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The application of Waterharmonica concept in the Metropolitan Region of São Paulo, Brazil - A Feasibility Study

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Abstract

To the sewage treatment plants (STPs) contained in the Metropolitan Region of São Paulo (MRSP) it was applied the Dutch Waterharmonica concept.

As part of it, it was given general characteristics of the STPs and the MRSP and about the Waterharmonica concept. To each of the STPs it was assessed the available area surrounding it, the treatment capacity for each Waterharmonica System and the main returns and extra functions these systems could bring to the MRSP and its environment, included increments in water quality, nature conservation, water storage and re-use and recreational values.

It was found that the Waterharmonica has different potential inside the MRSP, according to STP's location and size, however, improvements are possible in all the cases. In the central region, comparatively, usually smaller Waterharmonica Systems are possible, aimed to buffer rainfall peaks and effluent quality, while in the borders or urban fringes of the MRSP, bigger Waterharmonica System were possible, aimed to nature conservation and river's restoration.

Key words: Metropolitan Region of São Paulo (RMSP), Waste Water Treatment Plants (WWTP), Sewage Treatment Plants (STP), Waterharmonica, Effluent, Nature Conservation, Living Water, Water re-use.

Preface

The Metropolitan Region of São Paulo (MRSP) located in the Southeast of Brazil, is the most important economic region of the country, housing 10% of the Brazilian population. Due to the fast disordered growth this region is suffering concerning environmental issues, the most disturbing one is related to the water resources.

Most of the water bodies in the MRSP are polluted, which makes difficult the methods of obtaining drinking water and causes health issues and nature depletion. Currently there are 29 STPs in the MRSP and since the last decades, the sanitary company in the Region (SABESP) is developing several plans in order to increase the collection and treatment of sewage and promoting plans to improve the water quality from the water bodies and also the water re-use.

The Waterharmonica is a Dutch technology, which apply natural processes (constructed wetlands), has been used in some countries to improve the effluent quality and improving performance of the STPs, reducing levels of organic matter, nutrients, pathogens, besides developing natural areas and providing natural clean water for re-use. In order to evaluate the feasibility of this technology in the MRSP, an analysis of the STPs and the surrounding areas have been done using Google Earth, assessing mainly the size of these areas and its relief. Furthermore, data concerning flow and effluent quality from the selected STPs was collected.

Using this information it was possible to estimate how much of the effluent produced by the STP can be treated, and the expected removal of nutrients by the different Waterharmonica systems, based on its load. Moreover, it was suggested different kinds of re-use for the water produced in the Waterharmonica, according to the STP's location. For some Waterharmonica Systems it was also estimated water storage capacity, in order to buffer rainfall peaks.

After analysing all the data it was possible to conclude that the Waterharmonica system have a bigger potential to be applied in the urban fringes and rural areas, where there are bigger available areas and less effluent is produced by the STPs. However, this approach doesn't exclude the STPs in the urban agglomeration, where due to the less available space, great volumes of effluent and relatively small removal of contaminants, the Waterharmonica Systems have different potentials.

List of abbreviations

CETESB: Companhia ambiental do Estado de São Paulo (Environmental Company of the State of São Paulo)

CONAMA: Conselho Nacional do Meio Ambiente (National Council of the Environment)

DAEE: Departamento de água e energia elétrica (Electricity and Water departament)

GDP: Gross domestic Product

MRSP: Metropolitan Region of São Paulo

HRT: Hydraulic Retention Time

SABESP: Companhia de Saneamento Básico do Estado de São Paulo (Company of basic sanitation of the state of São Paulo)

SNIS: Sistema Nacional de Informações sobre Saneamento (National System of Sanitation information)

STOWA: Stichting Toegepast Onderzoek Waterbeheer (Foundation for Applied Water Research)

STP: Sewage treatment plant

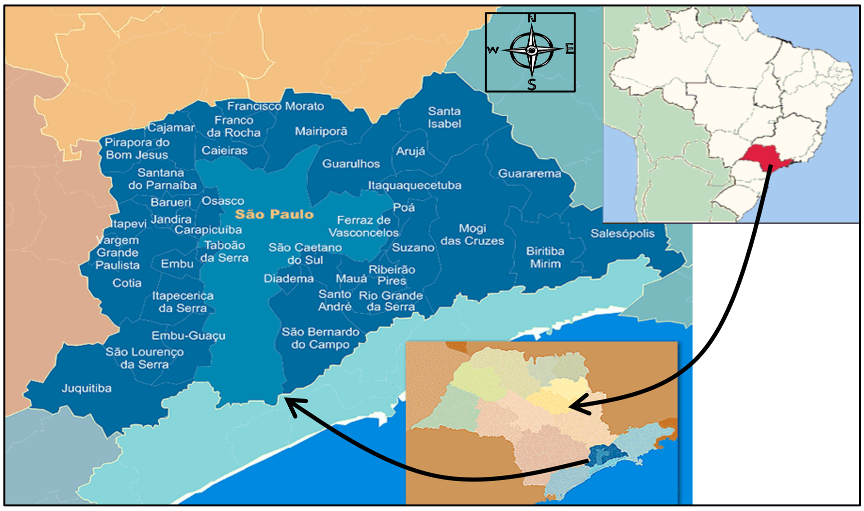
Contents

1. Introduction

1.1. The Metropolitan Region of São Paulo

The Metropolitan Region of São Paulo (MRSP) is facing several challenges related to the water management especially concerning the pollution of drinking water reservoirs, water scarcity, inefficient water use, and flooding. This region hosts almost 20 million people and it's located in the south-east region of Brazil, in the State of São Paulo, as show in figure 1. It consists of 39 municipalities (Whately, Diniz, & Instituto Socioambiental, 2009) and is the seventh most populous urban area in the world besides it's the Brazilian economic, financial and technical centre (IBGE, 2005), which generated a Gross Domestic Product (GDP) of around € 190 billion in 2008, accounting to 18.9% of the Brazilian total GDP (EMPLASA, 2013).

Figure 1. Brazil. State of São Paulo and Metropolitan Region.
Source: ("Portal Cidades Paulistas - Região Metropolitana de São Paulo" n.d.).



The State of São Paulo contains about 10% of the Brazilian fresh water resources, and the MRSP is located in the Upper Tietê River Basin, which is one of the largest rivers in the south-eastern region of Brazil, nevertheless, in the last decades several issues have been faced concerning the water resources in this area. The MRSP represents less than 10% of the state's surface but nearly half of the population of the state of São Paulo (which is around 43 million) lives in the RMSP (IBGE, 2005), what calls attention for the human impacts on the area. Since the early 20th century the major part of the sewage from the MRSP was deposited into the Tiete River, and into other water bodies without treatment (Kuniholm, 2012).

During the 70's the MRSP implemented several plans in order to improve the water quality of the rivers, increasing sewage network, building STPs and overseeing industries and illegal connections. Since then, the collection and treatment of sewage have been increasing, but the population residing in the urban area has also grown in a very fast and unplanned way, which brought severe environmental consequences. (Helmer et al., 1997).The management of water resources in São Paulo was disjointed and ineffective before 1991, because there was no communication between the two main environmental agencies (DAEE and CETESB). The DAEE, is a centralized state department that primarily issues water-use permits in Brazil, now the Environmental Company of the State of São Paulo (CETESB), was established in 1970 and became the first agency to monitor the water quality in the region, this governmental agency developed many policies concerning pollution control at the state level which helped regulating different kind of polluters (industries, residences, farms) and is also responsible for environmental enforcement. (Helmer et al., 1997).

Figure 2. Flood Episode in the east-MRSP.
Source: (Folha de S.Paulo, n.d.)

Figure 3. Cantareira Reservoir in the MRSP during a drought episode in 2014.
Source: (Folha de S.Paulo, n.d.)

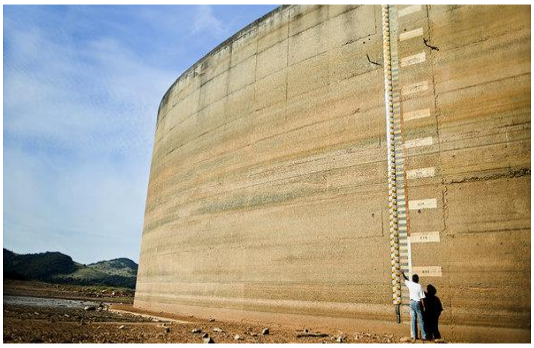


Figure 4. Barueri STP, part of the main system for sewage treatment.
Source: (Folha de S.Paulo, n.d.)

Due to the city's disordered and unplanned growing, its effects on the environment were intensified, with enormous effects. In the Upper Tietê River Basin, for example, lands before natural with native vegetation gave place to buildings and paved streets, which ends up waterproofing the soil, causing floods during heavy rainfalls. Besides that, the urban drainage system is not able to absorb all this water volume, which flows to the Tietê River, the biggest in the Region, causing severe flooding episodes practically every year in the MRSP, as illustrated in the figure 2. (Toledo & Costa, 2007).

However, not only floods problems, the MRSP faces problems concerning also the lack of water, since the region alone is unable to meet its population's water needs, and currently, the demand is equivalent to approximately the double of minimum availability, which is 39 m3/s. (Whately, Diniz, & Instituto Socioambiental, 2009). These constraints, force the water agencies to extract water from other watersheds (SABESP, 2011), which increase the hydric-stress in those areas, with several environmental aspects. Figure 3 shows low levels of the Cantareira Reservoir for potable water, during very severe drought in 2014.

The human impacts on the water resources are much intense in the MRSP, affecting it in several ways, including the not only the availability of water but also its quality on the human and natural environments. However, there are plans and infra-structure to alleviate these impacts and preserve this precious resource.

