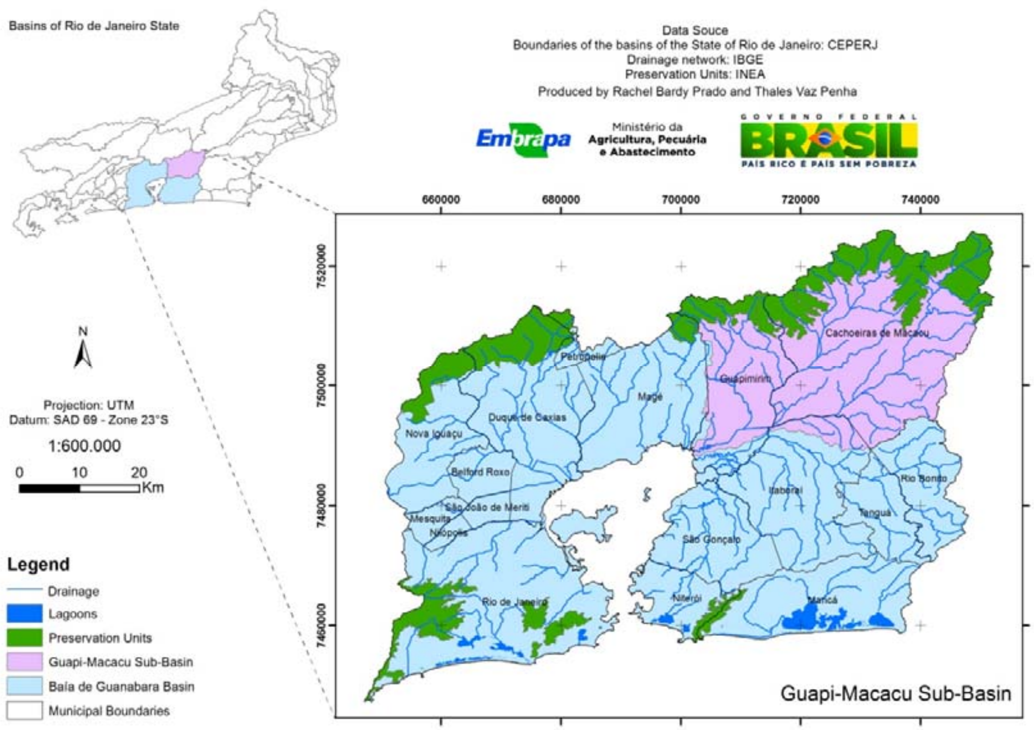

Figure 4: Location of the GMB in relation to other basins draining to Guanabara Bay (Governo do Estado do RJ, 2005).

The Macacu and Guapiaçu rivers are the source of drinking water for more than 2,5 million inhabitants from the cities of Cachoeiras de Macacu, Guapirim and Itaboraí (within the basin) and São Gonçalo and Nitéroi outside the basin (Dantas, Almeida, & Lins, 2007). Water resources are also used for irrigation, fish production and food and beverage production (Instituto BioAtlântica, 2009).

3.1.1 Relief

The GMB descends on its northern portion part from the Serra dos Órgãos Mountain, part of the Serra do Mar mountain range which raises up to 2200 m in this area. The East limits are the mountains Serranas da Botija and Monte Azul, and to the South Serras de Sambe and dos Garcias in the coastal range. Finally in the West it limits with Guanabara bay, where the basin drains (Fig. 5).

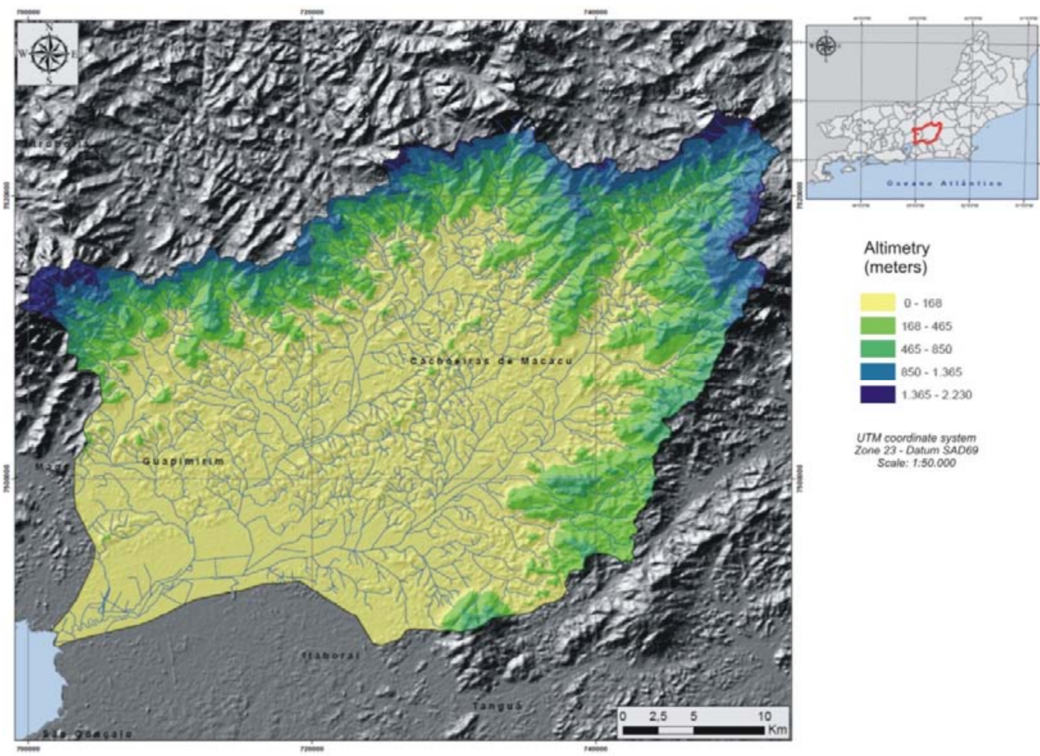

Figure 5: Relief of the GMB (Fernandez, 2012).

3.1.2 Climate

Serra dos Órgãos plays a significant role for the regional climate: it acts as a barrier to the humid winds coming from the Atlantic Ocean, which produces orographic precipitations of around 2500 mm in the steepest areas, whereas in the lower plains near Guanabara Bay, precipitation reaches a more modest value of 1500 mm (Nimer, 1989). Temperature also varies due to relief characteristics, presenting the plain valleys near the coast higher temperatures than in the mountainous area of the basin. Climatograms of Rio de Janeiro City (5 ma.s.l.) and Nova Friburgo (857 m.a.s.l.) show the difference in temperature and precipitation between the Guanabara Bay area and the mountainous area at northeast (Fig. 6).

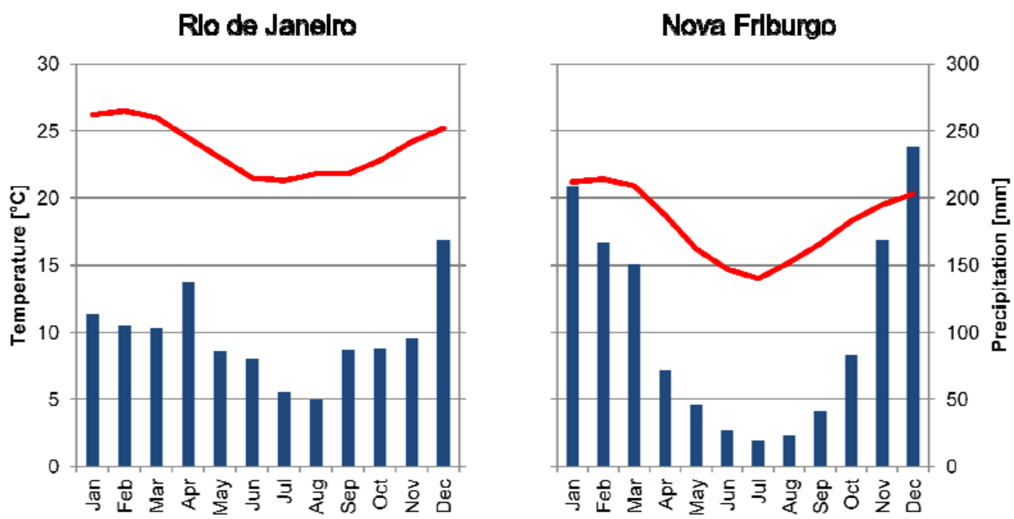

Figure 6: Climograph for Rio de Janeiro and Nova Friburgo cities. Elaborated with data obtained from (EMBRAPA-ESALQ/USP, 2003).

Despite mentioned strong gradients, most of the GMB area presents a climatic typology Am (Tropical monsoon or warm humid with at least one dry month) (IBGE, 2002).

3.1.3 Geology and soils

Soils of granitic and gneissic origin as those present in most BAF region are characterized by a poor primary mineral content due to intense wathering of the surface as a consequence of climate factors (high humidity and temperatures). Under these conditions, processes of ferralization and desilication take place, generating leaching of silicum compounds and cations such as Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}. Therefore, most nutrients are located and relatively fixed within the biomass layer over the soil (Scheffer & Schachtschabel, 2010; Shinzato, Carvalho Filho, & Geraldes, 2006).

The main soil classes present in the study area are Cambisols in the mountainous areas, Ferrasols in the lowlands and Fluvisols in the floodplains. Gleyic soils have also developed in the downstream area as a consequence of periodical seasonal flooding (Lumbreras, 2010; in Penedo, et al., 2011).

3.1.4 Vegetation and biodiversity

The study area presents four ecological formations: BAF, mangrove, marshes and *campos rupestres*.

The BAF is one of the most biodiverse ecosystems in the world, being one of the five biodiversity hotspots of South America (Myers et al., 2000). The high biodiversity represented by more than 20.000 plant species and nearly 1400 vertebrate species, is the result of the highly variable living conditions, mainly altitude and water availability gradients. Also, this biogeographic unit is relatively isolated from other biodiversity centers, which is the reason why the endemism rate is high especially in trees from which more than 50% are endemic (Conservation International, 2008; Galindo-Leal & Câmara, 2003). Regarding fauna, in the area are present 250 mammalian species (of which 55 are endemic), 240 of amphibians (90 endemic) and 1023 of bird (188 endemic).

Other ecosystem types present in the basin are:

- Mangroves: in the downstream area, where rivers meet Guanabara bay.
- Marshes and wetlands: located in alluvial zones and depressions with highly variable floristic composition.
- *Campos rupestres* (or high field mountains): located at the highest zones of the mountains or in very steep slopes. They typically posses a much less complex vegetation structure (herbaceous and some shrubs), but support several endemic plant and animal species.

3.1.5 Human environment: evolution of the population of the area

During the Brazilian colonial period, the area remained mostly unpopulated. Rivers, specially Macacu River due to its size, were used as inland waterways for the transportation of goods, by means of boats and canoes. Sugarcane industry was the greatest driving factor for the development of the area at this stage, with the establishment of *fazendas* (large estates) which made use of the rich alluvial soils that producers were able to find across the generally swampy area (Instituto BioAtlântica, 2009). The products were transported by boat to Rio de Janeiro to be consumed or exported. Communication routes served not only the agricultural production but also gold smugglers, an activity always in search of alternative routes to escape authorities and taxes (Nehren et al., 2009).

In the second half of the 19th century, the impulse moved towards coffee as the main developing crop (Instituto BioAtlântica, 2009; Nehren et al., 2009), which replaced sugarcane crops as its price had fallen and the production had moved to other areas. In fact, downturn of sugar plunged the economy of the region, and many of the sugarcane farms were abandoned.

At the beginning of the 20th century, development of transportation lines such as railroads stimulated the settlement of a “green belt” of farms through the lower part of the basin, fueled by food demand from the growing city of Rio de Janeiro. The production diversified, included bananas and oranges and intensely modified the landscape, especially around the city of Sao Gonçalo (Universidade Federal Fluminense & Fundação Euclides da Cunha, 2010a). The cultivation of coffee also declined after the 1929 economic crisis (Nehren et al., 2009), though coffee production still remains in some areas of Tanguá and Rio Bonito. Much of the old crops were replaced with pastures.

The strongest alterations of the river environment began at this time when the first rectifications of Macacu and Guapiaçu rivers by the Comissão Federal de Saneamento e Desobstrução dos Rios (Federal Commission of Sanitation and River Unblocking, from the national government) were conducted with the objective of gaining arable land by draining flooded areas. These works had a severe impact on the lowlands’ environment, altering water circulation, salinity and thus influencing the bay’s hydric system, and changing erosion-sedimentation dynamics (Instituto BioAtlântica, 2009).

By the mid-20th century, the region was one of the largest receivers of public investments, mainly oriented to revert the degradation caused by the sugarcane collapse and spreading of diseases like yellow fever and malaria which had infested the area in several opportunities. Works of channelization in the 1940’s by the Departamento Nacional de Obras e Saneamiento (National Department of Works and Sanitation - DNOS) and other channelization works pursued partially the goal of reducing the habitat of mosquitoes which transmitted the virus of malaria (Instituto BioAtlântica, 2009). The Imunana channel was built during these years in order to control flooding in the basin’s lowland, but changed the runoff patterns by connecting the Guapi-Macacu river with the Guapimirim (Dantas et al., 2007; Instituto BioAtlântica, 2009). These works boosted the economy of the area and expanded the available lands for agriculture.

The number of small farms grew especially around Sao Gonçalo, and also manufacturing activity entered into scene, with the installation of scale factories such as the cement factory of Mauá in Itaboraí and others in the area of food processing.

During the decade of 1960’s the population growth reached its biggest intensity, fueled by the expansion of paved route network. After 1970, the influence of the growing metropolis of Rio de Janeiro increased by the construction of the Rio-Niteroi bridge, accelerating the urbanization of the area. Mainly in Itaboraí, residential developments were built to host workers from Rio and Nitéroi, as well as summer residences established due to a growing industry of tourism in the *Região dos Lagos*, southeast of the GMB (Universidade Federal Fluminense & Fundação Euclides da Cunha, 2010a).

3.1.6 Demography and socioeconomics

GMB extends across three municipalities of the State of Rio de Janeiro: Guapimirim, Itaboraí and Cachoeiras de Macacu. Together they cover an area of 1740 km^2, with a population of 273.974 inhabitants, the 1,9% of the state (Instituto BioAtlântica, 2009).

Economic production derives in the greatest proportion from services (Table 2). Yet agriculture and ranching are the activities demanding the greatest share of land (See §3.1.7, below). Vegetable products such as *inhame* (*Colocasia sp.*), *jiló* (*Solanum gilo*) and *quiabo* (*Hibiscus esculentus*) are the main cultures in the area.

Table 2: GDP composition of municipalities within GMB and of the Rio de Janeiro State for the year 2007, in BRL (Adapted from Instituto BioAtlântica, 2009).

	Agriculture	**Manufacturing**	**Services**	**Total**
Guapimirim (1)	4.623	57.150	180.897	242.670
Itaborai (2)	2.090	202.551	742.742	947.383
Cachoeiras de Macacu (3)	23.831	249.938	200.604	474.373
3 Municipalities (1+2+3)	30.544	509.639	1.124.243	1.664.426
Rio de Janeiro State	952.607	113.000.802	125.532.688	239.486.097

Since the Campos and Santos marine oil deposit in the State’s continental shelf began to be developed and started producing oil and gas in the past two decades, petrochemical industry experienced strong development in the region. Framed in this scenario, GMB will host the *Complexo Petroquímico do Rio de Janeiro* (COMPERJ), an oil refinery of 45 km^2, near the cities of Itaboraí and Cachoeiras de Macacu. COMPERJ is the largest single venture of the national oil company, Petrobras. Other large scale projects in the area of the GMB are a gas pipeline, a highway (Arco Metropolitano do Rio de Janeiro, Rodoanel) and a dam across the Guapiaçu river in order to secure water provision to the eastern shore of the Guanabara Bay (Instituto BioAtlântica, 2009).