1.2. Current situation of sewage management in the MRSP

The main stakeholders in water management in MRSP are the state government, the main sanitary company SABESP and the 39 municipal governments. A basin committee for the Upper Tietê river basin, which covers the entire area of the MRSP and supplies half of its water, brings together all stakeholders (The World Bank, 2005).

Although the use of the rivers in the Metropolitan Region dates from centuries ago, only on the last decades, worries about the poor water quality began to show up and in 1991, after intense public outcry, it was launched the Tietê Project. With the goal of increasing sewage collection and treatment, this project was responsible for biggest part of the current infra-structure concerning sewage collection and treatment for the last years in the MRSP and it’s expected to end in 2018, reaching 87% of sewage collection and 84% of sewage treatment for the MRSP. (SABESP, 2011).

Currently, in the MRSP, there are at least 26 sewage treatment plants (STPs) and the biggest 5 of them, form the Main System of the MRSP which is responsible for the major part of the sewage treatment rate (one is show in the figure 4) and the others 21 STPs which are smaller are responsible for the remainder portion of the sewage (SABESP, 2011).

The main system has total capacity to treat 18 m3/s of domestic effluent, although this system is not fully operated and a great part of the sewage produced in the MRSP comes from industries. The total volume of sewage produced in the MRSP is about 25 m3/s, thus the total capacity of treatment in the main system needs to be increased in order to achieve this volume (Whately, Diniz, & Instituto Socioambiental, 2009).

According to the National System for Sanitation Information (free translation), in the MRSP less than 50% of the produced sewage, a mixture of both industrial and domestic sewage, is effectively treated, and the rest of it is released into the water bodies without treatment (Whately, Diniz, & Instituto Socioambiental, 2009). Still in 2015 about 2 million people (23%) will still be living without proper sanitation infrastructure in the MRSP. (Kuniholm, 2012).

The obstacle for the MRSP, is the enormity of the socio-economic and environmental problems, due to its giant population of almost 20 million, moreover, the problem is further by informal settlements and complicated by water quality policies that often call for the restoration of riparian and flood-plain areas, which are the same places that most informal settlements in the Upper Tietê River Basin are located, as exemplified in figure 5. (Kuniholm, 2012).

Figure 5. Improper habitations by the side of one of the Tietê River's streams.
Source: (Folha de S.Paulo, n.d.)

Uncontrolled urban occupation is a major threat to the water quality in the MRSP, since this occupation carries sewage, domestic waste and diffuse pollution loads, all generated in urbanized areas. This ends up increasing the production of sewage and continuously lowering the environmental quality of the water bodies, represented specially by high level of pollutants, low oxygen rates and few or none biodiversity in the water bodies of the Region. Imminent risks for the water stock are present, given not only the rising cost of treatment but also the higher level of the treatment that is needed, both for water and sewage.

1.3. National and State Water and Soil Policies

The classification of water bodies in Brazil is based on decree CONAMA 357/2005. The different kinds of water are divided in 4 classes, according to its quality, which is directly influenced by the degree of anthropologic impacts. For instance, rivers located in natural areas, free of human contamination, are framed at a lower classes (1 or 2) than urban rivers, with high pollution loads (class 4) and due to the amount of contaminants, pathogens and odour each class has a different purpose, as shown in table 1.

Table 1. Different uses for water based on its class.
Based on CONAMA 357/2005, own elaboration.

Kind of Uses		Classes			
		1	2	3	4
Supply for human consumption	After simplified treatment	X			
	After conventional Treatment	X	X		
	After advanced Treatment	X	X	X	
Preservation of the balance of aquatic communities		X			
Protection of aquatic communities		X	X		
Recreation	Primary contact	X	X		
	Secondary contact	X	X	X	
Irrigation	Vegetables and edible raw fruits	X			
	Parks with direct contact to the public	X	X		
	Trees, cereals and foragers crops.	X	X	X	
Agriculture and fishing		X	X		
Watering livestock		X	X	X	
Navigation		X	X	X	X
Landscape harmony		X	X	X	X

Each water class has a different maximum standard level of contaminants. The table 2 presents the main parameters that are related to the water quality and eutrophication process, as can be seen, there is no standard of maximum concentration for class 4 waters. The figure 6 shows the classification of the rivers in the MRSP, according to the CONAMA policy, as can be seen most of the water bodies present a bad water quality, being framed in the Class 3 and 4.

Table 2. Different pollutants and their allowed levels, based on the water class. Based on CONAMA 357/2005, own elaboration.

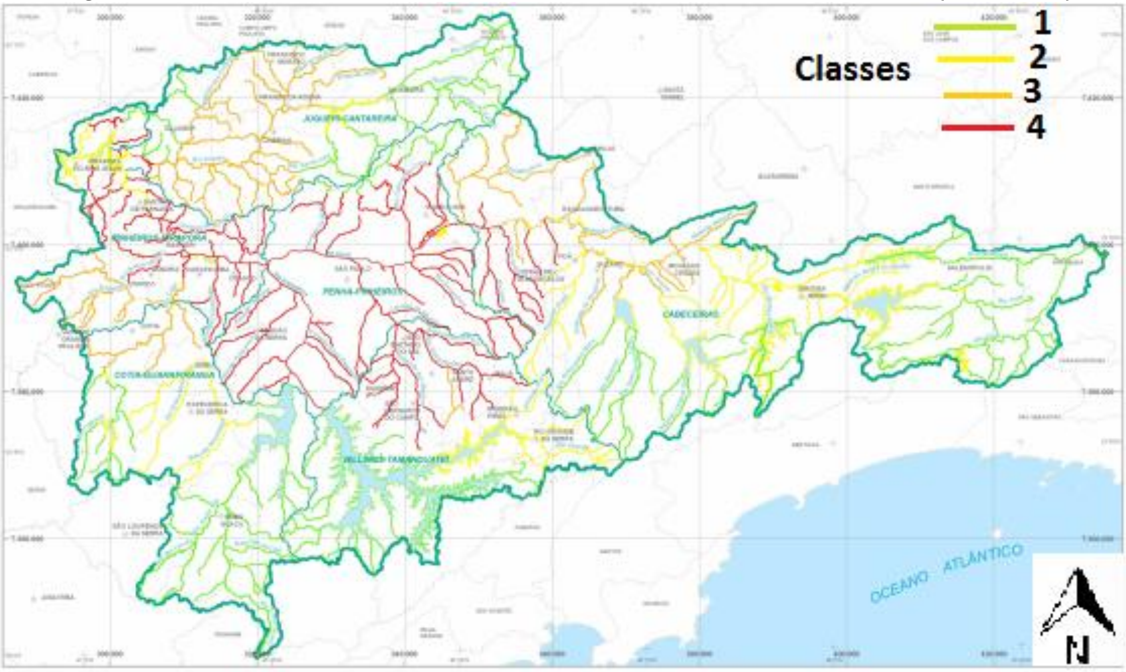
Standard level of contaminats for the different class of water in Brazil - CONAMA 357/2005					
Parameter		Water bodies - maximum alloweded concentrations			
Parameter	Unit	Class 1	Class 2	Class 3	Class 4*
BOD	mg/L	3	5	10	#
Ammonia	mg/ L	0,5 - 3,7	0,5-3,7	1-13,3	#
Nitrate	mg/L	10	10	10	#
Nitrite	mg/L	1	1	1	#
Phosphorus	mg/L	0,02- 0,1	0,03-0,1	0,05-0,15	#
Coliforms	n/100 ml	200	1000	2500	#

*In waters class 4 there are no maximum standards for contaminants.

Nationally, the discharge of effluents into the water bodies must follow the Brazilian directive CONAMA 430/2011. Which establish that the launching of effluent cannot exceed the conditions and standards of water quality set for their classes (except in the mixing zone). At State level, the decree 8.468/1976 of the state of São Paulo establish the standards levels of contaminants for effluent discharge. Besides the concentration of metals, the only parameter that is encompassed is the BOD that must be reduced by 80% for discharge from STPs.

The classification of the water bodies into the water classes for the MRSP is summarized in the figure 6.

Figure 6. Different classes for the water bodies inside the MRSP. Source: (MMA, n.d.)



However, besides the laws concerning water quality and discharge parameters, the MRSP has also laws related to the use of the soil, aiming the conservation of the water resources. In the MRSP, the periphery regions are in the neighbourhood of the sources for public water supply, the watersheds of the Region. The increasing negative impacts on the natural water production system, led society and government to develop a set of laws about the watersheds in the State of São Paulo and in the 70's.

These law regulates the use of land for the protection of water sources, courses, water reservoirs and other water resources of interest in the Metropolitan Region of São Paulo, it's centrally based on restrictions for the land use, environmental licensing and definitions of zones of interest to preserve, with this scope, the State Law 898/75 defined a big part of the MRSP as watershed protection area (Duarte & Malheiros, 2012), which means areas to be preserved, together with good quality water.