All these ventures led to the state government to change the legal zoning definition of the region of GMB from “rural” to “industrial” in 2006 (Instituto BioAtlântica, 2009; Universidade Federal Fluminense & Fundação Euclides da Cunha, 2010a).

Due to the population growth in recent years, the remaining BAF and the water resources of the region are in risk of degradation or disappearance, in the case that the projected population growth is not oriented under adequate planning policies (Instituto BioAtlântica, 2009).

3.1.7 Land use and related environmental issues

The river ecosystems show in the GMB a wide range of conservation statuses. While streams flowing through high mountainous ranges conserve a fully-functional status, once they reach the cultures and grazing areas below, they start to show signs of deterioration. In the lowlands of the basin, rivers lose significant proportion of its natural hydrological and ecological functions (Instituto BioAtlântica, 2009).

A recent study of soil uses in the GMB noted that natural vegetation and pastures are the most extended land use cover types (Fidalgo, et al., 2008). The natural vegetation constituted by forests is concentrated in the high-mountain or with high gradient areas, and in the swampy lower zones near the Guanabara bay. Together, these two land cover types sum up more than 85% of the area of GMB. Agricultural areas are concentrated along main roads and rivers where the access is easier (Figures 7 and 8).

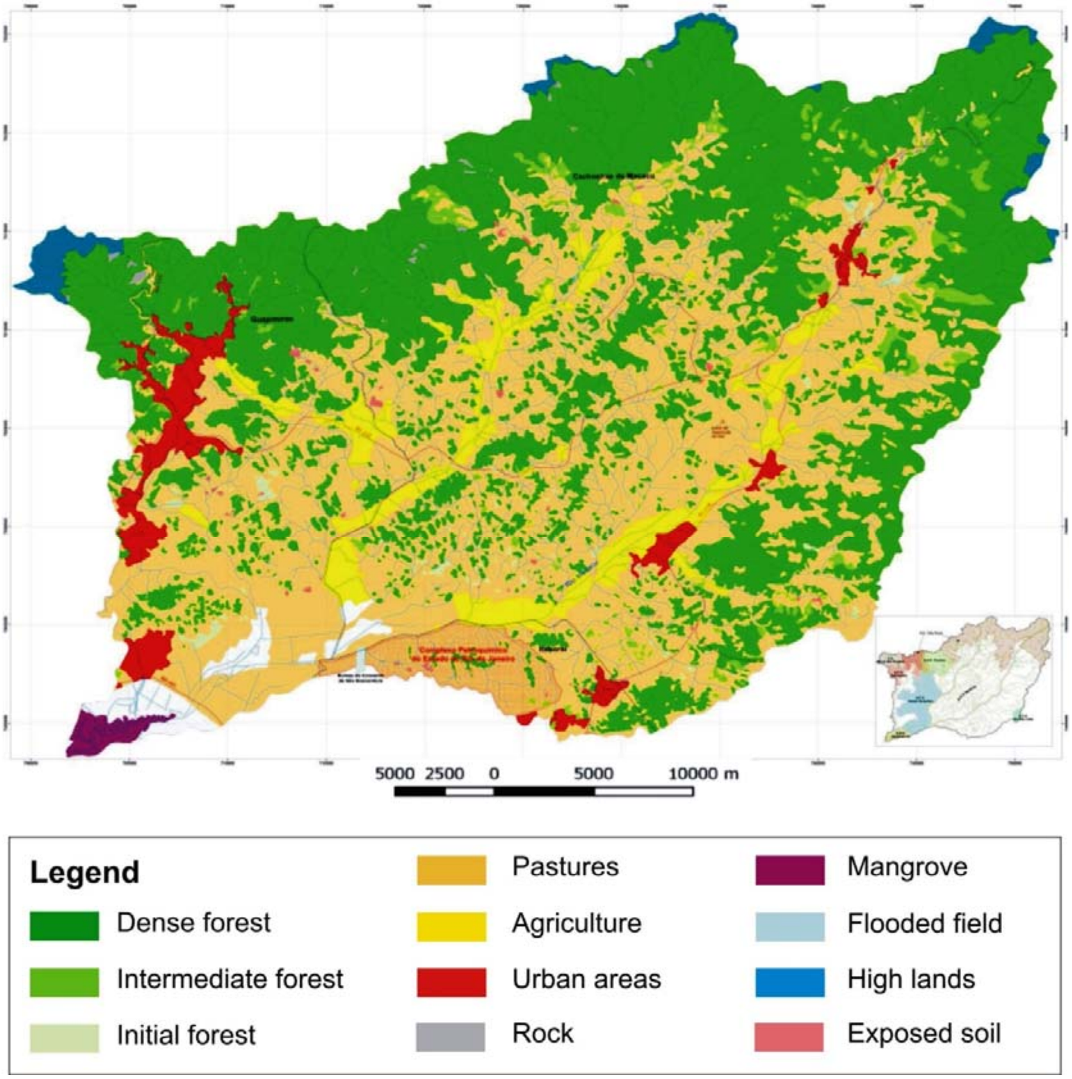

Figure 7: Land use and cover in the GMB (Fidalgo et al., 2008).

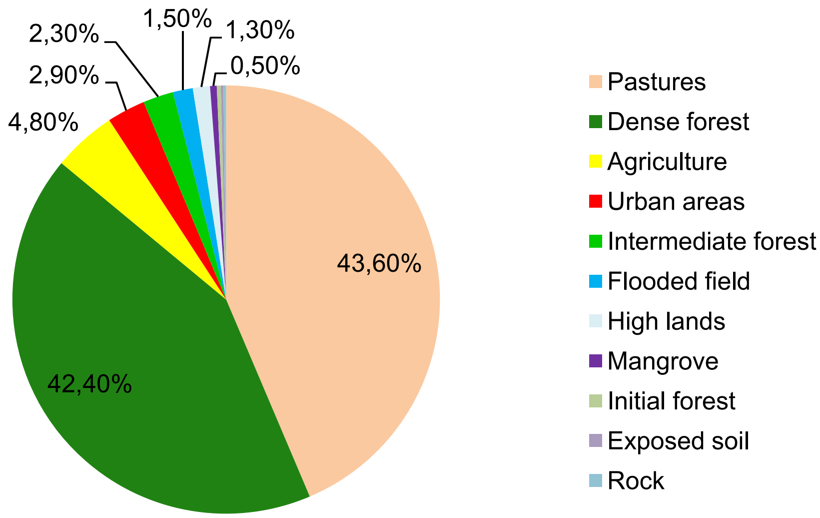

Figure 8: Percentage distribution of land use and cover in the GMB (Adapted from Fidalgo et al., 2008).

Regarding the river environment, unplanned urban growth and intensive soil use are seen as the greatest drivers of the destruction of riparian forests and riparian areas in general (Dantas et al., 2007). These two drivers derived in the following main impacts:

- **Modification of the natural course of rivers**: as described in §3.1.5, the rectification of water courses –associated to intensive soil use– is present in the GMB since several decades. Replacement of meanders and marshes with linear channels lacking riparian vegetation and water excess retention originated changes in water salinity, erosion and sediment dynamics alteration.
- **Chemical alteration of water:** directly through effluent spills from cities and small towns with no sewage systems (point sources). And indirectly, as a consequence of lixiviation of fertilizers from intensive agriculture (diffuse sources). Actually, these soil particles would be retained by riparian vegetation but in most cases, following the intensive agricultural model, it has been removed (E. Oliveira et al., 2009).
- **Increased streambank erosion:** Entry of cattle in the river channel is a major driver of riverbed and riverbank erosion (Blanco & Lal, 2008). This is a frequent situation in small streams of low order in other regions of the BAF (Silvano, et al., 2005), but no specific study was found for the GMB.

3.2 Environmental and water resources management in the GMB

3.2.1 Management of the river environment

In the State of Rio de Janeiro (SRJ), the water resources administration corresponds to the State Institute of Environment (INEA) which controls and supervises the compliance of regulations. These are, in turn, set by the *Conselho Estadual de Recursos Hídricos* (State Council of Water Resources, CERHI). For the purposes of water resources administration, the State territory was divided into hydrographic regions based on sub-basins distribution; the GMB is located in the Guanabara Bay basin hydrographic unit (INEA, 2011).

Water resources management plans are formulated for every hydrographic region by Basin Committees, which in this case is the Guanabara Bay Basin Committee. The current management plan was elaborated in 2005 (Governo do Estado do RJ, 2005).

3.2.2 Protection areas with focus on the river environment

Brazil's Forest Code, first enacted in 1934 and modified in 1965 and 2002, is the core legislation for the protection of the river environment. With national dimension, it establishes a protection status (Permanent Protection Area, APPs) for lands associated to water courses (SBPC & ABC, 2011) (Table 3).

Table 3: APPs established by the Forest Code (Adapted from Instituto Estadual do Ambiente (2010) and SBPC & ABC (2011).

Area	**Size (APPs)**	**Size (FMPs)**
Longitudinal stripe along water courses	Varies from 30 to 500 m depending on the rivers' width	Varies from 30 to 500 m depending on the rivers' width
Stripe along the shore of lakes, lagoons and water bodies	50 m	30 m
Around water springs	50 m	50 m
Mountain tops	Third superior part of mountains elevating more than 50 m from its surroundings	Not included
Steep hillsides	Hillsides steeper than 45°	Not included
"Restingas" (Coastal dunes) and plateaus	Not included	100 from the relief's line of change

SRJ implemented also Lateral Strips of Protection (*Faixa Marginal de Proteção*, FMP). The FMPs coexist with the APPs but while the first ones are focused on the protection of the water bodies, the APPs are focused on the vegetation (Instituto Estadual do Ambiente, 2010).

Specifically in the GMB area, SRJ's government has established an additional protection zone around the main rivers which compose the basin in 2002, the Environmental Protection Area of the Macacu River (*Área de Proteção Ambiental da Bacia do Rio Macacu*, APABRM). It is composed of a strip of land 150 meters wide along each side of the main two rivers in the basin (Macacu and Guapiaçu), complementing the already existing APP. The APABRM also extends over the tributary rivers, with a 50 meters wide stripe on each side of them. A controversy exists around APA's current limits and the overlapping with the already existing APP due to unclear definition in the law (G. Viana, personal communication, April 5th, 2012).

The objective of the APA is the environmental protection of Macacu River and its tributaries by means of a "positive influence" in land management and through limiting the extraction of sand and other damaging activities for water resources (Instituto BioAtlântica, 2009).

A management plan has been proposed for the APABRM after a study from *Instituto BioAtlântica* in 2009, but it yet has not been implemented by law.

3.2.3 Large scale protection areas

In Brazil, environmental protection areas are classified in two main groups (Instituto BioAtlântica, 2009): (1) the Conservation Units of Integral Protection, which include national parks, biologic reserves, natural monuments and Wildlife Shelters, where human residence is not allowed and only indirect uses are permitted (such as research and tourism); and (2) Conservation Units of Sustainable Use, such as Environmental Protection Areas (APAs) and natural reserves where residence and use of natural resources is allowed but under the guidelines of management plans.

SRJ has allocated more than 10% of its land to the protection of natural environments. Due to their steep relief of the GMB, most of the mountainous area remained unused during the population process and were the base for the establishment of a network of conservation units (Table 4 and Figure 9).

Table 4: Conservation units within the GMB (Instituto BioAtlântica, 2009). (1) Instituto Chico Mendes de Conservação da Biodiversidade (Chico Mendes Institute for Biodiversity Conservation). (2) Secretaria Municipal de Medio Ambiente do Guapirim (Municipal Secretary of Environment of Guapimirim)

Conservation unit	Category	Managing Institution	Area [ha]
APA Guapimirim	Sustainable Use	ICMBIO[1]	14.000
APA São João/Mico-Leão-Dourado	Sustainable Use	ICMBIO[1]	150.700
APA Petropolis	Sustainable Use	ICMBIO[1]	54.343
APA Bacia do Rio Macacu (APABRM)	Sustainable Use	INEA	82.436
APA Guapi-Macacu	Sustainable Use	SMMA Guapimirim[2]	n.a.
Parque Nacional Serra dos Órgãos	Integral Protection	ICMBIO[1]	10.600
Parque Estadual Três Picos	Integral Protection	INEA	46.350
Estação Ecológica do Paraíso	Integral Protection	INEA	4920

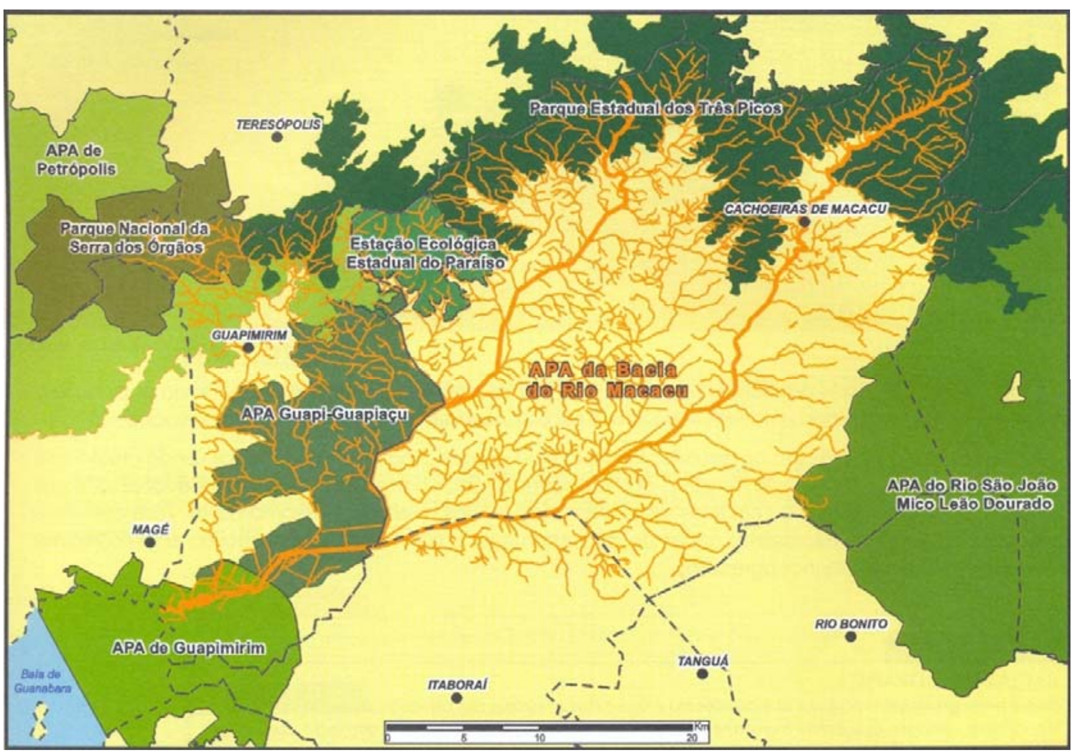

Figure 9: Environmental protection areas within or surrounding the GMB (Instituto BioAtlântica, 2009).

3.3 Previous research in the GMB

3.3.1 River physical environment

Among the environmental studies carried out during the elaboration process of the APABRM management plan, a physical-chemical and biological characterization of water resources investigation was reviewed for this study. The physical characterization included a river survey where a RAM was applied, based on the guidelines from Barbour et al. (1999).

Other reviewed study (Oliveira, et al., 2011) assessed ecological condition of rivers in the GMB according to an index based primarily on biological measurements (macroinvertebrates). Sampling sites had already been classified by means of a RAM focused on physical parameters, also following the guidelines from (Barbour et al., 1999).

3.3.2 Water quality

For the collection of water quality (WQ) data required for this study, existing research in the study area was reviewed. Two of the reviewed researches are part of government regular monitoring efforts: one from the *Autarquia Municipal de Água e Esgoto – Cachoeiras de Macacu* (Municipal Organism of Water and Sanitation of Cachoeiras de Macacu, AMAE) and other from INEA. The others are time specific studies performed by research institutions (Table 5).

Table 5: Reviewed WQ studies. (*) Data obtained from a personal communication from Penedo, S. (2012).

WQ data source	Temporal range	Nr. Of sampling sites within GMW	Frequency	Quantity of studied WQ parameters
Projeto Macacu (Universidade Federal Fluminense & Fundação Euclides da Cunha, 2010b)	2008-2009	7	Monthly	20
Guapiacu-Macau Multimetrix Index (R. B. S. Oliveira et al., 2011)	2007	33	Single study	8
DINARIO Project (Penedo et al., 2011)	2010-2012	11	Bi-monthly	12
AMAE-CM regular WQ monitoring data*	2008-2009	7	Daily	4
INEA single WQ monitoring data*	n.a.	25	Single study	7

Given the shared institutional framework and shared research resources, the data from DINARIO project was selected for use. Within this project, a study for the implementation of a WQ monitoring network in the GMB is under development since 2010 in collaboration with EMBRAPA (Penedo et al., 2011). Researchers have established a sampling network within GMB focusing on three specific sub-basins which are representative of the GMB in terms of land cover. They correspond to the streams Batatal, Caboclo and Manuel Alexandre. Land use in Batatal sub-basin is predominantly for agricultural purposes. The main crop grown there is banana (perennial), although other annual cultures such as maize, *inhame* (tubers from the genus *Dioscorea*), *aipim* (*Manihot esculenta*, a species of cassava or manioc), among others are also present. The Caboclo sub-basin is characterized by a mixed use of cattle production, agriculture and residential settlements. Together, Batatal and Caboclo sub-basins present almost 95% of the land uses which are the most frequent in the complete GMB (Penedo et al., 2011). The Manuel Alexandre sub-basin is located within a Nature Protection Area (REGUA) and its forest cover is under good state of conservation. For this reason, this area acts as a reference basin.

Authors from this research have provided WQ measurements for use in this study as well as water level measurements obtained at the downstream part of every sub-basin.

4 Methodology

An important requirement to achieve the objectives of this study was to recognize the current state of the RPE in the study area. Obtaining this information was paramount in order to a later analysis of the interaction between RPE and WQ. For the RPE's evaluation, the use of a rapid assessment method (RAM) was considered the best solution given the available resources of materials and time. Therefore the initial step was the revision of the available methods for river rapid assessment, and the identification of those with adequate potential of application in this study. Once a RAM was selected, it was adapted to the context of this research, and finally used to conduct a field survey.

Simultaneously, WQ data was obtained after a review of existing and ongoing research on this subject. The selection of the sampling sites location was defined partially in consideration of available WQ data.

Results of the river survey were the basis to obtain a RPE quality index, the SVAP Index, following the method's guidelines. SVAP Index values were then used to elaborate maps which show the spatial patterns of RPE quality. The package of information obtained as a result made up a database about RPE and WQ from which was possible to continue to the following step: the analysis of interactions between them. For this, statistical analysis was used in order to measure correlation.

Finally, from the basis of all gathered information (including field observations), a set of recommendations was elaborated in order to contribute to local water resources management.

A summary of the methodological steps in which this study was structured is showed in Fig. 10.

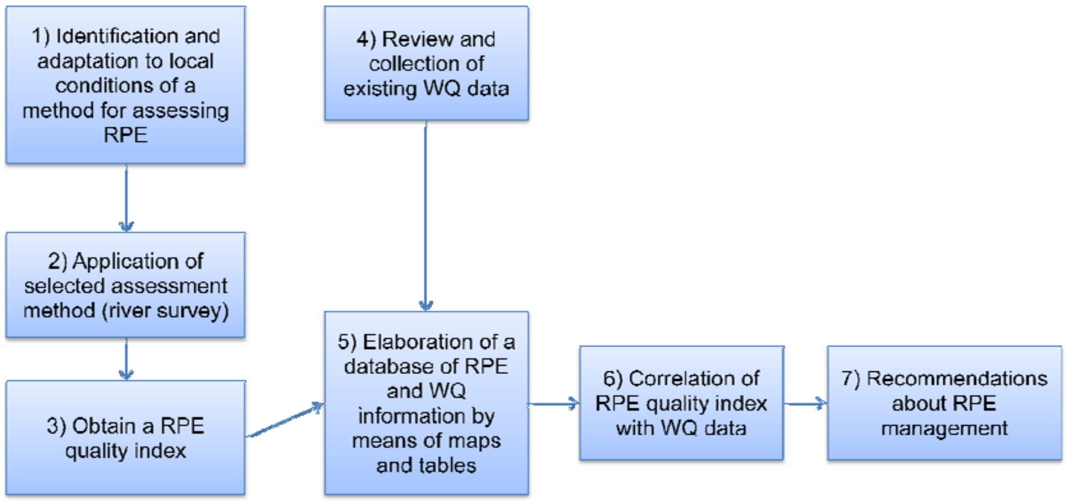

Figure 10: Summary of methodological steps used for this study.

4.1 River assessment method selection

Many Rapid Assessment Methods (RAMs) have been developed for a wide range of river ecosystem types and for different purposes of assessment. Table 1 (See §2.4) shows a group of RAMs considered for this study.

From the mentioned methods, the Stream Visual Assessment Protocol (SVAP) method by Bjorkland, Pringle, & Newton (2001) was selected according the following criteria:

- **Simplicity of use**: all the assessed parameters are measured by means of a visual scan of the area under evaluation. The complexity of the measurement tools required is low if any is required at all. Advanced or specific knowledge is not required for the measurements, what makes the protocol a practical tool for landowners and land users.
- **Reproducibility**: the tool allows an eventual reproduction or continuation of the assessment without difficulty.
- **Financially effective**: technical requirements as well as financial resources required for its use are low. This is an advantage for the continuity of its application.
- **Broad range of river ecosystem elements are evaluates**: without focusing in a specific element what leads to more specific measurements.

4.1.1 The Stream Visual Assessment Protocol

The Natural Resource Conservation Service (NRCS) is a non-regulatory agency of the U.S. Department of Agriculture established to enhance the environmental administration of natural resources within private lands.

Since the late 1990's, the NCRS initiated a closer involvement with landowners in order to provide a better assistance to them and thus improving resources management. One of the actions was focused in supporting stream assessment by means of a Stream Visual Assessment Protocol (SVAP). This assessment method was developed by a working group supervised by the NRCS and issued in 1998. The objective pursued by this working group was to provide riparian landholders with an easy and simple method to assess stream ecological conditions.

The SVAP is an assessment tool thought to be used at an introductory screening-level that can be used by people not familiar with stream assessment. The method is easy to learn and to understand, in order to allow landowners themselves to get involved in the assessment process and by this way increase their interest to improve their land's water resources management. Its simplicity constitutes on turning to visual inspection and avoiding the necessity of expensive and complex equipment during the investigation.

The protocol is composed of two main parts. First is the identification section, in which general information such as the location is recorded about the stream reach under evaluation. The second part includes the records of the assessment itself, composed by the scores of up to 15 parameters or elements. These parameters are evaluated with help from a set of narrative descriptions which describe a range of environmental "health" situations for every one of them. The parameters are Channel condition, Hydrologic alteration, Riparian zone, Bank stability, Water appearance, Nutrient enrichment, Barriers to fish movement, Instream fish cover, Pools, Insect/Invertebrate habitat, Canopy cover, Manure presence, Salinity, Riffle embeddedness and observed Macro-invertebrates (Bjorkland et al., 2001). The authors propose that only the parameters that are applicable to a specific reach would be assessed. Then, every parameter receives a score according to how they adjust to the cited descriptions, from 1 to 10, representing the highest score a closer match with the reference site conditions. The overall score for the reach under assessment is the mean average of the individual scores for every parameter.

4.1.2 Modifications of the SVAP method

Specific modifications were introduced to the SVAP method so as to adapt it to the objectives of this study. Adjustments of the protocol to the particular conditions of the studies for which it is used is proposed by Bjorkland et al. (2001) as one of the method's advantages. As final score is calculated by means of the simple mean of individual scores, the number of parameters included does not affect the overall result. In fact, some of the parameters may not be scored because its measurement is not applicable to the site's conditions, so the number of parameters composing the final scores is supposed to vary.

The parameter "Salinity" was excluded because this feature was already assessed in the WQ study (See §4.4). Also the parameter "Observed macroinvertebrates" was excluded, given that the focus of this study is on the river physical environment and the species recognition is based on biological knowledge of difficult availability in the study area.

The two excluded parameters were replaced with new ones thought to be more useful in this particular investigation: "Structural integrity of the riparian zone" and "Human waste", which have already been proven useful in another study by Lindgren & Röttorp (2009) where the SVAP method was used and also adapted. Finally, the parameter originally proposed as "Nutrient enrichment" in the SVAP method, was renamed to "Algal growth", in order to simplify its interpretation and use.

The total amount of parameters used for this study was consequently 15, as in the original version. The adapted version of the assessment protocol is shown in Annex 3.

4.2 <u>River survey</u>

4.2.1 Sampling location selection

Location of sampling sites was determined according to the following criteria:

A. Assessing the RPE in the same points where available WQ data was obtained (Group 1 of points, Table 6). Distribution of these points was that used by the WQ monitoring study (See §3.3.2).

B. Additional points in order to further evaluate the applicability of the assessment method (Group 2 of sites, Table 6).

Location of the group 2 of sampling sites was distributed as follows:

A. In the Batatal sub-basin in order to further intensify the sampling intensity. The objective in this sub-basin was to reach a sampling site every 500 m of river length, from its junction with Macacu river to its origin.

B. In the Guapiaçu river since it shows a wide range of environmental conditions: from the near-pristine valleys located upland to the rectified channels surrounded by intense agriculture in the lowlands.

In summary, RPE was assessed proposed for 27 sampling sites (Table 6). River survey was conducted between April and May 2012.

Table 6: Distribution of assessment sites according geographic location (sub-basins) and groups of data analysis.

River	Group 1 (WQ data available)	Group 2 (Self obtained turbidity measurements available)	Total
Batatal sub-basin	3	9	12
Caboclo sub-basin	3	0	3
Manuel Alexandre sub-basin	1	3	4
Macacu	2	0	2
Guapiacu	1	4	5
Guapi-Macacu	1	0	1
Total	11	16	**27**

4.2.2 Conduction of the assessment

The assessment procedure began in every site with the selection of a point along the river according to the accessibility and the distance from previously measured sites, as explained with the criteria detailed on §4.2.1. The geographic coordinates were then measured using a GPS device model GPS60 from the manufacturer Garmin, configured to measure with SAD69 datum.

The following step was to determine the river reach where the measurements were to be carried out. SVAP method proposes a reach of 12 times the width of the active channel (Fig. 11) , which matches other proposals from similar assessment methods (González del Tánago et al., 2006; Magdaleno et al., 2010; Munné et al., 2003; Naiman & Décamps, 1997) . After measuring the channel width using a measuring tape, the corresponding reach length was calculated and recorded. Then, it was delimited either upstream or downstream depending on the accessibility conditions. For distance measurements the GPS was used, or a hypsometer model Forestry 550 from *Nikon*, in the case the absence of visual obstacles allowed it (Fig. 12).

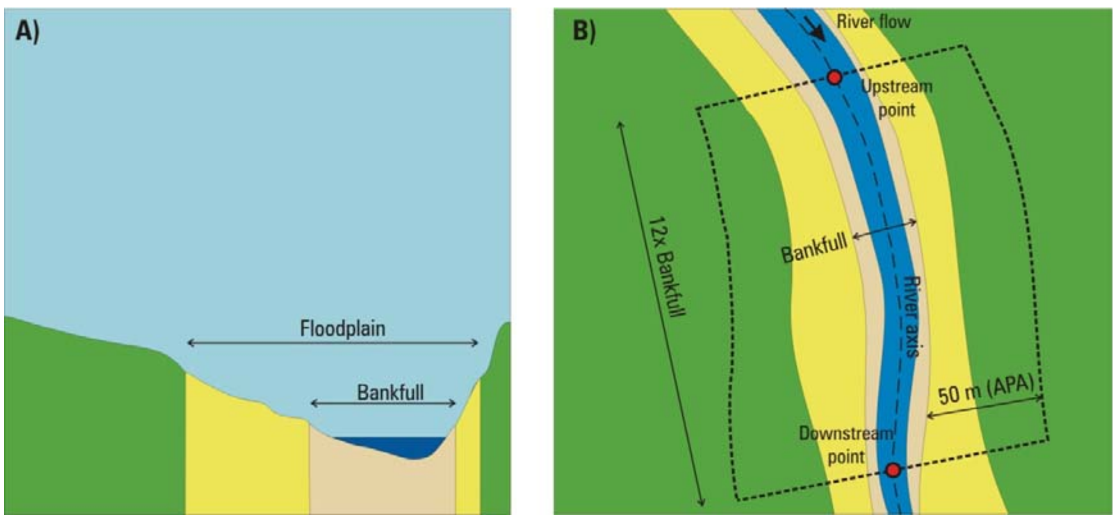

Figure 11: Schematic lateral (A) and top (B) view of a typical assessment point. Dotted line represents the limits of the sampling site.

Figure 12: Use of a hypsometer for measuring bankfull width.

Delineation of the assessment reach served also as an initial round to check if environmental conditions related to the parameters from the SVAP method remained stable or presented variations or special features (e.g. bridges, meanders, etc) along the reach. This round also was used to observe and record the land cover types present up to 50 m from the shoreline, along the reach.

Once delineation was complete, a second and more detailed scan of the reach was done, in order to evaluate the 15 parameters and score them. Scores were then recorded in the protocol. Some parameters required separate measurements on both sides of the river. In these cases identification of the river side was done always facing downstream. Finally, the turbidity was measured at the downstream point of the study reach.

4.2.3 Measurement of SVAP parameters

Next follows a description of the parameters used for the stream assessment, in the order they appear in the protocol and an explanation of the measurement procedure. The narrative descriptions used on the field for the grading are included in Annex 4.

Channel condition

This parameter measures the degree of modification of the river channel by human activities or works, such as channelization or straightening. Such modifications alter the natural interaction between the river and the banks during natural flow fluctuations.

For scoring this parameter evidences of channel alterations such as dikes or structures were searched in the stream banks and stream bottom along the reach.

Bank stability

If either the stream channel or the riparian vegetation were altered, the banks may show signs of impairment and erosion as they are a highly sensitive zone due to the effects of water flow.

This parameter was scored according the proportion of visible eroding surface within the reach and with an evaluation of the elevation profile of the banks.

Hydrologic alteration

As described in §2.1, temporal variations in the river’s flow, such as those generated during flooding, are one of the major drivers of modeling the river channel, determining its shape and thus many other factors such as habitat availability and diversity. Access of water flow to floodplain is also a driver of biological processes affecting the riparian vegetation and beyond.

The signals used for grading this parameter were the evidences of recent or past flooding along the banks that demonstrates its occurrence.

Size of riparian zone

As described (See §2.2), a healthy riparian zone is a key element for the proper functioning of the stream ecosystem.

This parameter was graded by measuring the width of the riparian zone with a tape (Fig. 13) on at least two points along the reach under evaluation, on every side of the stream. If the width presented strong variations within the reach under assessment, a third measurement was included in order to obtain a more representative value. The limit of the riparian zone was established by observing the zone of the bank where evidenced of hydrological processes were no longer observed.

The final score for the whole reach was determined by comparing the average width value to the width of the active channel (or bankfull), as proposed by the SVAP methodology (See details in Annex 4).

Figure 13: Typical aspect of the limit of the riparian zone (marked with a dotted line).

Riparian zone structural integrity

As mentioned before in this report (See §2.2), the riparian zone performs several functions that have an effect on water quality. For instance, it improves soil structure thus reducing erosion and filters lateral water flow. In consequence, the optimal state of a riparian zone in order to maximize its beneficial effects on water quality is that where the riparian zone is covered with dense vegetation, and does not show evidences of impairment such as trampling, vegetation removal or limitation, etc.