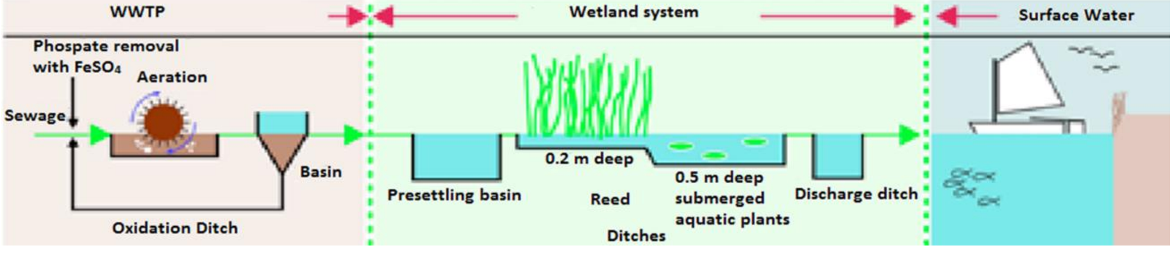
2. Waterharmonica: a natural approach

To conserve water resources, particularly in areas suffering from water shortage, the sewage re-use represents a very clever strategy. This practice has been reported in developing countries including Morocco, Tunisia, Egypt, Sudan, Namibia, India and China. On these countries, the sewage is used to irrigate crops and also to support fish culture. (Kivaisi, 2001). However, the use of raw sewage presents a high risk of transmission of water-borne diseases, for instance, by contamination of vegetables irrigated with non-treated sewage. (Stott, Jenkins, Bahgat, & Shalaby, 1999). Therefore, there is a need for adequate pre-treatment of sewage prior to its re-use and re-distribution into the environment. (Kivaisi, 2001).

For the pre-treatment enter the conventional techniques (such as activated sludge or other physical/biological techniques) and the eco-engineered systems (particularly constructed wetlands), that for instance, have been used for a long time in several countries to improve the quality of sewage. The effluent improvement in the wetlands is due their high rate of biological activity, being able to transform the harmful and contaminated sewage into harmless compounds or essential nutrients that can be applied for biomass production. (Kadlec & Knight, 1996).

The Waterharmonica concept, developed by Theo Claassen and Ruud Kampf (Claassen & Kampf, 2004; Kampf & Claassen, 2004), represents an innovative technique for future sewage management strategies. The Waterharmonica aims at the implementation of constructed wetlands (eco-engineered systems) subsequent to STPs, as illustrated in the figure 7.

Figure 7. General representation of a Waterharmonica System subsequent to a STP. Source: (Kampf & Boomen, 2013b).



These systems form a natural post-treatment for the effluent that comes from the STP, bridging the quality gap between effluents from treatment stations (water chain) and the surface water (water system). (Mels, Martijn, Kampf, & Claassen, 2005).

This called "quality gap" happens because the treated sewage is not really natural or usable: the oxygen concentration is low, the suspended solids contain a lot of 'loose' bacteria, the biodiversity is low and the eutrophic level is relatively high. It is, thus, reasonably clean but it is not ecologically healthy or even natural water, like the one expected in the surface water bodies. (Kampf & Boomen, 2013b).

The Waterharmonica is able to improve a bad functioning STP (e.g. overloaded) and also improve the effluent quality (e.g. to reduce pollutants levels), among other purposes. Due to the promising approach for improved management of sewage, this technique was awarded by STOWA (in the Netherlands) in 1996 and since then, extensive research has been carried out into the operation and effectiveness of these systems in several installations in the Netherlands, Sweden and Spain. (Kampf & Boomen, 2013b).

The Waterharmonica System consists of a set of ponds following a STP. These ponds can be configured for different purposes, but in a general way, it's designed with a pre-settling pond, as the first step, followed by a Daphnia pond, reed ditches, a deeper pond with aquatic plants, and a discharge ditch, as can be seen in the figure 7, which is only a general scheme of Waterharmonica system, however, several changes can be applied depending on their major function. (Kampf & Boomen, 2013b).

Each part of the Waterharmonica system has its own function, providing several improvements in the effluent quality and in the surrounding environment, these functions are summarized and briefly explained in the next sections. More details about removal efficiency for the Waterharmonica are given in the chapters 8 and 9.

2.1. Waterharmonicas around the world

Since 1994 several Waterharmonicas have been constructed in The Netherlands, Sweden and Spain, each system with different reasons and purposes for construction (Kampf & Boomen, 2013b), as exemplified in the Table 3.

Table 3. Some examples of Waterharmonica Systems in the Netherlands and their main functions. Based on (Kampf & Boomen, 2013b).

Waterharmonica	Primary Purpose/Reason for construction
Everstekoog, Texel, The Netherlands	Source of fresh water for agriculture on the island and disinfection of the effluent.
Empuriabrava, Spain	Supply water for a nature reserve, developing natural and local value.
Tilburg-Noord, The Netherlands	Buffer effluent during rainwater discharge in order to don't exceed the capacity of the receiver stream.
Waterpark Groote Beerze, The Netherlands	River restoration and development of wet ecosystems.
Kristalbad, The Netherlands	Develop a recreational green buffer zone, water buffering during rains (180,000 m^3) and improve the water quality.

As it can be seen, there are several possible reasons or motivations to build a Waterharmonica System, and one designed function doesn't necessarily exclude another, this way, a Waterharmonica System may have several functions.

2.2. Change in Suspended solids

In the effluent of the STP there are still high loads of solids which are composed mainly by washed sludge, pathogens and algae, as soon as the effluent enters in the Waterharmonica System the amount of suspended solids decreases greatly in the first and second ponds (pre-settling basin and daphnia pond).

The reduction in suspended solids occurs due to settling, predation, death by UV and decomposition. However, in the aquatic plant ponds, swamp forest or spawning ponds the amount of suspended solids increases again due to development of algae, zooplankton and macro-fauna. Thus, at the end of the system the suspended solids become much more 'natural' and similar to the ones found in the natural water systems. (Kampf & Boomen, 2013b).

2.3. Nutrients removal

The removal of nutrients (nitrogen and phosphorus) from the effluent in the Waterharmonica System occurs mainly in the reed ditches because of its large surface area for biofilm formation (Schreijer, 2000) the rest of the reduction in the amount of nitrogen and phosphorus is due mainly to capture by plants, denitrification and ammonia escape. Besides of that, a pond with submerged aquatic plants at the end of the system can improve even more the effluent quality, removing metals and specific contaminants. (Kampf & Boomen, 2013b).

2.4. Pathogens removal

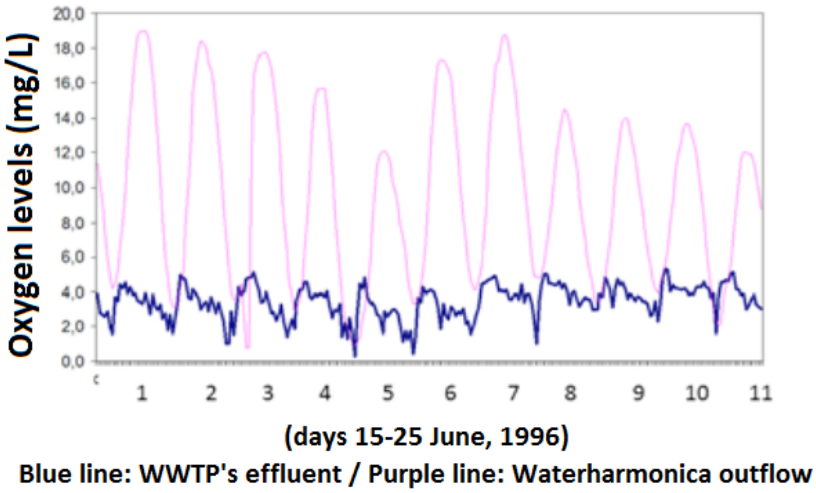
Escherichia coli is the most used indicator for pathogens and its concentration in STPs' effluents is on the order of 50.000 to 100.000 E. coli/100 mL.

In a Waterharmonica System, several studies have shown that a pathogen removal of 99 to 99.9% is possible. This reduction is mainly due to predation by zooplankton and daphnia in the first ponds but also death caused by UV radiation, this way, the removal efficiency is closely related to the Hydraulic Retention time for the Waterharmonica System (Kampf & Boomen, 2013b), as explained in chapter 9.

2.5. Oxygen rhythm

The effluent from the STP has a low-oxygen rate and the Waterharmonica System is able to develop a day-night rhythm in the oxygen level, as illustrated in Figure 8. The changes in oxygen levels is due to the photosynthesis of algae and aquatic plants during the day and during the night the processes of consumption by macro and micro-fauna take place, reducing the oxygen levels. The amplitude of this rhythm can be affected by the season, and other factors such as the coverage of the water surface by plants (e.g. duckweed), which block the sunlight and reduce the algae metabolism. (Kampf & Boomen, 2013b).

Figure 8. Rhythm of the oxygen levels in both STP and Waterharmonica effluents. Source: (Kampf & Boomen, 2013b).



2.6. Development of natural areas and biodiversity

The Waterharmonica creates new wetland areas, which will naturally be occupied by birds, frogs, fishes and other animals present in this kind of habitat. Furthermore, the last part of the system can be used (it usually is) as a fish spawning pond, which is connected to the receiver water body and with fish ladders, the fish can come in and out of the Waterharmonica. Increase in the number of species present in the Waterharmonica and shift to “cleaner species” is also observed in the Waterharmonica Systems. (Kampf & Boomen, 2013b). Besides of develop natural areas and increase the biodiversity, with the new fishing spawning ponds, the fish population in the receiving water bodies will also increase, helping on their restoration.

Special designs that aim to attract wild life were also made, for instance, the last part of the fish spawning pond at Grou and Soerendonk (Waterharmonica systems, in the Netherlands) has been developed as marshy pasture land which attracts several species of birds. (Sala & Kampf, 2011).

2.7. Buffer peaks loads

Due to a highly diversified supply of sewage that reaches a STP, the flow rate and the quality of the effluent leaving the treatment plant, change as well. These variations are easily buffered in a Waterharmonica, even with a small system there is far less risk of the standards being exceeded. (Kampf & Boomen, 2013b). During rainfall discharge, more than 90% of the suspended solids from a sludge overflow are buffered in the first ponds (settling and Daphnia pond). (Foekema & Roex, 2012). Buffering the pollutant levels leaving the STP, the lower is the risk of undesirable situations, such as excessive eutrophication of the water bodies, an important aspect when you aim to recover and improve water quality in the receiving water bodies.