Grading of this parameter was done through an estimation of the percentage of the reach lacking vegetation cover or presenting a cover not similar to that which the site would present in an undisturbed condition. For the estimation of the percentage value, a graphic example of the distribution was used (Annex 5) to perform the measurement in at least two points over the reach, on both sides of the river. The final score for the reach was defined with the average of these sub-scores.

Water appearance

The objective of this parameter is to reflect the visible amount of suspended materials in the water. If the amount of suspended materials is high, water turbidity increases what decreases the amount of light passing through the water. This can reduce the photosynthesis rate of aquatic organisms which in turn has an effect in the production of oxygen by these organisms.

This parameter was graded measuring the depth at which a measuring element (e.g. a graded tape) was no longer visible, and observing the presence of other elements which would show evidence of reduced water transparency such as foam or algal film on the water surface (Fig. 14).

Figure 14: Examples from the rivers Guapiaçu (left) and Caboclo (right) of water with turbid and clear appearance respectively.

Algal growth

The amount and type of aquatic vegetation in the stream is considered an indicator of excessive concentration of nutrients in the water. Abundant algal growth might be a response of human effluent spill or fertilizer lixiviation from cultures and as a consequence reduce the availability of dissolved oxygen for the rest of the aquatic biota.

This parameter was graded by comparing observed algal organisms with respect to the range proposed by the SVAP methodology (Fig. 15).

Figure 15: Situations describing a range of abundant (left) and poor (right) algal growth (photos from Batatal and Guapiaçu rivers respectively).

Manure presence

When livestock has access to the riverbanks or channel lixiviates from their depositions may serve as nutrient for algal growth and introduce bacterial contamination to water posing a risk for human health. This parameter includes the presence or absence of human wastewater spills to the stream which have a similar effect.

This parameter was graded only when evidences of livestock entering the river environment or wastewater spills were detected.

Human waste

Presence of people in or nearby the rivers, either living in the area or visitors, may conduce to the occurrence of human wastes of different types in the river environment.

This parameter was graded according to the amount of wastes observed.

Barriers to fish movement

A healthy fish population is a strong indicator of good water quality. Human alterations such as dams, bridges, tunnels, water withdrawals can block the movement of fish (or other aquatic organisms) along the water course and as a consequence isolate populations among them or even complete river sections. This parameter was graded according to the variety and abundance of barriers present in the reach.

Instream fish cover

Alteration of the aquatic environment may reduce the availability of habitat for aquatic organisms such as fish. Presence and diversity of certain elements within the river channel may function as indicator of the availability and diversity of aquatic habitat, such as riffles, pools, woody debris and others. This parameter was graded according the variety and abundance of such elements.

Pools

Presence of pools along the stream is evident for a natural channel shape, and they are a key component of fish habitat (Pedersen, 2003). This parameter was graded after the abundance and morphological variety of pools. Variety of pools was estimated by measuring its depth with a graded tape and comparing results within the studied reach.

Insect/invertebrate habitat

Riverbed substrate, that is, the materials at the bottom of the channel, is a fundamental element for the establishment of insect and/or other invertebrate organisms. A disturbed river environment may present unstable conditions for substrate, for example in channelized rivers where water flow speed is increased and substrate washed away. Optimal conditions of substrate include a variety of elements within a relative small stream reach (5x the active channel width).

This parameter was graded after the variety and abundance of substrate elements such as gravel, fine woody debris, submerged logs, undercut banks, among others (Fig. 16).

Figure 16: Example of a site presenting a good diversity of habitat and/or insect habitat (photo from Caboclo river).

Canopy cover over the stream channel

Woody plants growing over the stream channel provide shade which keeps water at lower temperatures. Absence of this cover would increase the water temperature, and increase the capacity of water to hold dissolved oxygen and support organisms.

Scoring of this parameter was carried out using a graphic tool (Annex 5) to estimate the percentage of the stream channel surface shaded by trees.

Riffle embeddedness

Riffles are areas where water breaks over rocks or other debris causing surface agitation. Typical substrate in riffle areas is composed of thick rock particles such as cobble and gravel. The degree to which these particles are covered in thinner sediment, such as lime, determines the suitability of the stream as a habitat for fish spawning. An excessive load of fine sediment may be caused naturally during floods but also human activities such as channel modifications, active erosion of the riverbanks by cattle trampling, sediment load from upland areas under erosive stress, among others, can induce these effects.

This parameter was graded by estimating the percentage of the gravel and cobble surface covered with sediment. Also a graphic aid was used (Annex 4).

4.2.4 Complementary measurements

Additional measurements to those proposed in the SVAP were carried out. Firstly, the type of land cover in the area corresponding to the APARM, that is, 50 m upland from the river's shore was recorded. Only a visual inspection was used for this measurement, recording main characteristics whenever possible (e.g. crop type).

Secondly, the water turbidity was measured. The available WQ data includes turbidity measurements, but it is available for a reduced number of sites. Therefore, obtaining additional data would allow a more detailed analysis of the interaction RPE-WQ. The selection of the Turbidity parameter was based on the simplicity of the procedure to carry out measurements and the availability of equipment. The used instrument was a portable turbidimeter model 2100P ISO from the manufacturer *Hach*, with a reading range of 0-1000 FNU, a resolution of 0,01 FNU on the lowest range of operation and an accuracy of ± 2%.

Finally, altitude readings from the GPS device were registered and considered for the analysis of the SVAP Index.

4.3 Obtaining SVAP Index of RPE quality

Following the SVAP guidelines, individual scores were then grouped into a spreadsheet in order to calculate the overall scores for the individual sampling sites, which were then classified in four categories expressing its RPE quality or state, from "Excellent" to "Poor". A SVAP Index of 6 or less, correspond to "Poor", between 6,1 and 7,4 to "Fair", between 7,5 to 8,9 to "Good", and over 9 to "Excellent".

4.4 Review and collection of available WQ data

The study from which WQ data was taken identified 11 sampling sites where water quality has been monitored. These points are distributed within GMB as shown in Table 6, and were the base to determine the group 1 of sampling sites. Frequency of monitoring is bimonthly, thus data from 11 sampling campaigns is available from June 2010 to February 2012). From the studied WQ parameters, 13 were selected for the analysis of correlation with SVAP: temperature, electrical conductivity, dissolved oxygen, pH, turbidity, nitrate, nitrite, ammonia, ortho-phosphate, total nitrogen, total phosphorous, total dissolved solids and total suspended solids.

For the analysis of correlation, a single value from each of these parameters was required. This single value should offer a stable representation of the river's water condition, because SVAP parameters represent river elements whose variations in time occur at a slower pace than yearly hydrologic cycles. For instance, channel condition might present sudden abrupt variations after a human modification, or an extreme flood event. But it is considered that the return period for events like these is much larger than a year.

In consequence, the median values were calculated for each WQ parameter from the data obtained during the 11 sampling campaigns, which cover approximately 2,5 hydrologic cycles (or years). The median and not mean value was used to avoid the effect of extreme measurements.

As mentioned, also from the research of Penedo et al. (2011) water level measurements were provided. These measurements were obtained at the lower sampling points of the three sub-basins. Data was graphed and used to visually detect flow cycles and flood recurrence, and in this way, sustain field observations for the parameter Hydrologic alteration. Though the nature of the assessment method selected for this study is mainly visual inspection, this comparison allowed a more precise definition of scores for the aforementioned parameter.

4.5 Shaping of a database of RPE quality and WQ data

4.5.1 Mapping of results

With the objective of visualizing the spatial patterns of the obtained SVAP Index values, a series of maps were created in collaboration with the team of geographic analysis at

EMBRAPA laboratories. The software ArcGIS 10 from ESRI was used, considering the projection SAD69, UTM zone 23.

Initially, a map delineating the three sub-basins was created, from the digital elevation model (DEM) of the GMB processed by Fidalgo, Carvalho Júnior, and Godoy (2009), using the SWAT tool for ArcView 3.2 from ESRI.

As next step, the assessment points were imported to a shapefile in ArcGIS 10 and integrated with the sub-basin map. Also with ArcGIS, a zone of 50 m wide parallel to the river’s axis (buffer) was created, in order to reflect the area under protection by the APA Macacu (see §3.2.1), using the Spatial Analyst tool from the mentioned software. This buffer zone was later divided into sections, corresponding each to a separate sampling site. For this, half the distance between a downstream point and the next upstream point was used to successively divide the river sections. The upper section of every sub-basin was defined from the highest point and upward. Though this may pose a risk of excessive generalization, it was decided since the upper zones of the three sub- basins present a relatively homogeneous land cover type, as shown in (Fidalgo et al., 2008).

Finally, the SVAP scores data was associated to the corresponding sections, which were colored according to their environmental quality group.

4.5.2 Altitudinal patterns

The behavior of the SVAP Index values in relation to the relief profile was also studied. For this purpose, all the SVAP Index values were analyzed against altitude readings for each sampling site obtained from the GPS. Data was also analyzed separately for the Batatal sub-basin.

4.6 Correlation of RPE quality index with WQ data

Two separate analyses were carried out. First, the correlation between the turbitidy measurements obtained during the river survey and the SVAP Index values was measured. Next, the correlation between WQ data and (1) SVAP Index values and (2) SVAP parameters individually was determined.

Correlations were measured using Spearman rank correlation, a non parametric analysis option suitable in cases when the data did not meet the assumptions about normality, homoscedasticity and linearity (McDonald, 2009). Calculations were made using VassarStats Statistical Computations tools (Lowry, 2012).

4.6.1 Turbidity

The analysis was carried out using all measurements (from all sites) but also a separate analysis was made considering separately the measurements from the Batatal sub-basin.

4.6.2 Water quality data

WQ data was used to measure correlation against (1) SVAP Index values individually, in order to study the general interaction between RPE and WQ, and (2) separate SVAP parameters, with the purpose of observing specific interactions with the components of the RPE studied by the SVAP method.

5 Results and discussion

5.1 River survey

Application of SVAP was carried out in the 27 proposed sampling sites. However, measurement of some of the parameters proposed by SVAP presented some particular difficulties. They were most frequently related to the structural changes a river shows along its course: upstream rivers are more confined, their bankfull zone is smaller (and therefore so is its riparian zone) and habitat availability in the river channel is more diverse. In lower areas, bankfull and floodplain area are larger and their morphological complexity is greater, and aquatic habitats are less diverse. This situation posed in some cases difficulties for the interpretation of the scoring scale proposed by SVAP to define the quality status for each parameter.

Another difficulty that might have biased measurements is that some of the parameters require certain practice to obtain more accurate results, as is the case with percentage estimation for canopy cover and others. For this study, a single field survey was carried out, so this type of bias needs to be considered.

Next follow more detailed observations about the application of the SVAP for every parameter, including examples of previously mentioned difficulties. After that, resulting SVAP Index values are presented and discussed.

Scores for the individual SVAP parameters, the primary results of the survey, are presented in the Annex 6. The table A7.1 in Annex 7, shows the results from complementary measurements, and includes also the names of the sampling sites and the corresponding river where they are located.

5.1.1 Measurement of SVAP parameters

The **Channel Condition** parameter was found near natural conditions in the three sub-basins, where the most frequent disturbances affecting this parameter were bridge abutments and small dams (Fig. 17) built with recreational purposes using mostly rocks and almost no concrete or consolidated structures. Considering the localized effect of these constructions, scores for this parameter were relatively high, between 7 and 10.

Figure 17: Examples of the most frequent disturbances to stream channel found in upstream reaches: small dams made of rocks and bridge abutments. These two are from Caboclo river at the "07_CABA" point.

The situation was different in lowlands, where the assessment reached channelized sectors of rivers in the plain areas of the GMB. Here, rivers Macacu and Guapiaçu flow through lineal artificial channels, generally with two also embankments on every side of the river (Fig. 18). As result, riverbanks are steep and channel presents a homogeneous water depth and thus flow speed. In consequence, habitat variability is reduced along the channel. Scores were consequently much lower at these points (from 1 to 3).

Figure 18: Typical aspect of lowland sections of the rivers where channelization has been executed. Notice the steep banks. In this case Guapiaçu river at the assessment point "06_GAC".

The **Bank Stability** parameter obtained lower scores in reaches where human alterations such as channelization and constructions over the banks were present. These disturbances generate losses of soil structure, thus increasing the intensity of erosive processes associated to the river flow abrasion. This was more frequently observed in the lower parts of the basin. Examples of disturbances are cattle trampling which increases soil compaction and prevents growth of vegetation which would otherwise increase soil stability. Furthermore, embankments after channelization present an excessive gradient and lack vegetation cover, triggering soil collapse (Fig. 19).

Particular cases were points 11_BATF and 10_BATH in the Batatal sub-basin, which showed lower scores (between 4 and 5). These sites are located in a valley where Batatal river flows through meanders, what causes erosion on the cutting-side banks.

Figure 19: Examples of human-induced bank instability, both in Batatal river: cattle trampling (left, marked with an arrow) and channel modification (right).

Evidences of **Hydrologic Alteration** were in general more easily found in the upstream areas. Here human activity is less intensive and therefore they persist longer. Examples of evidences are vegetal debris attached to riparian vegetation or fine woody debris piles accumulated after flooding, as shown in the Fig. 20.

Absence of large-scale dams prevents regulation of flow fluctuations, thus scores resulted high in most sites. Worth of mention is an existing dam in the São Joaquim River, a tributary of the Macacu river, upstream from Cachoeiras de Macacu city. It is used for water collection for the city, and was the only observed dam in operation in the basin. However, it affects a small tributary and more detailed study would be required to determine wether it affects Macacu river flow or not.

Reaches located in the downstream areas where rivers are channelized, were scored low because the artificial channel morphology (steep banks) prevents the effects of yearly floodings.

Figure 20: Example evidences of hydrologic alteration at Batatal and Manuel Alexandre rivers. Arrows show the accumulation of vegetal debris.

Scores for this parameter were later contrasted with water level measurements provided by Penedo et al., (2011). The water level graphs (Annex 2) show for the three sub-basins, occurrence of periodical level rise events. The events in which water level rises at least 50% from the normal level have a frequency that is greater than that proposed by Bjorkland et al. (2001) for the best condition of hydrologic alteration (See Annex 4). Therefore, the high scores measured on the field were proved to be adequate. This situation refers only to the points located in the three sub-basins.

Size of Riparian Zones showed a tendency of decrease along the river's descent, following the SVAP Index tendency (explained in §5.1.3). Frequent observations in the lowlands were croplands extending to almost the riverbanks, and the removal of woody vegetation.

This is one of the parameters that presented interpretation difficulties. SVAP proposes channel width as a measuring magnitude to qualify extension of riparian zones. But experience on the field showed that rivers located upstream presented naturally a riparian zone which was narrower than the river channel width. This contradiction may impose a bias to under qualify riparian zones in upstream areas.

The case with the **Riparian Zone Structural Integrity** parameter shows no clear tendency. In general, closeness to roads or villages –human activities–, meant degradation of the structure of riparian zones independently to the position in the basin and thus lower scores.

The scores for **Water Appearance** parameter also decreased from up to downstream areas. This parameter may have been influenced by the occurrence of storms during the assessment period. The SVAP contemplates this situation by including the necessity of recording weather conditions of the previous days to assessment time.

Scoring of parameter **Algal Growth** presented no particular difficulties. In reaches located in upstream areas, algae were clearly absent from the riverbed, what functioned as a reference condition. Situation changed near towns or villages where rocks presented a layer of algae which changed its color and texture.

Manure Presence was sporadic, mostly near agricultural and cattle grazing areas. Where this parameter reached the lowest scores (between 3 and 1) it was due to the presence of direct human wastewater discharges from buildings near the rivers. Evidences of manure were found in 11 of the 27 sites; in consequence only 11 scores were obtained. Sites with absence of manure were not scored, as indicates the SVAP.

Barriers for fish movement were not frequently observed. However, small dams made with cobble, of low height and with apparent recreational purposes were registered and lead to a lower than 10 score in some sites.

An exception was found in the Guapi-Macacu river, at the beginning of the Imunana channel (point “26_CEDAE”). Here, a concrete dam for water deviation purposes was the blocking element with the largest and strongest effect on fish path that was observed during the survey (Fig. 21).

Figure 21: Water diversion structure at the beginning of Imunana channel.

Instream Fish Cover scores resulted heterogeneous with values from 3 to 10 and no apparent distribution patterns. Extremes of the river courses, both up and downstream, showed the lower scores. In the first case, higher flow speed due to greater gradient may reduce the stability of vegetal debris thus reducing complexity of fish cover. In the second, habitat degradation is a consequence of human interventions.

The parameter to evaluate the presence of **Pools** obtained greater scores in the higher zones of the GMB. Lowland areas under the influence of severe channelization presented lower variability in water depth. Therefore presence of pools was scarce. However, frequency of pools decreases naturally at lower gradient rivers where waters run more slowly. This situation was not contemplated by the SVAP and posed a difficulty when scoring downstream sites.

Insect/Invertebrate Habitat scores were generally high, fluctuating from 7 to 10. Mentioned conditions of faster water flow where gradient is high may possibly prevent the accumulation of vegetal debris in these areas, thus reducing habitat availability.

The parameter **Canopy Cover** was not measured in 18 out of 27 sites, due to the river's active channel width exceeding the limit proposed by SVAP method of 15 m. For sites where measurement did apply, reaches located upstream where vegetation structure maintained continuity with that beyond the riparian zone obtained higher scores.

Finally, **Riffle Embeddedness** scores resulted lower at reaches located in plain areas. This is the third parameter for which presented interpretation difficulties, since riffles are naturally more frequent up than downstream. This may lead to a biased scoring or at least present distortions for the comparison of up and downstream scores.

5.1.2 Complementary measurements

Results of turbidity and altitude measurements are shown in Annex 7. As was the case with water appearance parameter (described above), turbidity measurements resulted lower at the upstream sites and increased gradually when moving downstream.

5.1.3 SVAP Index of RPE quality

SVAP Index values are presented in Annex 6, in separate tables corresponding each one to an individual sub-basin. A fourth table shows the scores for the rest of the sites.

These tables also include the scores for individual parameters, and the total number of scores obtained at each site. As described (See §4.2.3), even though all parameters were evaluated, depending on applicability conditions some of them have not been scored.

As a first and general observation, SVAP scores resulted higher in the upstream parts of the evaluated sub-basins and in the GMB in general. The more downstream the point is located, the lower SVAP score, a result which correlates with land use patterns described for the area.

In terms of individual sub-basins, sampling sites in Manuel Alexandre sub-basin obtained the higher scores, with an average of 8,82 points. From the four sites assessed in this area, three were classified under the category “excellent” (more than 9 points).

Sub-basins of Batatal and Caboclo presented mean values of 7,88 and 7,86 respectively.

The correlation between the scores of SVAP Index and individual parameters was analyzed using the Spearman correlation coefficient (Table 7). This analysis shows which individual parameters adjust the most with the general tendency of the SVAP Index.

Table 7: Spearman correlation coefficients for the relation between SVAP Index and individual SVAP parameters. n.s.: not significant correlation (P>0,05).

Parameter	r_s	**Parameter**	r_s
Channel Condition	n.s.	Human Waste	n.s.
Bank Stability	0,73	Barriers to Fish Mov.	n.s.
Hydrologic Alteration	0,73	Instream Fish Cover	n.s.
Size of Rip.Zone	n.s.	Pools	0,94
Structural Integrity of Rip.Z.	n.s.	Insect Habitat	n.s.
Water Appearance	0,73	Canopy Cover	n.s.
Algal Growth	0,91	Riffle Embeddedness	0,76
Manure Presence	n.s.		

5.2 Review of WQ data

The obtained WQ values representative for the 11 sampling sites from the group 1 are shown in Annex 1.

5.3 Database of RPE quality and WQ data

5.3.1 Spatial patterns

Fig. 22 shows all sampling locations and the SVAP Index obtained at each one of them. This map allows a clear overview at GMB scale of the general tendency of decreasing SVAP Index values from up to downstream sampling sites.

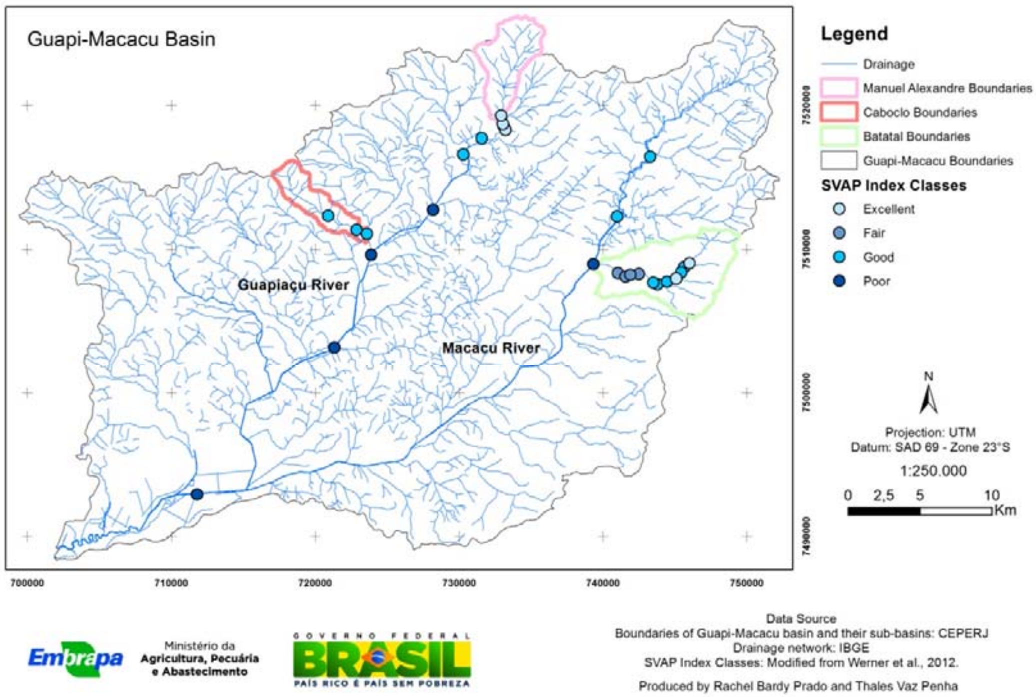

Figure 22: Map showing the location of all sampling sites, as well as their SVAP Index class.

Figures 23, 24 and 25 show the spatial distribution pattern of SVAP scores for the Manuel Alexandre, Batatal and Caboclo sub-basins by sampled reach. These maps also include land use cover type, in order to better understand its effect on river environment.

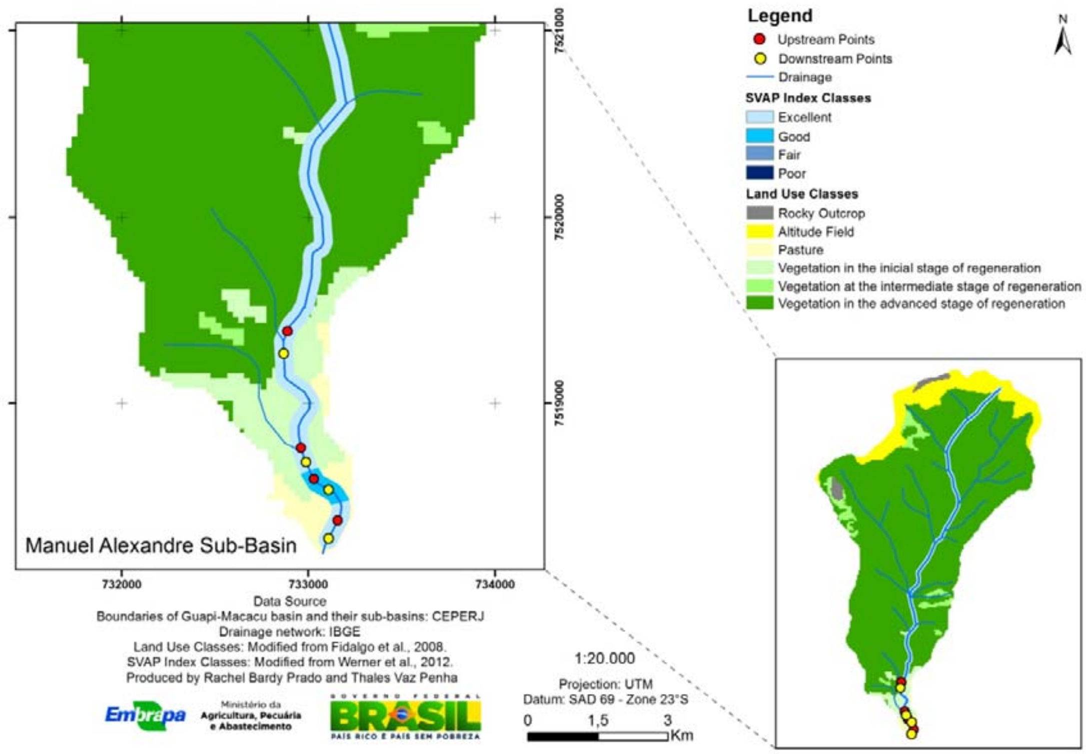

Figure 23: Map of SVAP Index scores for sampled reaches within Manuel Alexandre river sub-basin.

In the area of Manuel Alexandre sub-basin, RPE quality was the highest in average, in concordance with land use there. Not only forests are the predominant land cover but they are also under conservation status. The good condition of RPE there functions well as a comparison basis for other areas of similar morphological characteristics.

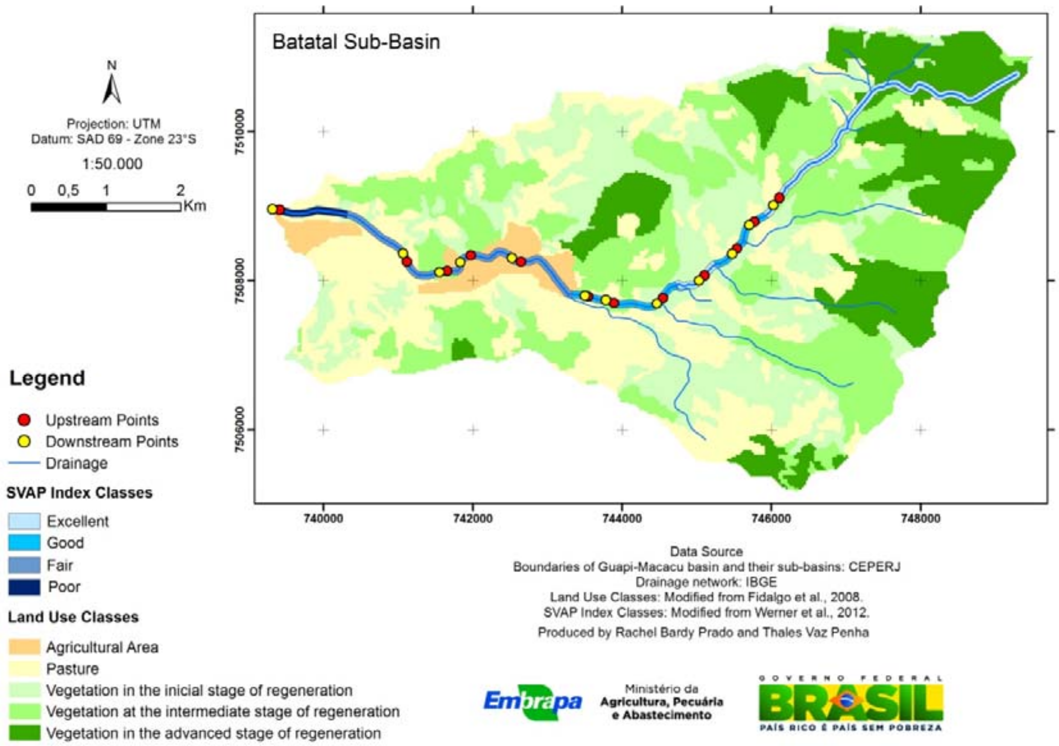

Figure 24: Map of SVAP Index scores for sampled reaches within Batatal river sub-basin.

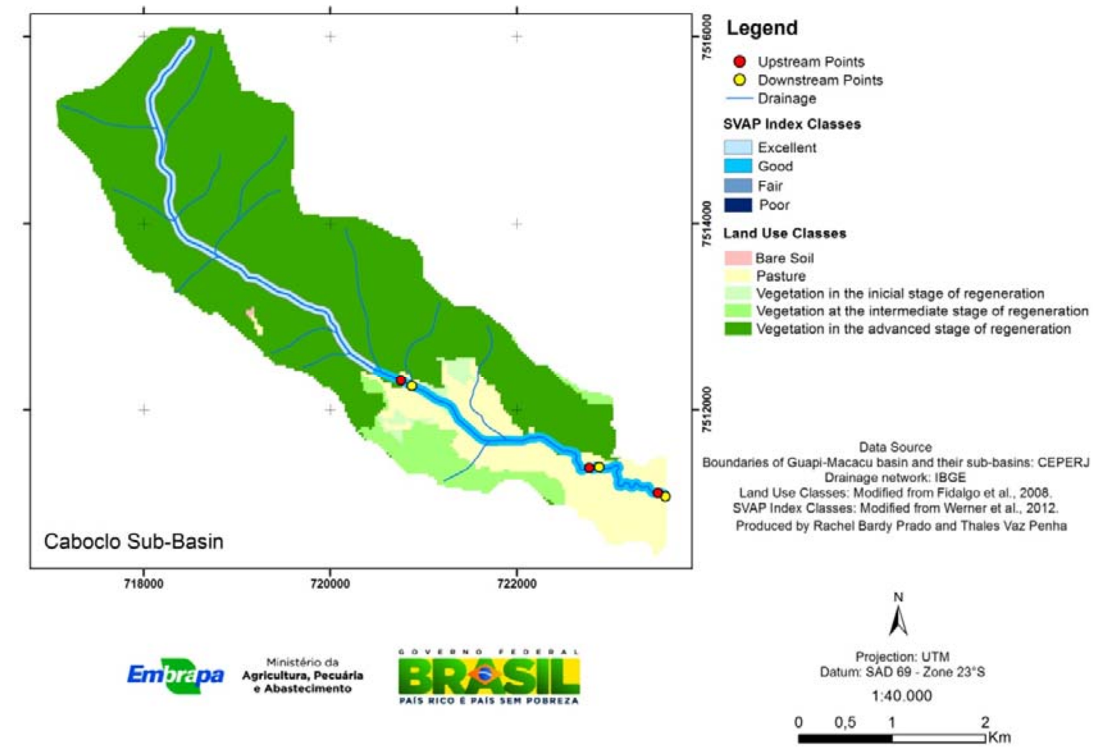

Figure 25: Map of SVAP Index scores for sampled reaches within Caboclo river sub-basin.

In the area of Caboclo and Batatal, the effect of human activities on SVAP Index becomes clear. A greater heterogeneity of land uses correlates with the more variable SVAP Index values. Particularly in Batatal sub-basin, the heterogeneous mosaic of land uses together with a rugged relief profile seems to be the cause of local variations of the SVAP Index, sometimes away from the general tendency of decrease from up to downstream (See also Fig. 27). Agriculture would seem to have a negative effect on the SVAP Index, since all reaches near this activity have a lower score.

5.3.2 Altitudinal patterns

As it was described in chapter §3.1.7, the more intensive land use types in the GMB are located in the lowland valleys, where gradient decreases and the relief is flatter. A scatter plot of SVAP Index scores vs. altitude (Fig. 26) shows that all sites above 100 m obtained a SVAP Index score of almost 8 or more, what confirms the described tendency.