2.8. Buffer Rainfall Peak Loads

Some Waterharmonicas Systems are design to store rainfall water, avoiding floods and overflow of the water bodies. Systems, like Tilburg-Noord and Kristalbad, in the Netherlands, are designed to buffer precipitation peaks.

For instance, in one Waterharmonica in the Tilburg-Noord STP, during excessive rainfall episodes, the natural receiving water system could no longer handle the whole water volume, so a Waterharmonica was built in order to buffer the surplus, acting as a temporary storage place for the water, until the receiving Water System was able to handle the extra volumes. Now, the Kristalbad system, with a relatively long hydraulic retention time of 4 days and a regular flow of 40000 m3/day, shows that even if the flows increases 350% (to 140000 m3/day) the effect in the hydraulic retention time is not proportional, because the retention time changes from 4 to 2.5 days illustrating very well the adaptability of the Waterharmonica during flow increases. (Kampf & Boomen, 2013b).

2.9. Water re-use

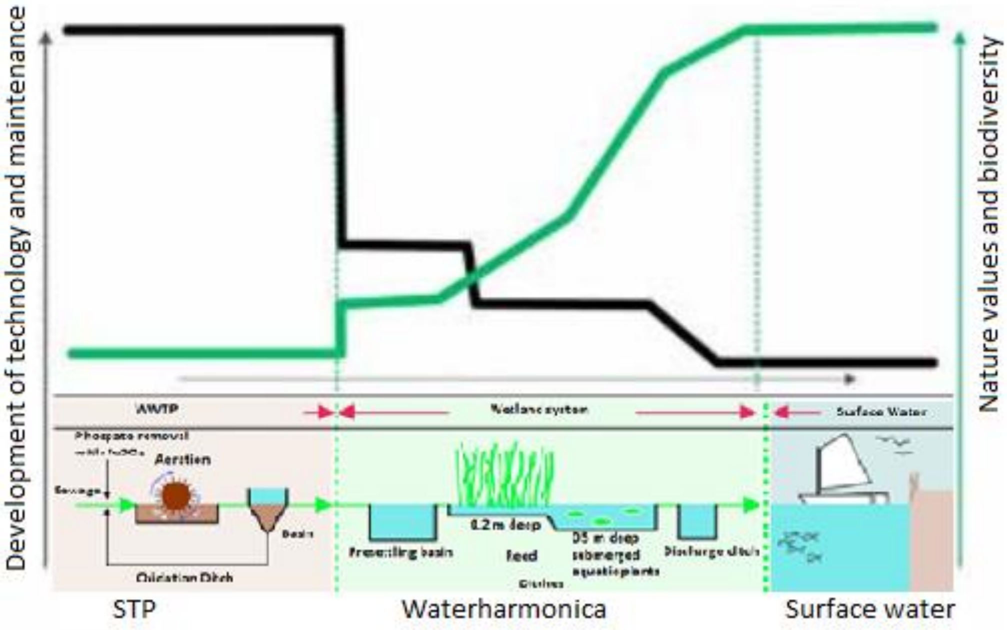
The main goals of the Waterharmonica system is 'to give water back to nature', and allow the direct re-use of the treated effluent, in the fields, cities and industries, for washing and irrigation or even for drinking water production, after specific proper treatment. Depending on the use for which the water is intended, specific requirements can be laid down on its design, management and maintenance. For instance, designs can be modified to change specific aspects or pollutant levels in the effluent quality from the STP, depending on the need. The point is that a Waterharmonica represents a new source of clean water and this water may have numerous different uses, depending on the region the Waterharmonica is located.

2.10. Other aspects to consider about the Waterharmonica Systems

The main disadvantage of the Waterharmonica system is the necessity of great areas in order to construct all the required structure. Yet, in comparison to conventional treatment systems, the Waterharmonica Systems (essentially, a constructed wetland) have usually low cost, are easily operated and maintained and make low or no-use of electricity. They are applicable at small and large scale, producing an effluent with constant quality.

The improvement in the effluent quality and its reuse is only some of all the advantages. The system can work as a source of biomass (Mels et al, 2005), besides it develops recreational and natural areas, attract wild life, store water, etc. Summarizing, it converts the value still contained in the STP effluent into natural values, values which technical and conventional techniques doesn't have or bring to the environment, in fact, technology and maintenance need are inversely proportional to the nature values and biodiversity a certain technology can bring, as exemplified in Figure 9 for a general Waterharmonica System. (Kampf & Boomen, 2013b).

Figure 9. Relation between technology and nature values in the Waterharmonica sections. The black line represents the need of technology and maintenance and the green line represents the nature values and biodiversity. Source: (Kampf & Boomen, 2013b).



The Waterharmonica technology is a very promising equipment to be applied in developing countries like Brazil, due to its relatively small costs and simple management. In addition, being a tropical country with abundant sunlight, Brazil benefits the plants development during the whole year. Moreover, the government of São Paulo, responsible for the water bodies, is willing to improve the quality from the water bodies and increase the rates of water re-use, so, the Waterharmonica System seems to be very suitable for this scenario.

However, the Waterharmonica system is not widespread, due to lack of awareness and local expertise to develop the technology on a local basis. (Kivaisi, 2001). So, in order to verify the viability of application of the Waterharmonica concept in the Metropolitan Region of São Paulo, several STPs were evaluated, as a first step to the development of this technology in Brazil. Specific evaluations and estimates for the possible Systems in the MRSP are displayed in the chapters 6, 7, 8 and 9.

3. Objective and Main research question

3.1. Objective

Give recommendations to Government of São Paulo, about eco-engineered technologies to apply in order to improve the low environmental quality of the water bodies in the Metropolitan Region.

3.2. Main research question

How to apply the Waterharmonica concept to improve the effluent quality of a sewage treatment plant and convert it into usable surface water, employing natural processes, in the densely populated Metropolitan Region of São Paulo, Brazil?

4. Methodology

In order to apply the Waterharmonica concept in the MRSP, some specific aspects must be analysed and for this analysis it was used Google Earth® and Google Maps®. The analysis is necessary in the surrounding areas of the STPs before start the planning, because if there's not enough or adequate area near or around the STP, the Waterharmonica System is not possible to be built.

The analysis takes into consideration some relevant aspects, such as the availability of land, the relief and the proximity to airports. These aspects are directly related to the physic feasibility aspects of a Waterharmonica Systems and they are briefly explained on the table 4.

Table 4. Relevant aspects and their influence in the Waterharmonica performance.

Aspects	Influence on the Waterharmonica
Availability of space	Waterharmonica systems require big areas to be constructed. The bigger the area, the higher the treatment capacity and contaminants removal.
Relief of the area	Flat and downhill areas are more feasible for Waterharmonica systems, avoiding extra costs with pumping stations and pipes.
Proximity to airports	Waterharmonica systems attracts birds, for this reason it should be avoided near airports.

Used the tools Google Earth and Google Maps, it was possible to find 26 STPs in the MRSP. After identified the locations, the aspects presented in the table 4 were evaluated and the results are summarized in the Table 5. From the 26 STPs that were found, only 10 presented the physical structure and adequate location to apply the Waterharmonica concept.

Table 5. Summary of the area assessment for the different STPs found in the MRSP.

WWTPs in the MRSP	Availabity of Space		Feasible Relief		Close by Airports		Feasible for Waterharmonica	
	Yes	No	Yes	No	Yes	No	Yes	No
ABC	X		X			X	X	
Arujá	X		X			X	X	
Barueri	X		X			X	X	
Biritiba	X		X			X	X	
Bon-sucesso	X		X		X			X
Cipó		X		X		X		X
Cotia	X			X		X		X
Embu-guaçu	X		X			X	X	
Juquitiba	X			X				X
Mairiporã	X			X				X
Mauá		X		X				X
Mogi-leste	X		X			X	X	
Parque Novo Mundo	X		X			X	X	
Pirapora	X			X		X		X
Remédios		X		X		X		X
Riacho Grande		X	X			X		X
Rio Grande da Serra	X			X		X		X
Salesópolis	X		X			X	X	
Santana do Parnaíba		X	X			X		X
São João	X		X		X			X
São Lourenço da Serra	X			X		X		X
São Miguel	X		X			X	X	
Suzano	X		X			X	X	
Terra Preta	X			X		X		X
Vargem Grande Paulista	X		X		X			X
Várzea do Palácio	X		X		X			X

After selecting the feasible STPs concerning the area and location, it's time to collect data about the volume and quality of the effluent from the STP. Information such as effluent load, nitrogen and phosphorus levels are important to develop the design of the Waterharmonica, and to calculate the required size of the ponds and the treatable volume of effluent from the STP.

Unfortunately, only a very small part of this information was available at the internet (mainly the effluent volume), and SABESP is not willing to provide this data via phone or other electronic means. For this reason, some of the designs were developed using not so recent data (from 1999, 2000, and 2006) for effluent quality and for some STPs, which the required information was not available, effluent quality was estimated, based on the effluent characteristics from similar STPs, with close flows, size and efficiency.

With specific information about the STPs, the next step is to answer 5 questions to guide development of the designs. The questions are presented below:

- **Effluent aspects:** What is the volume and the quality of the effluent from the STPs?
- **Goal:** Is there a need to improve water quality of the receiving surface water body?
- **Flood:** Is there a need of storing peak flows of precipitation at or near the STP?
- **Re-Use:** Could the re-processed effluent be re-used by individuals, farmers or companies?

- **Advantages:** What extra features does the Waterharmonica add compared to other techniques or devices?

Answer this questions is necessary to give new insights about the kind of effluent re-use, for the specific STPs, according to its location. Some main functions were proposed, as can be seen in the table 6, these functions were attributed for the different STPs, in the next chapters.

Table 6. Different uses for the Waterharmonica discharge based on its location.

Location	Function
Near Rivers / Streams	Provide water for river restoration
Near Parks	Provide water for lakes and irrigation
Near Industries	Provide water for cleaning and other uses
Near Farmlands	Provide water for crop irrigation and animals
Near Urban Areas	Provide water for urban cleaning and irrigation
Near Flooding Areas	Store Water during rainfall peaks

From the available area near or around the STP, the feasible volume to be treated was calculated, based on effluent load entering the Waterharmonica System. For some specific STPs the extra capacity to store water during rainfall peaks were also calculated.

The quality of the "natural clean water" produced by the Waterharmonica will vary for the different Systems, and according to its use, different final quality is needed. For instance, water that is used to wash urban areas doesn't need to be as clean as the water used to irrigate croplands.

The last step is to compare and show the costs of the Waterharmonica systems, taking into consideration the price of the land and all the needed infrastructure, versus conventional techniques used for sewage treatment or effluent polishing.

At the end some estimates about the Waterharmonica efficiency are given.

5. Possible Waterharmonica Designs

5.1. Development of designs

Ten STPs from the MRSP were selected to develop a Waterharmonica design, as shown in Figure 10. Due to their location and characteristics, they were divided in two different groups. From the 10 STPs selected, five of them are located in the urban agglomeration (green marker with black dot), and other 5 in rural areas or urban fringes (green marker).

Figure 10. Location of the selected STPs over the MRSP. Source: Google Maps®, own elaboration.

The first group (Suzano, Barueri, Novo Mundo, São Miguel and ABC) forms the main system for sewage treatment in the MRSP and are responsible for the greatest part of all the sewage treated on the RMSP, for these STPs, the treatment is always based on activated sludge technology, on secondary level. (SABESP, 2011).

The second group is formed by smaller STPs, located in the urban fringes that uses more simple treatment such as ponds (aerobic, anaerobic, facultative and maturation). (Riccitelli, Semura, & Zelmikaitis, 2005). Another characteristic different from the first group is that each of these plants are responsible for treat the sewage anything other than the city which they are located. (SABESP, 2011).

The design of the Waterharmonicas depends on their intended functions, although, different functions can be combined. For the Waterharmonica designs' elaboration, it was followed some guidelines, especially regarding to the water load entering the Waterharmonica System. Here it was used the same division in load's classification used by Kampf and Boomen (2013a).

It was chosen to split the Waterharmonicas in load classes, because around the STPs not always the land available for the Waterharmonica construction is enough to meet all the load classes. Splitting the designs into classes, it's easier to realize either which classes of Waterharmonica are possible to build for each STP , varied loads depending on the wanted water quality and natural values in a Waterharmonica or how many percent of this total flow can be treated in the Waterharmonica, in the available area.

Finally, the Waterharmonicas were divided into 5 different load classes, from "extremely low" to "extremely high" and each class represents different functions, as briefly illustrated in the Table 7. However, the goal on this document is to give a first insight about the opportunities and potential Waterharmonicas for the Metropolitan Region of São Paulo, at this moment, it's not the objective to give specific characteristics of the designs, such as ponds sizes and types and the actual removal efficiencies.

Anyhow, the next step to further development of the designs would be to define each of the Waterharmonicas with more specific purposes (i.e. removing nutrients or water storage or recreational, etc.), this way, it’s possible to make the designs with a deeper planning and specificity such as size of ponds and kinds of vegetation to use.

Table 7. Rough guidelines for designing Waterharmonicas, split up into the load classes ‘extremely low’ to ‘extremely high’ and give some idea about relevant functions.
Source: Based on Tables 1 and 6 (Kampf & Boomen, 2012), own elaboration.

Class by the load	Net load (m/day)	Examples of Waterharmonica	Relevant functions and characteristics
1. Extremely Low	**< 0.05**	Klaterwater	To produce water with a low level of nutrients and pathogens;
2. Low	**0.05 - 0.1**	Elburg	To lower the nutrient level in STP effluent (taken out of operation);
3. Medium	**0.1 - 0.2**	Waterpark Groote Beerze in Hapert; Aqualân Grou; Kristalbad; Sint Oedenrode; Soerendonk; Vollenhove	River restoration and to promote wet habitats; To develop nature and spawning ponds/fish migration; Urban projects related to the water cycle; Regional buffering water; “Greening” of effluent and improvement of water quality; Bird sanctuary with watchtower;
4. High	**0.2 - 0.3**	Everstekoog; Sint Maartensdijk; Land van Cuijk	Source of fresh water for agriculture and nature; To reduce nutrients’ levels; Research into helophyte filters; Recreation;
5. Extremely High	**> 0.3**	Tilburg-Noord	To buffer effluent during rainwater discharge due to the limited capacity of the receiving stream;

6. Designs for the urban agglomeration (main system)

This group of STPs forms the Main System for sewage treatment in the MRSP, they are located in the central region, use activated sludge and usually have bigger treatment capacities, besides of that, each of them serve several municipalities, not only the city they are present. They are also located in areas affected by flooding as shown in section 8.5 of this report.

They are located in areas with smaller available areas to build a Waterharmonica System, which means that not all the different load classes are always possible.

The effluent quality shown here is not much precise, due to the lack of information about this aspect on the internet, they are mostly an estimation made by the authors as explained in section 4 of this report. Among others explained later, an interesting aspect about the designs in the urban agglomeration is the possibility to bring back some green areas to the MRSP, which can be used for nature improvement and also for recreation.

6.1. Suzano

Table 8. General characteristics of Suzano STP. Source: (SABESP, 2011).

Town		Administration
Suzano		SABESP
Treatment type		**Removal efficiency**
Activated Sludge		90% for organic matter
Effluent quality (mg/L)		**Daily flow (m^3/s)**
Nitrogen	**Phosphorus**	0.815
48.0	4.5	
Geographical info		**Total available area (ha)**
Centre-east part of the MRSP; Neighbour to wetlands of the Tietê river; Directly connected to the Tietê river; Neighbour to urban agglomerations (north and south);		60.0

Figure 11. General view and available area for Suzano STP. Source: (Google Maps, 2014).

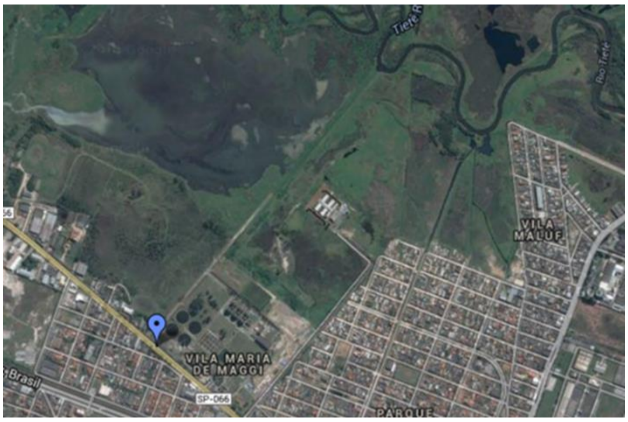


Table 9. Uses for the Waterharmonica discharge, Suzano STP.
- Tietê river restoration; - Supply water for urban use;

Table 10. Area requirements and its capacity to treat the effluent from Suzano STP.

Class by the load	Net load (m/day)	Needed area (ha)	Available area (ha)	Daily water production (m^3/day)	Potential to treat in available area
1. Extremely Low	**< 0.05**	140.8	60	30006.8	42.6%
2. Low	**0.05 - 0.1**	70.4		60013.6	85.2%
3. Medium	**0.1 - 0.2**	35.2		> 70416.0	> 100%
4. High	**0.2 - 0.3**	23.5		> 70416.0	> 100%
5. Extremely High	**> 0.3**	< 23.5		> 70416.0	> 100%

6.2. Barueri

Table 11. General characteristics of Barueri STP. Source: (SABESP, 2011).

<table>
<tr><th colspan="2">Town</th><th>Administration</th></tr>
<tr><td colspan="2">Barueri</td><td>SABESP</td></tr>
<tr><th colspan="2">Treatment type</th><th>Removal efficiency</th></tr>
<tr><td colspan="2">Activated Sludge</td><td>90% for organic matter</td></tr>
<tr><th colspan="2">Effluent quality (mg/L)</th><th>Daily flow (m³/s)</th></tr>
<tr><th>Nitrogen</th><th>Phosphorus</th><td rowspan="2">9.18</td></tr>
<tr><td>46.0</td><td>3.0</td></tr>
<tr><th colspan="2">Geographical info</th><th>Total available area (ha)</th></tr>
<tr><td colspan="2">North-west part of the MRSP;

Directly connected to the Tietê river;

Surrounded by urban agglomerations;</td><td>33.0</td></tr>
</table>

Figure 12. General view and available area for Barueri STP. Source: (Google Maps, 2014).

Table 12. Uses for the Waterharmonica discharge, Barueri STP.
- Tietê river restoration; - Supply water for urban use; - Supply water for industrial use;

Table 13. Area requirements and its capacity to treat the effluent from Barueri STP.

Class by the load	Net load (m/day)	Needed area (ha)	Available area (ha)	Daily water production (m^3/day)	Potential to treat in available area
1. Extremely Low	**< 0.05**	1586.3	33	16500.0	2.1%
2. Low	**0.05 - 0.1**	793.2		32998.0	4.2%
3. Medium	**0.1 - 0.2**	396.6		65996.0	8.3%
4. High	**0.2 - 0.3**	264.4		98994.0	12.5%
5. Extremely High	**> 0.3**	< 264.4		> 98994.0	> 12.5%

6.3. ABC

Table 14. General characteristics of ABC STP. Source: (SABESP, 2011).