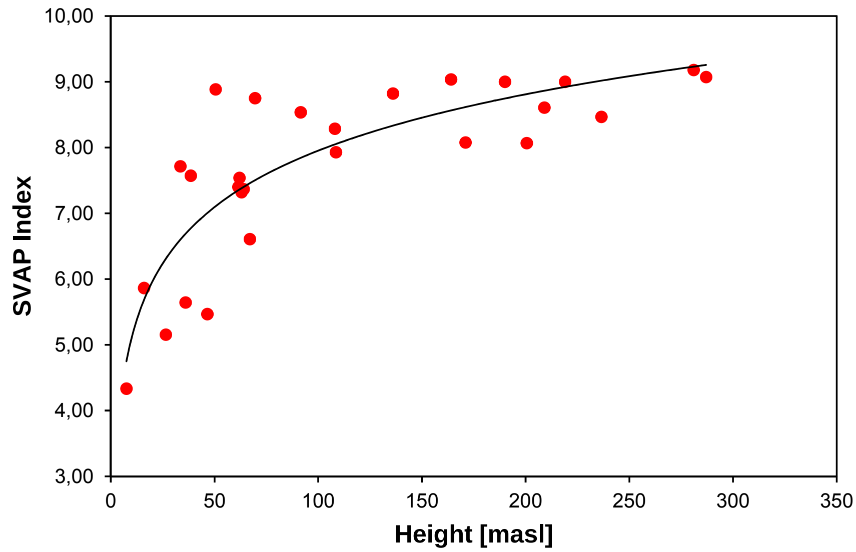

Figure 26: Relation between SVAP Index values for all sites with altitude.

This tendency is visible with increased when focusing on the Batatal sub-basin data (Fig. 27) where a larger amount of measurements is available. In this case, SVAP Index values returned to higher values in some points of the river's course. This is probably as a consequence of the heterogeneity of land uses in this area, where the intensity of land use does not increases at a steady rate.

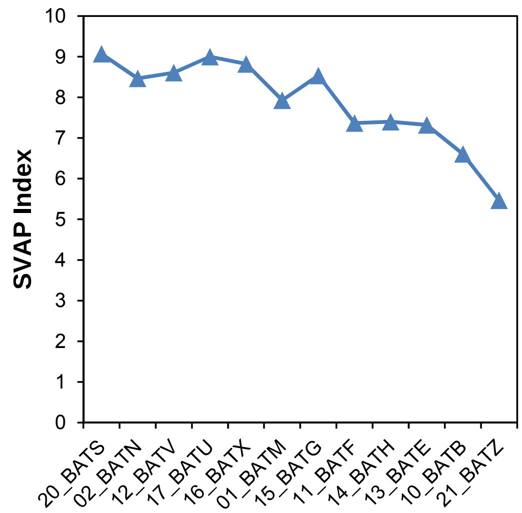

Figure 27: SVAP Index values from the sampling sites along the Batatal river, in order from up to downstream.

These results confirm also that the more intensive human activities which take place in the lower areas have an impact on the river environment.

5.4 Correlation of RPE quality index with WQ data

5.4.1 Turbidity

The SVAP Index resulted to be correlated negatively with turbidity, that is, SVAP Index decreases with higher turbidity values. The Spearman correlation coefficient (r_s or ρ) was of -0,824 (d.f.: 25, P=1,30E-7).

The turbidity measurement from the “06_GAC” assessment site shows an unusually high value (See Table A7.1, Annex 7). For this reason, a second correlation analysis was conducted excluding this data pair. This exclusion is funded on a Dixon’s Q test for outlier detection (Verma & Quiroz-Ruiz, 2006). In this case, r_s was of -0,802 (d.f.: 24, P=5,49E-7).

Scatter plots of each data set are shown in Fig. 28.

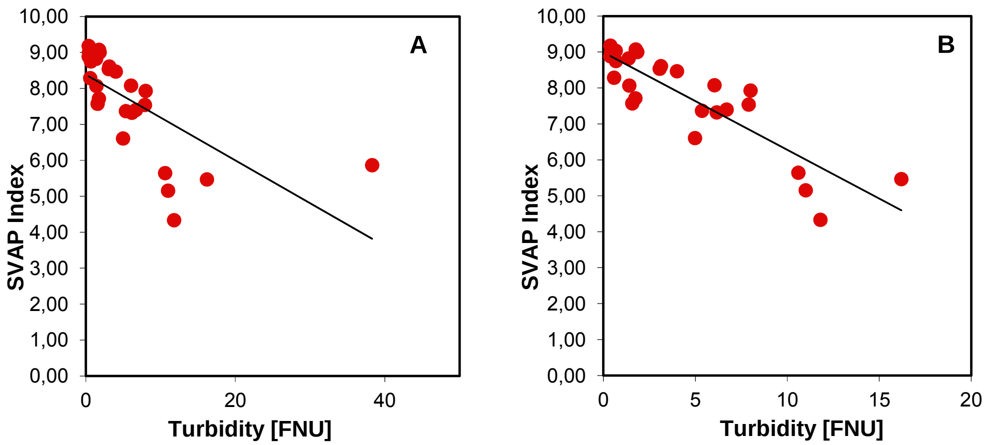

Figure 28: Relation between SVAP Index scores and turbidity measurements within the GMB. Graph A includes all data (r_s=-0,824; d.f.=25; P=1,30E-7). In graph B, an outlying data was removed (r_s=-0,810; d.f.=24; P=5,49E-7).

Focusing the analysis on the Batatal sub-basin, also a strong negative correlation is observed (r_s=-0,839) (Fig. 29). The number of measurements in the Manuel Alexandre and Caboclo sub-basins is smaller and a separate analysis of correlation would not reach an acceptable level of confidence.

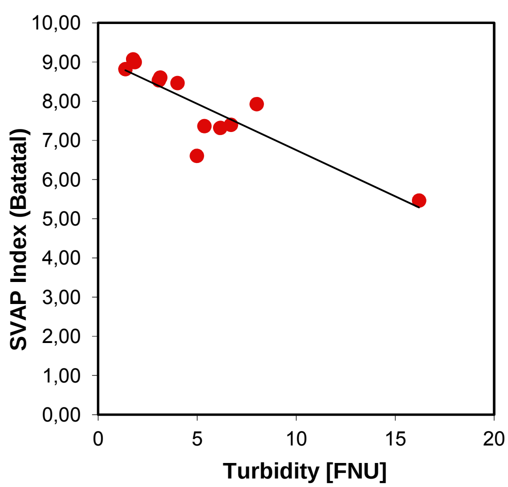

Figure 29: Relation between SVAP Index scores and turbidity measurements within the Batatal sub-basin (r_s=-0,839; d.f.=10; P= 6,4E-4).

As stated in the research review (see §2.2), a healthy river ecosystem and especially a well-functioning riparian zone retain soil particles by increasing its deposition and reducing erosion. Therefore, a negative relation between riparian zone quality and turbidity may be expected.

5.4.2 WQ data

SVAP Index showed correlation with 7 from the 13 WQ parameters (Table 8).

Correlation resulted higher with total suspended solids (TSS) (r_s=-0,89) and electrical conductivity (EC) (r_s=-0,81), for which the negative coefficient shows that a decrease in SVAP Index will result in an increased TSS and turbidity. SVAP Index also correlated negatively with turbidity, temperature (T), total dissolved solids (TDS), ammonia (NH_3^+) and total phosphorus (TP) respectively.

The analysis of correlation between the individual SVAP parameters and the water quality variables showed presence of correlation in 34 of the 195 comparisons, that is, over 17% (Table 8). A selection of scatter plot graphics showing particular relations is included in Annex 8.

For the Manure Presence parameter no significant results were obtained due to the lack of data, given that this parameter is scored only when evidence of livestock is observed. This situation poses a severe limitation for the use of the SVAP method, in the case when obtained data is to be analyzed by means of statistical tools.

Table 8: Spearman correlation coefficients (r_s) between SVAP Index, the parameters composing it and water quality variables. n.s.: not significant correlation (P>0,05).

Parameter	T	EC	DO	pH	Turb idity	NO3	NO2	NH3	OP	TN	TP	TDS	TSS
SVAP Index	-0,76	-0,81	n.s.	n.s.	-0,78	n.s.	n.s.	-0,66	n.s.	n.s.	-0,66	-0,70	-0,89
Channel Condition	n.s.	-0,71	n.s.	n.s.	-0,76	n.s.	n.s.	-0,72	n.s.	n.s.	-0,82	n.s.	n.s.
Bank Stability	-0,77	n.s.	n.s.	n.s.	-0,69	n.s.	n.s.	-0,61	n.s.	n.s.	n.s.	n.s.	-0,60
Hydrologic Alteration	n.s.	-0,77	n.s.	n.s.	-0,78	n.s.	n.s.	n.s.	n.s.	-0,61	-0,66	n.s.	-0,76
Size of Rip.Zone	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Structural Integrity of Rip.Z.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Water Appearance	n.s.	-0,77	n.s.	n.s.	-0,77	n.s.	n.s.	n.s.	n.s.	-0,62	-0,67	n.s.	-0,76
Algal Growth	-0,81	-0,62	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-0,64
Manure Presence	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Human Waste	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Barriers to Fish Mov.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Instream Fish Cover	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-0,68	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Pools	-0,90	-0,74	n.s.	n.s.	-0,74	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-0,63	-0,79
Insect Habitat	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Canopy Cover	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-0,80
Riffle Embeddedness	-0,81	-0,67	n.s.	n.s.	-0,81	n.s.	n.s.	-0,67	n.s.	n.s.	-0,78	n.s.	-0,83

Some of the correlations RPE quality-WQ parameters are consistent with reviewed research about river ecosystem characteristics and processes (Chapter 2). That is the case for instance with the interaction between the parameter presence of pools and temperature, algal growth vs. temperature, water appearance vs. total suspended solids among others.

However, some other interactions also strongly supported by reviewed research, as the effect of canopy cover over water temperature, or the effect of riparian zones on nutrient and sediment content remained unrelated in this particular analysis.

Two factors might have limited the effectiveness of using statistical comparison tools in this analysis: (1) the low quantity of sampling sites for which WQ data is available (11 sites) and (2) this analysis compares values for specific points along the river, ignoring the effect of RPE conditions along previous sections of the river (the “upstream effect, as described in §2.1). Interactions among the river’s biotic and abiotic elements are highly complex, and to prove an analysis method right, several attempts must be done to adjust it to the local conditions.

6 Conclusions and recommendations

6.1 Conclusions

6.1.1 RPE status

The physical habitat of rivers in the GMB is increasingly degraded from up to downstream, together with land use intensity and river ecosystem alteration. From the studied parameters composing the RPE, channel condition, size of riparian zone and water appearance are those which showed a higher degree of deterioration in the up-downstream direction, probably due to the effect of channelization of rivers in the lowlands. Other parameters showed different patterns, e.g. structure of riparian zone and human waste had lower scores in areas near to roads or residences, independently their position on the basin.

Results of the survey in the sub-basins allowed a more detailed observation of how human activities, as shown in a land use map, affect the conditions of rivers.

It can be said in general, that the survey's results are consistent with the environmental situation described by other studies carried in the GMB.

6.1.2 Relation RPE-WQ

SVAP Index values were found to correlate to some WQ variables, giving an insight of the relation between these two elements of the river ecosystem. Correlation resulted especially strong with turbidity data, for which the number of obtained measurements was greater.

However, the lack of correlations with some other key parameters –e.g. Riparian zone– evidences that interactions among the factors which at last determine water chemistry are highly complex and cannot be explained with simple linear relations. Future research is needed in order to study how the "space shift" (separation in space and time) between a disturbance and its effect on water chemistry operates in the particular conditions of the GMB.

Given this complexity, the use of SVAP as a method to predict WQ conditions in a watershed can therefore not be recommended. However, the method resulted useful in order to characterize in detail some elements of the river environment that would be difficult to assess with other methods such as satellite image analysis. Those elements are for instance small scale channel disturbances, presence of garbage and cattle, and habitat quality.

6.1.3 Application of SVAP in the GMB

SVAP showed numerous advantages: it is easy to use, fast to apply, and required financial resources are low. It may also be useful for educational purposes: in the case it is applied by local people it may well function as a way for them to learn about the environment where they live and the effect their activities have on it, and also about the effects of the physical characteristics of riparian zones on water chemistry.

Given the diverse conditions of the GMB, in terms of relief morphology and land use intensity, it was proven necessary a mechanism of adaptation of the protocol to these variable conditions. Some of the reviewed RAMs already consider this possibility and include a classification of, for example, the valley type before starting the assessment. Classification can also be focused on water bodies, based on physical parameters such as gradient. This would allow adjusting the assessment to the different types of rivers, thus avoiding misinterpretation of some parameters whose variability occurs naturally along the river course.

6.2 Recommendations

Mentioned advantages make of RAMs in general and SVAP in particular evaluation tools that can be recommended for their incorporation to regular water resources monitoring plans.

For the case of the GMB, it is in practice INEA the institution currently in charge of regular water quality monitoring at a basin scale. With INEA as a coordinator, implementation of a physical environment monitoring could be done with collaboration from municipalities, other government institutions such as schools, non-government organizations and the public, in a community-based scheme. The motivation for these institutions to participate in such a program would lay on the educational opportunities it offers. INEA should offer training for the application of the protocol.

Regular use of SVAP seems useful for detection of small-scale changes in the river environment that cannot be detected with other systems such as remote sensing analysis. Besides, RPE conditions can provide additional information for adjusting the location of water quality sampling sites or determining the necessity of new ones.

Expected population growth in most of the basin due to the construction of COMPERJ increases the necessity of monitoring the river environment's conditions in order to avoid further deterioration.

Finally, the potential and advantages of RAMs could be further underpinned with the use of smartphones. Currently, development of user-defined applications has become possible for these devices, allowing its use as dataloggers. This technology is being used in many investigations or monitoring programs in which local people is involved, for instance with collection of data. Acquisition of the devices might be a constraint, but its potential is substantial, since they allow a much faster and efficient data collection, for instance point location can be detected and recorded automatically by an integrated GPS device.

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Annexes

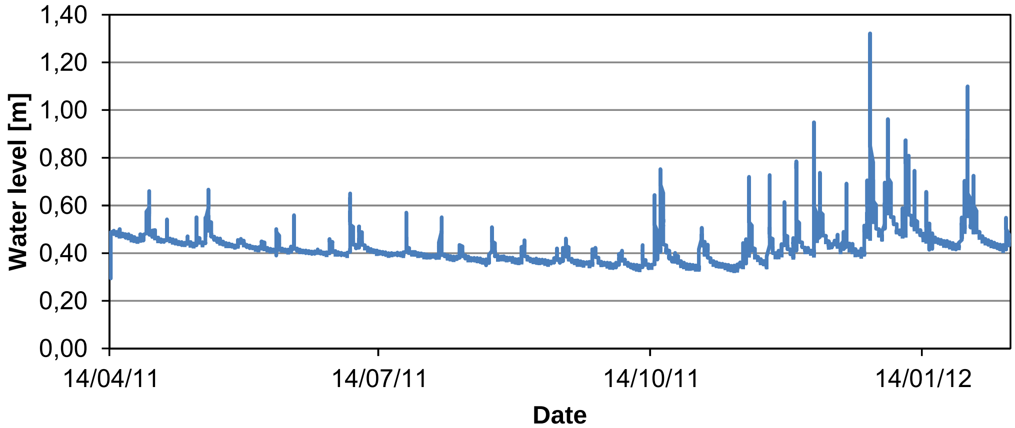
ANNEX 1: Water quality data

Table A1.1: Mean values for selected water quality parameters. Measurements were carried out within a water quality monitoring system project by Penedo et al. (2011). Data delivered by R. Bardy (Personal communication, April 2012). Parameters: T = Temperature [°C]; EC = Electrical conductivity [$\mu S \cdot cm^{-1}$]; DO = Dissolved oxygen [$mg \cdot l^{-1}$]; pH; Turbidity [NTU]; NO3 = Nitrate content [$mg \cdot l^{-1}$]; NO2 = Nitrite content [$mg \cdot l^{-1}$]; NH3 = Ammonia content [$mg \cdot l^{-1}$]; OP = Ortho-phosphate content [$mg \cdot l^{-1}$]; TN = Total N content [$mg \cdot l^{-1}$]; TP = Total P content [$mg \cdot l^{-1}$]; TDS = Total dissolved solids [$mg \cdot l^{-1}$]; TSS = Total suspended solids [$mg \cdot l^{-1}$].