<table>
<tr><th colspan="2">Town</th><th>Administration</th></tr>
<tr><td colspan="2">São Paulo</td><td>SABESP</td></tr>
<tr><th colspan="2">Treatment type</th><th>Removal efficiency</th></tr>
<tr><td colspan="2">Activated Sludge</td><td>90% for organic matter</td></tr>
<tr><th colspan="2">Effluent quality (mg/L)</th><th>Daily flow (m³/s)</th></tr>
<tr><th>Nitrogen</th><th>Phosphorus</th><td rowspan="2">0.71</td></tr>
<tr><td>20.0</td><td>2.0</td></tr>
<tr><th colspan="2">Geographical info</th><th>Total available area (ha)</th></tr>
<tr><td colspan="2">Central part of the MRSP;

Surrounded by urban agglomerations;</td><td>29.3</td></tr>
</table>

Figure 13. General view and available area for ABC STP. Source: (Google Maps, 2014).

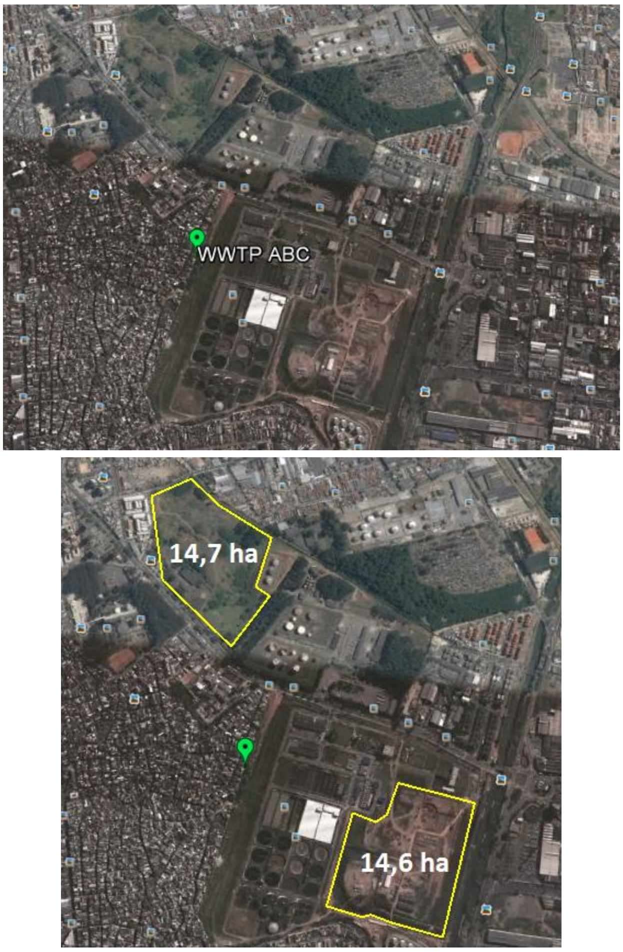


Table 15. Uses for the Waterharmonica discharge, ABC STP.
- Recover streams; - Supply water for urban re-use; - Supply water for industrial re-use;

Table 16. Area requirements and its capacity to treat the effluent from ABC STP.

Class by the load	Net load (m/day)	Needed area (ha)	Available area (ha)	Daily water production (m³/day)	Potential to treat in available area
1. Extremely Low	**< 0.05**	122.7	29.3	14648.6	23.9%
2. Low	**0.05 - 0.1**	61.3		29321.0	47.8%
3. Medium	**0.1 - 0.2**	30.7		58546.5	95.4%
4. High	**0.2 - 0.3**	20.4		> 61344.0	> 100%
5. Extremely High	**> 0.3**	< 20.4		> 61344.0	> 100%

6.4. Novo Mundo

Table 17. General characteristics of Novo Mundo STP. Source: (SABESP, 2011).

<table>
<tr><th colspan="2">Town</th><th>Administration</th></tr>
<tr><td colspan="2">São Paulo</td><td>SABESP</td></tr>
<tr><th colspan="2">Treatment type</th><th>Removal efficiency</th></tr>
<tr><td colspan="2">Activated Sludge</td><td>90% for organic matter</td></tr>
<tr><th colspan="2">Effluent quality (mg/L)</th><th>Daily flow (m³/s)</th></tr>
<tr><th>Nitrogen</th><th>Phosphorus</th><td rowspan="2">2.05</td></tr>
<tr><td>15.0</td><td>2.0</td></tr>
<tr><th colspan="2">Geographical info</th><th>Total available area (ha)</th></tr>
<tr><td colspan="2">North-central part of the MRSP;

Directly connected to the Tietê river;

Surrounded by urban agglomerations;

Neighbour to the “Tietê Ecological Park”;</td><td>9.2</td></tr>
</table>

Figure 14. General view and available area for Novo Mundo STP. Source: (Google Maps, 2014).

Table 18. Uses for the Waterharmonica discharge, Novo Mundo STP.
- Tietê river restoration; - Supply water for the ponds of the neighbour park;

Table 19. Area requirements and its capacity to treat the effluent from Novo Mundo STP.

Class by the load	Net load (m/day)	Needed area (ha)	Available area (ha)	Daily water production (m³/day)	Potential to treat in available area
1. Extremely Low	**< 0.05**	354.6	9.2	4599.8	2.6%
2. Low	**0.05 - 0.1**	177.3		9199.6	5.2%
3. Medium	**0.1 - 0.2**	88.6		18409.6	10.4%
4. High	**0.2 - 0.3**	59.1		27598.8	15.6%
5. Extremely High	**> 0.3**	< 59.1		> 27598.8	> 15.6%

6.5. São Miguel

Table 20. General characteristics of São Miguel STP. Source: (SABESP, 2011).

<table>
<tr><th colspan="2">Town</th><th>Administration</th></tr>
<tr><td colspan="2">São Paulo</td><td>SABESP</td></tr>
<tr><th colspan="2">Treatment type</th><th>Removal efficiency</th></tr>
<tr><td colspan="2">Activated Sludge</td><td>90% for organic matter</td></tr>
<tr><th colspan="2">Effluent quality (mg/L)</th><th>Daily flow (m^3/s)</th></tr>
<tr><th>Nitrogen</th><th>Phosphorus</th><td rowspan="2">0.69</td></tr>
<tr><td>40.0</td><td>3.0</td></tr>
<tr><th colspan="2">Geographical info</th><th>Total available area (ha)</th></tr>
<tr><td colspan="2">North-east part of the MRSP;

Directly connected to the Tietê river;

Surrounded by urban agglomerations;

Neighbour to the “Tietê Ecological Park”;</td><td>34.0</td></tr>
</table>

Figure 15. General view and available area for São Miguel STP. Source: (Google Maps, 2014).

Table 21. Uses for the Waterharmonica discharge, São Miguel STP.
- Tietê river restoration; - Supply water for the ponds of the neighbour park;

Table 22. Area requirements and its capacity to treat the effluent from São Miguel STP.

Class by the load	Net load (m/day)	Needed area (ha)	Available area (ha)	Daily water production (m^3/day)	Potential to treat in available area
1. Extremely Low	**< 0.05**	119.2	34.0	17004.6	28.5%
2. Low	**0.05 - 0.1**	59.6		34009.1	57.0%
3. Medium	**0.1 - 0.2**	29.8		59616.0	> 100%
4. High	**0.2 - 0.3**	19.9		59616.0	> 100%
5. Extremely High	**> 0.3**	< 19.9		59616.0	> 100%

7. Designs for the Urban Fringes

These STPs are located near farms and green areas, they use diverse types of sewage treatment, from activated sludge to more simple techniques such as anaerobic and facultative ponds, they have smaller treatment capacities if compared to the Main System and usually they serve only the municipality they are located or another neighbour municipality.

As they are located outside of the urban agglomeration they present bigger land availability, which means that there's enough space to build Waterharmonica System with any load class and to treat all the effluent produced by the STP, enhancing their potentials. Again, the effluent quality shown here is more an estimation made by the authors.

Among others, an interesting aspect of these designs is the possibility of improving nature conservation on the urban fringes, enhancing not only the biodiversity, which is expected to be bigger on these areas as they are more preserved, but also to improve water quality in the MRSP as general, because most of them are located in areas designed as Watershed protection areas, as explained in section 8.3 of this report.

7.1. Mogi Leste

Table 23. General characteristics of Mogi Leste STP. Source: (Riccitelli et al, 2005).

Town		Administration
Mogi das Cruzes		SEMAE
Treatment type		**Removal efficiency**
Activated Sludge		90% for organic matter
Effluent quality (mg/L)		**Daily flow (m^3/s)**
Nitrogen	**Phosphorus**	0.072
19.0	3.0	
Geographical info		**Total available area (ha)**
East part of the MRSP; Surrounded by farmlands; Directly connected to the Tietê river; Neighbour to a recreational park;		42.0

Figure 16. General view and available area for Mogi Leste STP. Source: (Google Maps, 2014).

Table 24. Uses for the Waterharmonica discharge, Mogi Leste STP.
- Crop irrigation on farmlands; - Supply water for the ponds of the neighbour park;

Table 25. Area requirements and its capacity to treat the effluent from Mogi Leste STP.

Class by the load	Net load (m/day)	Needed area (ha)	Daily water production (m^3/day)	Potential to treat in available area
1. Extremely Low	**< 0.05**	12.4	6220.8	100%
2. Low	**0.05 - 0.1**	6.2		
3. Medium	**0.1 - 0.2**	3.1		
4. High	**0.2 - 0.3**	2.1		
5. Extremely High	**> 0.3**	< 2.1		

7.2. Arujá

Table 26. General characteristics of Arujá STP. Source: (Riccitelli et al, 2005).