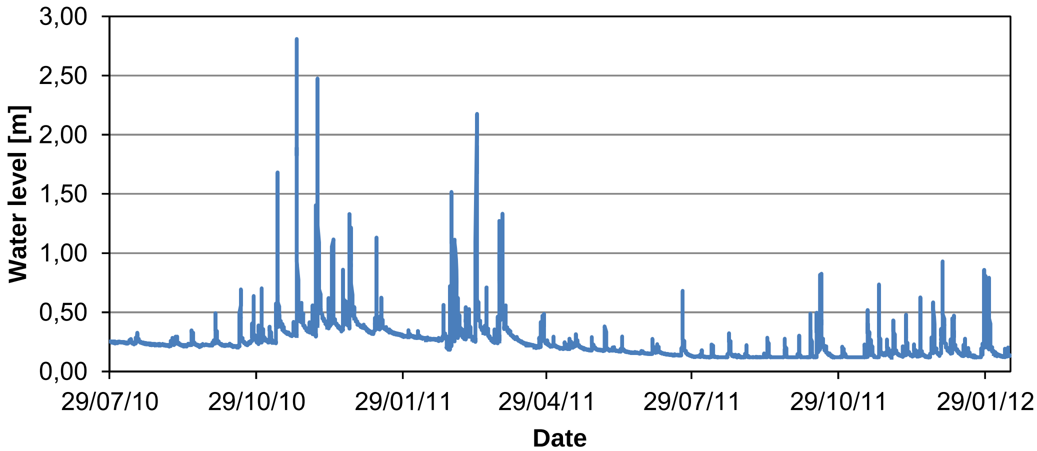
		T	EC	DO	pH	Turbidity	NO3	NO2	NH3	OP	TN	TP	TDS	TSS
No. of considered measurements for median calculation		7	9	7	9	7	9	8	8	6	7	7	6	6
Sampling site (Penedo et al., 2011)	**Sampling site (this study)**													
MA	05_MAL	20,6	15,67	8,36	7,12	0,68	0,45	0,004	0,035	0,11	0,527	0,022	21,65	1,40
CN	07_CABA	22,4	22,00	8,87	7,19	0,89	0,55	0,002	0,021	0,09	0,814	0,025	30,35	1,00
CM	08_CABM	23,0	27,00	9,27	7,14	1,71	0,40	0,003	0,036	0,16	0,497	0,026	44,85	2,00
CB	09_CABB	23,3	31,02	9,16	7,23	2,80	0,60	0,005	0,24	0,19	0,967	0,060	45,10	2,20
BN	02_BATN	20,9	17,00	8,47	7,08	1,77	0,60	0,003	0,034	0,10	0,654	0,027	11,35	0,80
BM	01_BATM	22,5	20,00	8,76	7,00	1,52	0,40	0,003	0,042	0,19	0,157	0,021	22,90	0,60
BB	10_BATB	24,2	25,00	7,85	7,00	3,37	0,30	0,003	0,053	0,09	0,309	0,036	30,41	3,00
MACN	03_MACA	22,2	21,67	7,91	7,35	1,58	0,30	0,003	0,065	0,07	0,124	0,026	32,90	0,40
MACB	04_MACB	24,5	33,00	8,17	7,19	5,37	0,50	0,008	0,11	0,11	1,310	0,045	36,20	3,00
G	06_GAC	24,2	32,00	8,74	6,95	11,11	0,50	0,003	0,078	0,09	0,740	0,051	35,20	12,12
CEDAE	26_CEDAE	22,6	36,00	6,14	6,71	9,87	0,50	0,005	0,088	0,14	1,180	0,069	58,60	24,20

ANNEX 2: Water level measurements

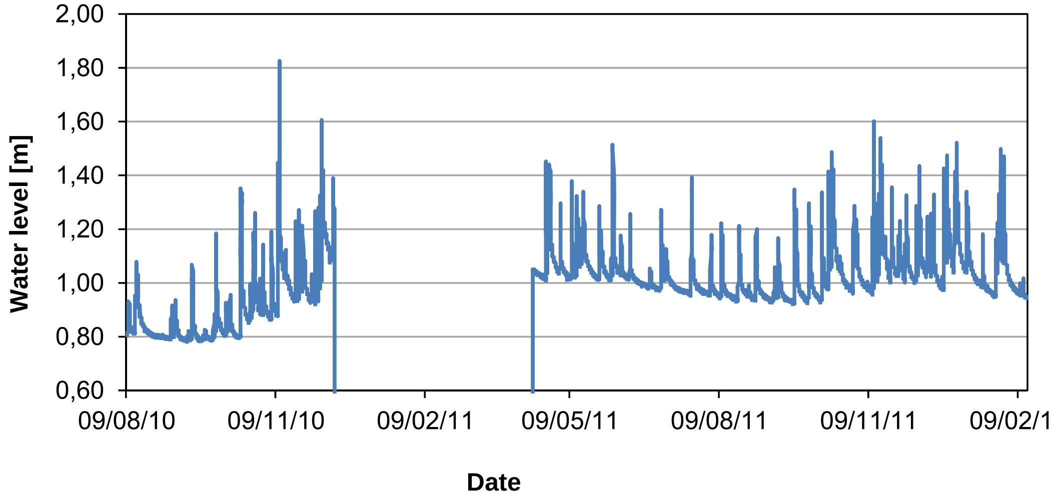
The measurements here presented were obtained within a water quality monitoring system project by Penedo et al. (2011). Data delivered by A. Künne (Personal communication, June 2012).



Graph A2.1: Batatal river. Data range: Jul-10 to Feb-12.



Graph A2.2: Caboclo river. Data range: Jul-10 to Feb-12.



Graph A2.3: Manuel Alexandre river. Data range: Aug-10 to Feb-12. Measurements are not available for the period from Dec-10 to Apr-11.

ANNEX 3: SVAP Form

DINARIO	**Dinario Project** Module III, Soil and water dynamics / W.P. 4: Water resources management River environment assessment in the Guapi-Macacu Basin Stream Visual Assessment Protocol (SVAP)	Embrapa

i. Site identification			
Site id. number:		Date:	Time:
Evaluator's name:		Weather conditions today: During last week:	
River:			
Geographic coordinates	beginning of reach		
	end of reach		
River reach length [m]:			
Photos id.	left margin		
	right margin		
Active channel width [m]:		Bankfull width [m]:	

ii. Land use in the surrounding area (up to 50 m perpendicular to shoreline)	
Land cover type [%]	**Additional information**
Forest:	Primary? Secondary?
Grazing/pasture:	Type of cattle? Confined animal feeding operations?
Crops:	Annual? Perennial? Types of crop? Cover of every type?
Urban:	Residential? Industrial? Water uptake? Effluent spill?
Conservation reserve:	
Rocks:	
Exposed soil:	Sand banks? Sand removal operations?
Comments:	

<table>
<tr><th colspan="4">Assessment scores
To complete, use scoring description at pages 3-5</th></tr>
<tr><th>River ecosystem component</th><th>Parameters</th><th>Score</th><th>Comments</th></tr>
<tr><td rowspan="2">Structure</td><td>1. Channel condition</td><td></td><td></td></tr>
<tr><td>2. Bank stability
(final score is the lowest)
<table><tr><th>Side</th><th>%</th><th>Score</th></tr><tr><td>Left</td><td></td><td></td></tr><tr><td>Right</td><td></td><td></td></tr></table></td><td></td><td></td></tr>
<tr><td>Hydrology</td><td>3. Hydrologic alteration</td><td></td><td></td></tr>
<tr><td rowspan="2">Riparian vegetation</td><td>4. Size of riparian zone
(final score is the lowest)
<table><tr><th>Transect</th><th>1</th><th>2</th><th>3</th><th>Average</th><th>Score</th></tr><tr><td>Left bank</td><td></td><td></td><td></td><td></td><td></td></tr><tr><td>Right bank</td><td></td><td></td><td></td><td></td><td></td></tr></table></td><td></td><td></td></tr>
<tr><td>5. Riparian vegetation structural integrity
(final score is the lowest)
<table><tr><th>Side</th><th>%</th><th>Score</th></tr><tr><td>Left</td><td></td><td></td></tr><tr><td>Right</td><td></td><td></td></tr></table></td><td></td><td></td></tr>
<tr><td rowspan="4">Water quality</td><td>6. Water appearance</td><td></td><td></td></tr>
<tr><td>7. Algal growth</td><td></td><td></td></tr>
<tr><td>8. Manure presence</td><td></td><td></td></tr>
<tr><td>9. Human waste</td><td></td><td></td></tr>
<tr><td rowspan="6">Aquatic habitat</td><td>10. Barriers to fish movement</td><td></td><td></td></tr>
<tr><td>11. Instream fish cover</td><td></td><td></td></tr>
<tr><td>12. Pools</td><td></td><td></td></tr>
<tr><td>13. Insect/invertebrate habitat</td><td></td><td></td></tr>
<tr><td>14. Canopy cover over water body</td><td></td><td></td></tr>
<tr><td>15. Riffle embeddedness</td><td></td><td></td></tr>
<tr><td colspan="2">Sum of all scores [A]</td><td></td><td></td></tr>
<tr><td colspan="2">Total number of parameters assessed [B]</td><td></td><td></td></tr>
<tr><td colspan="2">Overall score [A/B]</td><td></td><td></td></tr>
<tr><td>> 9.0: Excellent</td><td>7.5 - 8.9: Good</td><td>6.1 - 7.4: Fair</td><td><6.0: Poor</td></tr>
</table>

ANNEX 4: SVAP Form scoring guide

Scoring description

1. Channel condition

Natural channel; no structures, dikes. No evidence of downcutting or excessive lateral cutting.	Evidence of past channel alteration, but with significant recovery of channel and banks. Any dikes or levies are set back to provide access to an adequate floodplain.	Altered channel; <50% of the reach with riprap and/or channelization. Excess aggradation; braided channel. Dikes or levees restrict floodplain width.	Channel is actively downcutting or widening. >50% of the reach with riprap or channelization. Dikes or levees prevent access to the floodplain.
10	7	3	1

2. Bank stability

Banks are stable; banks are low (at elevation of active flood plain); 33% or more of eroding surface area of banks in outside bends is protected by roots that extend to the base-flow elevation.	Moderately stable; banks are low (at elevation of active flood plain); less than 33% of eroding surface area of banks in outside bends is protected by roots that extend to the base-flow elevation.	Moderately unstable; banks may be low, but typically are high (flooding occurs 1 yr out of 5 or less frequently); outside bends are actively eroding (overhanging vegetation at top of bank, some mature trees falling into stream annually, some slope failures apparent).	Unstable; banks may be low, but typically are high; some straight reaches and inside edges of bends are actively eroding as well as outside bends (overhanging vegetaion at top of bare bank, numerous mature trees falling into stream annually, numerous slope failures apparent).
10	7	3	1

3. Hydrologic alteration

Flooding every 1.5–2 yr. No dams, no water withdrawals, no dikes or other structures limiting the stream's access to the floodplain. Channel is not incised.	Flooding occurs only once every 3–5 yr; limited channel incision, or Withdrawals, although present, do not affect available habitat for biota.	Flooding only once every 6–10 yr; channel deeply, or Withdrawals significantly affect available low flow habitat for biota.	No flooding; channel deeply incised or structures prevent access to floodplain or dam operations prevent flood flows, orWithdrawals have caused severe loss of low flow, or Flooding occurs on a 1-year rain event or less.
10	7	3	1

4. Size of riparian zone

Natural vegetation extends at least two active channel widths on each side.	Natural vegetation extends one active channel width on each side, or If less than one width, covers entire flood plain.	Natural vegetation extends 1/2 of the active channel width on each side.	Natural vegetation extends 1/3 of active channel width on each side, or Filtering function moderately compromised.	Natural vegetation less than 1/3 of active channel width on each side, or Lack of regeneration, or Filtering function severely compromised.
10	8	5	3	1

5. Riparian vegetation structural integrity

< 20 % of the natural vegetation is fragmented.	20-40 % of the natural vegetation is fragmented.	40-60 % of the natural vegetation is fragmented.	60-80 % of the natural vegetation is fragmented.	> 80% of the natural vegetation is fragmented.
10	8	5	3	1

6. Water appearance			
Very clear, or clear but tea-colored; objects visible at depth 0,9–1,8 m (less if slightly colored); no oil sheen or foaming on surface; no noticeable film on submerged objects or rocks.	Occasionally cloudy, especially after storm event, but clears rapidly; objects visible at depth 0,45–0,9 m; may have slightly green color; no oil sheen on water surface.	Considerable cloudiness most of the time; objects visible to depth 0,15–0,45 m; slow sections may appear pea-green; bottom rocks or submerged objects covered with heavy green or olive-green film, **or** Moderate odor of ammonia or rotten eggs.	Very turbid or muddy appearance most of the time; objects visible to depth <0,15 m; slow moving water may be bright-green; other obvious water pollutants; floating algal mats, surface scum, sheen or heavy coat of foam on surface, **or** Strong odor of chemicals, oil, sewage, other pollutants.
10	7	3	1

7. Algal growth			
Clear water along entire reach; diverse aquatic plant community includes low quantities of many species of macrophytes; little algal growth present.	Fairly clear or slightly greenish water color along entire reach; moderate algal growth on stream substrates.	Greenish water color along entire reach; overabundance of lush green macrophytes; abundant algal growth, especially during warmer months.	Pea green, gray, brown water along entire reach; dense stands of macrophytes clog stream; severe algal blooms create thick algal mats in stream.
10	7	3	1

8. Manure presence (do not score this element unless livestock operations or human waste discharges are present)			
No evidence of livestock having access to riparian zone.	Evidence of livestock having access to riparian zone	Occasional manure in stream or waste storage structure located on the flood plain.	Extensive amount of manure on banks or in stream, **or** Untreated human waste discharged to the stream.
10	7	3	1

9. Human waste			
No evidence on human waste within the reach.	Occasionally evidence on human waste within the reach.	Considerable amount of waste material within the reach.	Extensive amounts of waste material within the reach, **and/or** Stationary refuse dumps on the bank.
10	7	3	1

10. Barriers to fish movement				
No barriers.	Seasonal water withdrawals inhibit movement within the reach.	Drop structures, culverts, dams, or diversions (<1 foot drop) within the reach.	Drop structures, culverts, dams, or diversions (>1 foot drop) within 3 miles of the reach.	Drop structures, culverts, dams, or diversions (>1 foot drop) within the reach.
10	8	5	3	1

11. Instream fish cover				
>7 cover types available	6 to 7 cover types available	4 to 5cover types available	2 to 3 cover types available	None to 1 cover type available
10	8	5	3	1
Cover types: pools, boulders/cobble, riffles, woody debris, overhanging vegetation, dense macrophyte beds, undercut banks, isolated pools (places that not connect with the main stream) and root mats under the water.				