Town		Administration
Arujá		SABESP
Treatment type		**Removal efficiency**
Two aerated ponds Two facultative ponds HRT = 5 – 10 days		-
Effluent quality (mg/L)		**Daily flow (m^3/s)**
Nitrogen	**Phosphorus**	0.15
25.0	2.0	
Geographical info		**Total available area (ha)**
North-east part of the MRSP; Surrounded by farmlands;		44.7

Figure 17. General view and available area for Arujá STP. Source: (Google Maps, 2014).

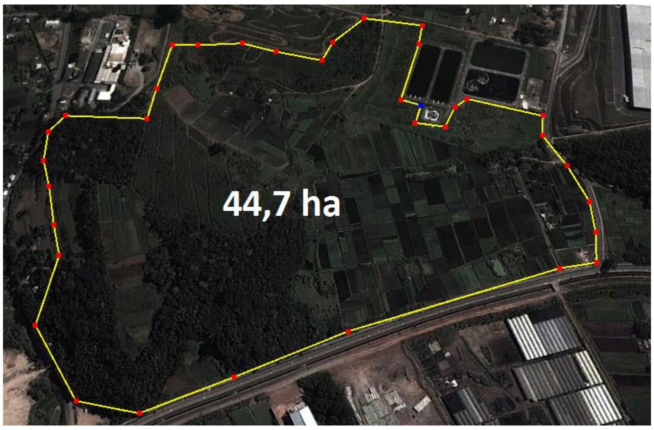


Table 27. Uses for the Waterharmonica discharge, Arujá STP.
- River restoration (Baquirivu stream); - Crop irrigation on farmlands;

Table 28. Area requirements and its capacity to treat the effluent from Arujá STP.

Class by the load	Net load (m/day)	Needed area (ha)	Daily water production (m^3/day)	Potential to treat in available area
1. Extremely Low	**< 0.05**	26.0	12960	100%
2. Low	**0.05 - 0.1**	13.0		
3. Medium	**0.1 - 0.2**	6.5		
4. High	**0.2 - 0.3**	4.3		
5. Extremely High	**> 0.3**	< 4.3		

7.3. Salesópolis

Table 29. General characteristics of Salesópolis STP. Source: (Riccitelli et al, 2005).

Town		**Administration**
Salesópolis		SABESP
Treatment type		**Removal efficiency**
Anaerobic pond (5 days) Facultative pond (15 days)		95% for organic matter
Effluent quality (mg/L)		**Daily flow (m^3/s)**
Nitrogen	**Phosphorus**	0.024
32.0	3.0	
Geographical info		**Total available area (ha)**
Extreme-east part of the MRSP; Surrounded by farmlands;		15.0

Figure 18. General view and available area for Salesópolis. Source: (Google Maps, 2014).

Table 30. Uses for the Waterharmonica discharge, Salesópolis STP.
- Crop irrigation on farmlands; - Supply water for animal consumption (livestock);

Table 31. Area requirements and its capacity to treat the effluent from Salesópolis STP.

Class by the load	**Net load (m/day)**	**Needed area (ha)**	**Daily water production (m^3/day)**	**Potential to treat in available area**
1. Extremely Low	**< 0.05**	4.1	2073.6	100%
2. Low	**0.05 - 0.1**	2.1		
3. Medium	**0.1 - 0.2**	1.0		
4. High	**0.2 - 0.3**	0.7		
5. Extremely High	**> 0.3**	< 0.7		

7.4. Embu-Guaçu

Table 32. General characteristics of Embu-Guaçu STP.
Source: (Riccitelli et al, 2005).

Town		Administration
Embu-Guaçu		SABESP
Treatment type		**Removal efficiency**
UASB reactor + facultative pond		-
Effluent quality (mg/L)		**Daily flow (m^3/s)**
Nitrogen	**Phosphorus**	0.09
28.0	3.0	
Geographical info		**Total available area (ha)**
South-west part of the MRSP; Surrounded by woodlands;		42.0

Figure 19. General view and available area for Embu-Guaçu STP.
Source: (Google Maps, 2014).

Table 33. Uses for the Waterharmonica discharge, Embu-Guaçu STP.
- River restoration; - Supply water for urban use;

Table 34. Area requirements and its capacity to treat the effluent from Embu-Guaçu STP.

Class by the load	Net load (m/day)	Needed area (ha)	Daily water production (m^3/day)	Potential to treat in available area
1. Extremely Low	**< 0.05**	15.6	7776.0	100%
2. Low	**0.05 - 0.1**	7.8		
3. Medium	**0.1 - 0.2**	3.9		
4. High	**0.2 - 0.3**	2.6		
5. Extremely High	**> 0.3**	< 2.6		

7.5. Biritiba-Mirim

Table 35. General characteristics of Biritiba-Mirim STP.
Source: (Riccitelli et al, 2005).

Town		Administration
Biritiba-Mirim		SABESP
Treatment type		**Removal efficiency**
1 aerated pond 3 facultative ponds 1 maturation pond		-
Effluent quality (mg/L)		**Daily flow (m^3/s)**
Nitrogen	**Phosphorus**	0.055
22.0	3.0	
Geographical info		**Total available area (ha)**
West part of the MRSP; Neighbour to wetlands of the Tietê river; Very close to the Tietê river;		23.2

Figure 20. General view and available area for Biritiba-Mirim STP. Source: (Google Maps, 2014).

Table 36. Uses for the Waterharmonica discharge, Biritiba-Mirim STP.
- Crop irrigation on farmlands; - River restoration; - Increase biodiversity (i.e. spawning ponds);

Table 37. Area requirements and its capacity to treat the effluent from Biritiba-Mirim STP.

Class by the load	Net load (m/day)	Needed area (ha)	Daily water production (m^3/day)	Potential to treat in available area
1. Extremely Low	**< 0.05**	9.5	4752.0	100%
2. Low	**0.05 - 0.1**	4.8		
3. Medium	**0.1 - 0.2**	2.4		
4. High	**0.2 - 0.3**	1.6		
5. Extremely High	**> 0.3**	< 1.6		

8. Interpretations of results and first estimates

The principal aim of this work is not to provide a complete selection of designs with all the components of the Waterharmonica System, but to give the first providences and plans about the ideas and locations for future Waterharmonica Systems in the MRSP.

The exploration so far, has showed that in a region like the MRSP, several STPs have the requirements and one or more good reasons for the development of a Waterharmonica system. There are many interests and stake holders (government, population, companies in the area, etc.) involved in the development of a Waterharmonica system and all the parts must be involved for the planning and building-up processes. In this chapter it was assessed, the possible Waterharmonica Systems and their effective contribution and feasibility for the Metropolitan Region of São Paulo, in different perspectives, that includes:

- **Space:** Is there enough space in and/or around the STP for the different classes of Waterharmonica?

- **Legislation:** Can a Waterharmonica System helps the STP to meet discharge parameters according to the legislation into effect in the MRSP?

- **Nature:** Can a Waterharmonica System helps to maintain and strengthen wild life where it's located and neighbourhood?

- **Re-use:** Is there any anthropological uses for the water produced in the Waterharmonica System, according to its region?

- **Water storage:** Can a Waterharmonica system helps to reduce floods in the MRSP?

- **Recreational values:** Which Waterharmonica systems would be located near recreational areas such as natural parks?

The results of the assessment are summarized in the Table 38. It's important to highlight that the green + and ++ characters represent positive scores in a specific aspect while the yellow - represents a negative score or insufficient aspect and the 0 represents an intermediary score, not necessarily influencing the Waterharmonica contribution for the MRSP or its feasibility. The information summarized below is an estimation, intended to be used for further elaboration, prioritization and selection of Waterharmonica systems in the Metropolitan Region of São Paulo.

Table 38. Motivation for the development of the Waterharmonica Systems, based on spatial characteristics.

STP	Sufficient space in-situ	Sufficient space in the surroundings	Improve discharge values to meet parameters	Accomplish water standards for the river class	Watershed/nature protection	Water re-use	Water storage/ Buffer rainfall peaks	Recreational and nature values
	Space		Opportunities and interest for the Waterharmonicas					
Suzano	+	0	+	+	0	0	++	0
Barueri	-	-	0	0	0	+	+	0
ABC	0	0	0	0	0	+	+	0
Pq. Novo Mundo	-	-	0	0	0	+	+	+
São Miguel	+	0	0	0	+	+	+	+
Mogi Leste	+	0	+	+	0	+	0	++
Arujá	+	0	+	+	+	+	0	0
Salesópolis	+	0	+	+	++	+	0	0
Embu-Guaçu	0	+	+	+	++	+	0	0
Biritiba-Mirim	+	0	+	+	++	0	0	0

The information summarized in the Table 38 is explained in more details in the following sections:

8.1. Available Space

In most of the cases (except for Barueri and Pq. Novo Mundo), the area in the grounds or around the STPs is large enough to host a Waterharmonica, which means that in the available space, is possible to treat 100% of the effluent produced by the STP in at least one class of Waterharmonica (vide designs' chapter).

For these STPs with enough space, more than one class of Waterharmonica design is possible, which is very promising, because since the variety of designs is bigger, there are different possibilities which these Waterharmonicas can be applied, as approximately illustrated in Table 7, on chapter 5.

However, even for the STPs without enough space is still possible to treat at least partially (maximum of 12.5% for Barueri and 15.6% for Novo Mundo) the effluent produced by these STPs. These cases are still interesting because even though the space is not proportional to the STP's needs, it's still possible to create new green areas around these STPs and provide a flow of water with much better quality for the receiving water bodies. Moreover, it illustrates how difficult it is to return nature to the urban environments.