12. Pools			
Deep and shallow pools abundant; greater than 30% of the pool bottom is obscure due to depth, or the pools are at least 1.5 m deep.	Pools present but not abundant; between 10–30% of the pool bottom is obscure due to depth, or the pools are at least 1 m deep.	Pools present but shallow; between 5–10% of the pool bottom is obscure due to depth, or the pools are less than 1 m deep.	Pools absent or the entire bottom is discernible.
10	7	3	1

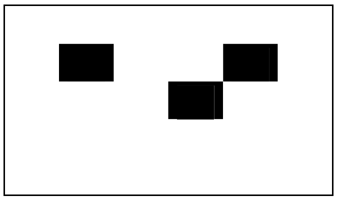
13. Insect/invertebrate habitat			
At least 5 types of habitat available. Habitat is at a stage to allow full insect colonization (woody debris and logs not freshly fallen).	3–4 types of habitat. Some potential habitat exists, such as overhanging trees, which will provide habitat but have not yet entered the stream.	1–2 types habitat. Thesubstrateis often disturbed, covered, or removed by high stream velocities and scour or by sediment deposition.	None to 1 type of habitat.
10	7	3	1
Cover types: Fine woody debris; submerged logs; leaf packs; undercut banks; cobbles; boulders; coarse gravel; other:			

14. Canopy cover over stream channel (do not assess this element if active channel width is greater than 15 m; do not assess this element if woody vegetation is naturally absent e.g. wet meadows).			
>75 % of water surface shaded of vegetation	50-75 % of water surface shaded of vegetation	25-50 % of water surface shaded of vegetation	< 25 % of water surface shaded of vegetation
10	7	3	1

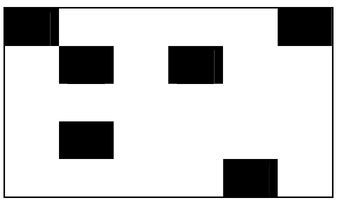
15. Riffle embeddedness (Do not assess this element unless riffles are present or are a natural feature that should be present)				
Gravel or cobble particles are < 20% embedded in bottom sediment.	Gravel or cobble particles are 20-30 % embedded in bottom sediment.	Gravel or cobble particles are 30-40 % embedded in bottom sediment.	Gravel or cobble particles are > 40 % embedded in bottom sediment.	Riffle is completely embedded in sediment.
10	8	5	3	1

<u>ANNEX 5: Graphic example of percentage distribution</u>

Adapted from a research from Lindgren & Röttorp (2009).



10%



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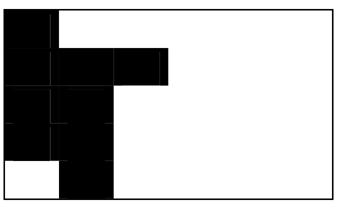
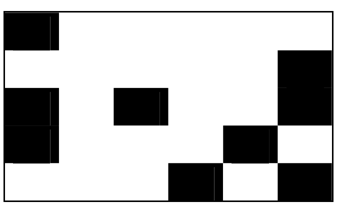
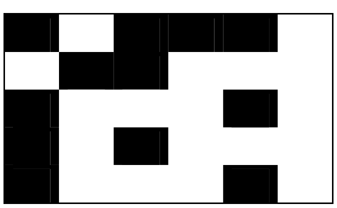


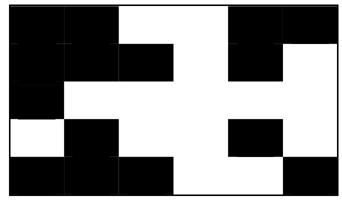
30%



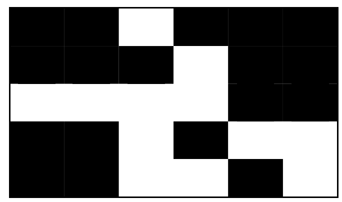
30%



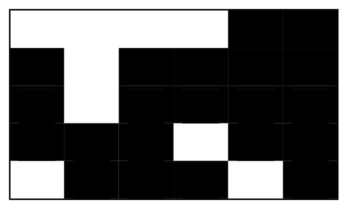
40%



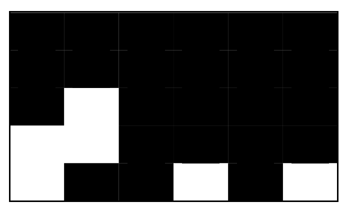
50%



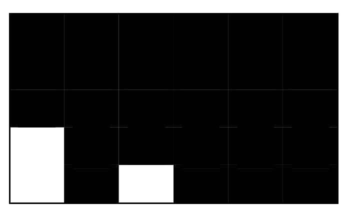
60%



70%



80%



90%

ANNEX 6: SVAP Index scores for individual parameters and general scores

Table A6.1: SVAP Index and individual parameter scores for Batatal (12 sites) and Caboclo (3 sites) sub-basins. N.A.: Not applicable measurement.

Sub-basin	Site Id	Channel condition	Bank stability	Hydrologic alteration	Size of riparian zone	Structural integrity of riparian zone	Water appearance	Algal growth	Manure presence	Human waste	Barriers to fish movement	Instream fish cover	Pools	Insect/invertebrate habitat	Canopy cover over channel	Riffle embeddedness	Sum of scores	No. of assessed parameters	SVAP Index	SVAP Category
Batatal	01_BATM	9	6	10	4	4	10	9	N.A.	7	9	5	8	10	10	10	111	14	7,93	Good
	02_BATN	8	9	10	3	5	10	10	5	10	9	8	10	10	10	10	127	15	8,47	Good
	10_BATB	8	4	10	5,5	1	10	8	N.A.	7	10	8	5	10	3	3	92,5	14	6,61	Fair
	11_BATF	8	4	10	3,5	8	10	7	7	10	10	10	7	10	1	5	110,5	15	7,37	Fair
	12_BATV	9	9	10	6	6,5	10	8	N.A.	10	9	8	7	8	10	10	120,5	14	8,61	Good
	13_BATE	9	4	10	5,5	2	10	8	N.A.	9	10	10	3	10	7	5	102,5	14	7,32	Fair
	14_BATH	9	5	10	4	9	10	7	7	9	10	10	7	10	1	3	111	15	7,4	Fair
	15_BATG	10	10	10	6	6,5	10	9	N.A.	8	10	8	5	7	10	10	119,5	14	8,54	Good
	16_BATX	8	8,5	10	8	10	10	10	N.A.	10	10	8	7	7	7	10	123,5	14	8,82	Good
	17_BATU	10	10	10	9	10	10	9	N.A.	10	10	8	3	7	10	10	126	14	9,00	Excellent
	20_BATS	10	10	10	10	10	10	10	N.A.	10	10	5	5	7	10	10	127	14	9,07	Excellent
	21_BATZ	5	3	8	2	2	7	8	1	10	10	5	7	10	1	3	82	15	5,47	Poor
	mean	8,58	6,88	9,83	5,54	6,17	9,75	8,58	5,00	9,17	9,75	7,75	6,17	8,83	6,67	7,42	-	-	7,88	
Caboclo	07_CABA	8	9	10	7	9	10	10	N.A.	10	9	8	10	7	7	10	116	14	8,86	Good
	08_CABM	10	7	10	3	2	10	8	N.A.	10	10	8	7	10	1	10	106	14	7,57	Good
	09_CABB	7	5	10	4,5	6,5	10	9	N.A.	10	10	8	7	10	3	8	108	14	7,71	Good
	mean	8,33	7	10	4,83	5,83	10	9	-	10	9,67	8	8	9	3,67	9,33	-	-	8,05	-

Table A6.2 SVAP Index and individual parameter scores for Manuel Alexandre sub-basin (4 sites). N.A.: Not applicable measurement.

Sub-basin	Site Id	Channel condition	Bank stability	Hydrologic alteration	Size of riparian zone	Structural integrity of riparian zone	Water appearance	Algal growth	Manure presence	Human waste	Barriers to fish movement	Instream fish cover	Pools	Insect/invertebrate habitat	Canopy cover over channel	Riffle embeddedness	Sum of scores	# of assessed parameters	SVAP Index	SVAP Category
M. Alexandre	05_MAL	10	10	10	6	3	10	10	7	10	10	5	10	7	3	10	121	15	8,07	Good
	18_MALB	10	10	10	8,5	9	10	10	7	10	10	8	7	7	N.A.	10	126,5	14	9,04	Excellent
	19_MALM	10	10	10	10	10	10	10	N.A.	10	10	5	7	7	7	10	126	14	9,00	Excellent
	27_MALA	10	9,5	10	10	10	10	10	N.A.	10	10	5	7	10	7	10	128,5	14	9,18	Excellent
	mean	10	9,88	10	8,63	8	10	10	7	10	10	5,75	7,75	7,75	5,67	10			8,82	
Sites outside sub-basins	03_MACA	7	9	10	3	5	10	10	N.A.	9	10	5	10	7	N.A.	10	105	13	8,08	Good
	04_MACB	7	7	7	5	9	8	9	N.A.	8	10	5	7	8	N.A.	8	98	13	7,54	Good
	06_GAC	3	5	3	2,5	9	3	N.A.	3	8	10	8	N.A.	10	N.A.	N.A.	64,5	11	5,86	Poor
	22_GUAC	10	8	10	5,5	5	10	10	7	10	10	10	10	7	N.A.	10	122,5	14	8,75	Good
	23_GUAP	10	5	10	5,5	10	10	9	N.A.	10	10	8	10	10	N.A.	8	115,5	13	8,88	Good
	24_GUAA	1	5	3	6,5	6,5	8	8	5	10	10	3	1	7	N.A.	5	79	14	5,64	Poor
	25_GUAD	1	4	3	1	3	7	8	5	9	10	5	1	10	N.A.	N.A.	67	13	5,15	Poor
	26_CEDAE	1	6	3	1	1	1	8	3	10	3	5	N.A.	10	N.A.	N.A.	52	12	4,33	Poor

ANNEX 7: Complementary measurements

Table A7.1: Measurements complementary to SVAP parameters carried out at sampling sites. (1) River margins were identified always facing downstream. (2) Altitude was measured always at the lower point of the study reach.

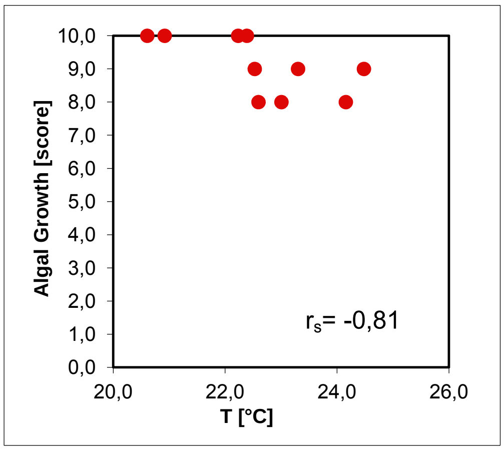
River	Point name	Land use at APP (50m)		Turbidity [FNU]	Point altitude [masl][2]
		Left margin[1]	Right margin[1]		
Batatal	01_BATM	Urban (Residential, commercial), Road	Urban (Residential)	8,00	108,5
Batatal	02_BATN	Pasture (horses)	Urban (residential)	4,00	236,5
Batatal	10_BATB	Pasture (with primary forest), Road	Pasture (horses)	4,98	67
Batatal	11_BATF	Crops (banana, *aipim*, *inhame*)	Urban (Residential)	5,36	64
Batatal	12_BATV	Urban (Residential)	Urban (Residential)	3,13	209
Batatal	13_BATE	Crops (*aipim*, banana)	Forest (secondary), Crops (*aipim*, tangerines)	6,16	63
Batatal	14_BATH	Crops (*aipim*, banana)	Crops (Lemon)	6,70	61,5
Batatal	15_BATG	Crops (sugarcane), Pastures	Crops (Sugarcane, corn)	3,06	91,5
Batatal	16_BATX	Forest, Road	Forest, Road	1,37	136
Batatal	17_BATU	Forest	Crops (Banana)	1,84	190
Batatal	20_BATS	Forest	Pasture	1,76	287
Batatal	21_BATZ	Crops (*aipim*)	Pasture (cattle)	16,20	46,5
Caboclo	07_CABA	Crops (corn)	Crops (coconuts)	0,58	108
Caboclo	08_CABM	Crops (*aipim*)	Crops (orange, lemon)	1,57	38,5
Caboclo	09_CABB	Crops (*aipim*)	Crops (*aipim*)	1,74	33,5
Guapiaçu	06_GAC	Crops (*aipim*), Urban (residential), Road	Crops (*aipim*), Urban (residential), Road	38,30	16
Guapiaçu	22_GUAC	Urban (residential)	Pasture	0,68	69,5
Guapiaçu	23_GUAP	Pature (cattle)	Forest	0,38	50,5
Guapiaçu	24_GUAA	Crops (*aipim*)	Pasture	10,60	36
Guapiaçu	25_GUAD	Pasture, Crops (coconuts)	Crops (corn), Urban (residential, road)	11,00	26,5
Guapi-Macacu	26_CEDAE	Pasture (cattle)	Pasture (cattle)	11,80	7,5
Macacu	03_MACA	Urban (residential)	Urban (residential)	6,04	171
Macacu	04_MACB	Crops (corn, fruit trees)	Urban (residential)	7,90	62
Manuel Alexandre	05_MAL	Pasture (horses)	Forest (secondary), Conservation reserve	1,41	200,5
Manuel Alexandre	18_MALB	Pasture (horses)	Forest	0,67	164
Manuel Alexandre	19_MALM	Forest (Conservation reserve)	Forest (Conservation reserve)	0,42	219
Manuel Alexandre	27_MALA	Forest (Conservation reserve)	Forest (Conservation reserve)	0,38	281

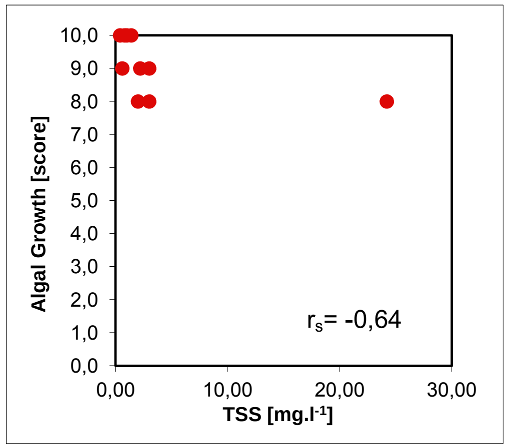
ANNEX 8: Scatter plot graphs

Selection of graphs showing relation between SVAP individual parameters and WQ parameters.

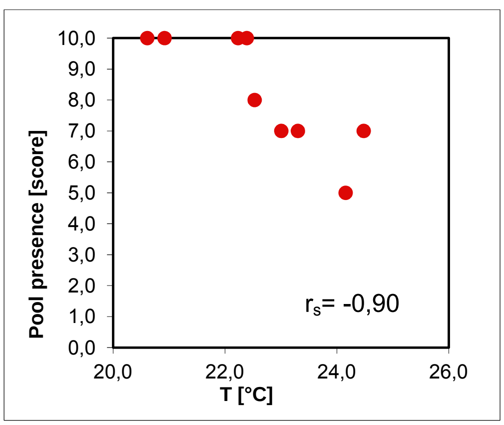
8.1) Analysis where correlation was present (P<0,05)

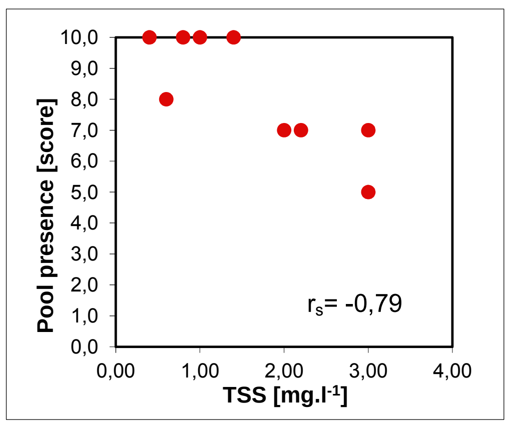
8.1.1 Algal growth vs. T and TSS





8.1.2 Pool presence vs. T and TSS





8.2) Analysis where correlation was not present

8.1.2 Canopy cover vs. T and Size of Riparian Zone vs. Turbidity