At last, the lands highlighted as available for the different STPs, on the designs' chapters, should be verified in order to establish either if they are private or state properties. Since the State government or State companies should start improvement works, if the lands are already owned by the State, the building process is simplified and costs are reduced.

8.2. Legislation

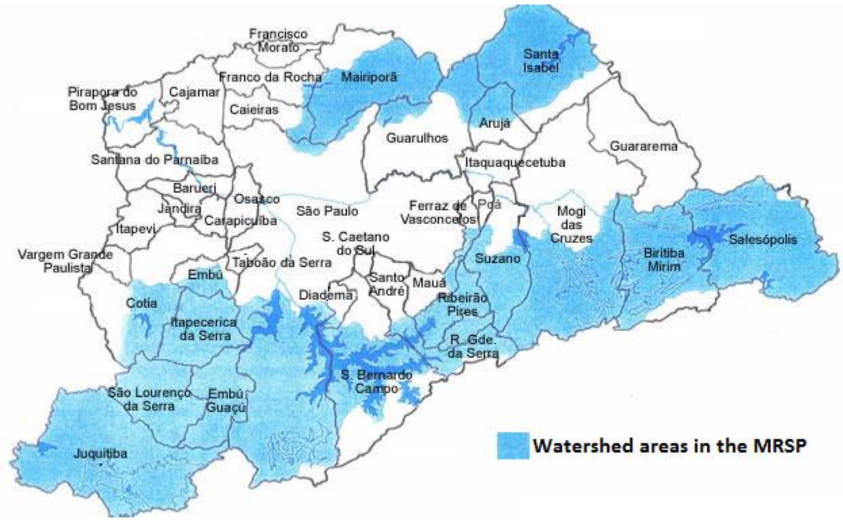
As stated in the Introduction, the MRSP is almost totally contained in the Upper Tietê River Basin, where there are State laws to deal with sewage discharge and water quality. However, these laws are different for the different parts of the MRSP. As illustrated in figure 6 a large part of water bodies in the central area on the MRSP is classified as Class 4, which means there are no standards for sewage discharge or water quality, therefore, the STPs included in this area (São Miguel, Pq. Novo Mundo, ABC and Barueri) were not accounted as possible to improve discharge or quality parameters, despite it's known that a Waterharmonica would probably improve these parameters, however, there are no laws to accomplish for these STPs.

For all the other STPs, especially the ones included on the urban fringes, there are sewage discharge and water quality standards, therefore, it's mandatory to accomplish these standards and a Waterharmonica would play an important role improving the quality of the effluent leaving the STP, especially in terms of reducing BOD, nutrients, pathogens and suspended solid levels, leading to a slow but continuous improvement of the water quality in the region.

8.3. Watershed/nature protection

For this aspect, it was taken into consideration the areas defined as "Watershed Protection Areas", which means places that are under specific State laws, especially regarding restrictions to land-use and environmental licensing. These laws have the objective of preserving the watersheds and water reservoirs, from the increasing negative impacts on the water quality caused by the population increase, especially human occupation and depletion of natural areas. These areas occupy around 50% of the Metropolitan Region of São Paulo (Duarte & Malheiros, 2012), as illustrates figure 21.

Figure 21. Watershed protection areas in the different municipalities of the MRSP. Source: (Duarte & Malheiros, 2012)



As it can be noticed, the most of the STPs assessed in this document are located in municipalities present in watershed protection areas, with special attention to the municipalities of Salesópolis, Biritiba-Mirim and Embu-Guaçu that are almost 100% inside these protection areas, also, STPs from other municipalities are partially contained in these areas.

The implementation of Waterharmonica increases the watershed and nature conservation, it produces a better effluent from the STP, which means a better quality water reaching the streams and reservoirs, it creates new natural areas, which will contribute also for the animal wild life. It's also interesting to take into account when woodlands or wetlands are near the STPs, because the Waterharmonicas can act as a "green corridor" between disconnected natural structures.

8.4. Water re-use

Water re-use is possible from all Waterharmonica Systems here designed, however, in the context of this document, it's considered only uses that are not directly linked to nature conservation and restoration. Which means that one must choose either the purpose of the Waterharmonica is restoration of nature or provide water for human re-use (i.e. urban/farm irrigation, livestock, industrial, etc.)

The only STPs excluded from this aspect are the Suzano and Biritiba-Mirim, because of their location that is in the very wetlands of the Tietê river, which means that a Waterharmonica system could be more an extension of the natural wetlands than a new structure and it could be used especially to increase the biodiversity in the area, (e.g. attracting more birds and creating new ponds for fish spawning), however, if this water is destined for human re-use, this nature potential would be affected.

For the other systems designed, which are part of areas with less influence of nature, the effluent from the Waterharmonica Systems could be used for industries or urban irrigation, and especially in the urban fringes, for other purposes, such as irrigation of farmlands or animal consumption, creating a new source of safe water to be used.

As the effluent produced by the Waterharmonicas have reduced levels of suspended solids and pathogens, it could also be used for the production of drinkable water, after appropriate treatment. However with a better quality, this water would need less or more simplified treatment, which represents cost reduction.

8.5. Water storage/Buffer rainfall peaks

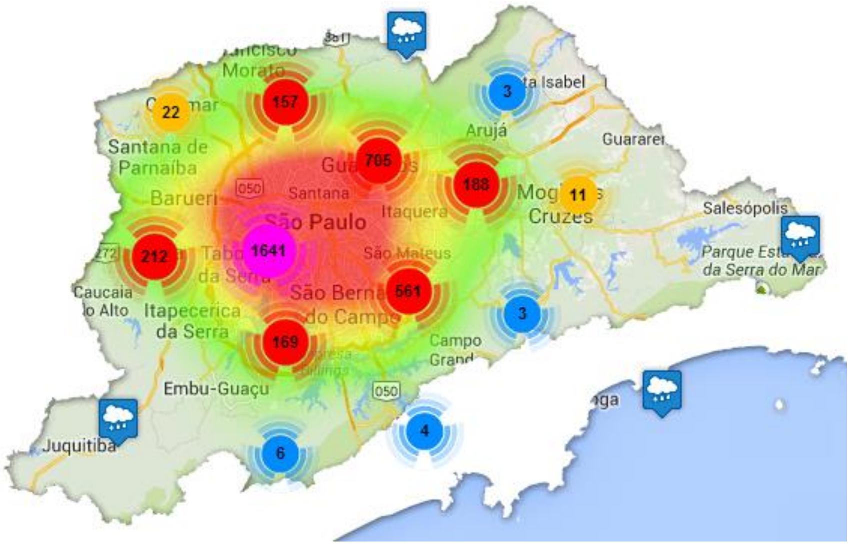
In order to store water and relieve the effects of rainfall peaks, a Waterharmonica system need to be planned taking into consideration not only the changes in the effluent and nature, but also the design and size of the ponds.

In general, if the main purpose of the Waterharmonica is water storage, designs must be done in such way that a water layer of 1.5 m or more can be stored, in the other hand, if the goal is to obtain a natural value, the raise in the water surface should not be bigger than 0.5 m. Yet, to join both characteristics, low volumes are required, and an effluent load of approximately 0.05 m/day can be used as good estimation. (Kampf & Boomen, 2013a).

As a Waterharmonica is formed by a series of ponds and channels, all capable of storing water, the deepest are these ponds and channels, the bigger is the storage capacity. So, the calculations for water storage capacity were made taking into account that each Waterharmonica will be built deeper than it's necessary, with some *"extra depth"* for storage of rainfall water.

Concerning to floods in the MRSP, there's an online platform, hosted by a local news website (G1 São Paulo, 2014) and called *"Map of the Flooding"* (free translation), where the population itself can register the numerous flooding episodes on the Metropolitan Region, according to the region. As illustrated in figure 22 the flooding areas vary through the MRSP, and there are some regions more affected by flooding episodes than others (red region).

Figure 22. Number of flooding complaints distributed over the MRSP.
Source: (G1 São Paulo, 2014)



Based on the *"Map of the Flooding"*, the STPs located in the red and green areas (where there's the biggest number of flooding registered) were selected and their capacity for storing rainfall water, was estimated, as shown in Table 39. It's interesting to note that all of them are part of the Main System for sewage treatment of the MRSP (mainly the central region).

Table 39. Water storage capacity for different Waterharmonicas, based on the extra depth for their ponds.

Total Rainfall Water Storage					
		Extra depth (m)			
STP	**Area (ha)**	**0.50**	**0.75**	**1.00**	
Barueri	33.0	165.0	247.5	330.0	x 1000 m^3
ABC	29.3	146.5	219.8	293.0	x 1000 m^3
Pq. Novo Mundo	9.2	46.0	69.0	92.0	x 1000 m^3
Sao Miguel	34.0	170.0	255.0	340.0	x 1000 m^3
Total Water Storage		**527.5**	**791.3**	**1055.0**	x 1000 m^3

As it's noticed, this specific STPs are located on the middle of the urban agglomeration, which means that not all of them have a big area for a Waterharmonica. Even though, in relatively small areas inside the city, it's possible to store between 500,000 and 1,000,000 m^3 of water, which would not add to the overflowed areas, helping specially the population on these areas.

8.6. Recreational values

Regarding recreational purposes, here it was considered only the proximity to natural parks, not involving direct human contact with the effluent from the Waterharmonica, which means that bathing areas and similar places were not taken into account.

In this aspect, the Waterharmonica could play two different roles. Firstly, it could be integrated as part of the natural park, as sort of an extension, connecting both water system (the STP) and water chain (water bodies in the park), especially in the Mogi Leste STP due to its proximity to the natural park. However, for STPs São Miguel and Novo Mundo this is a hard alternative, because the STPs and the natural park are separated by urban agglomerations. A second role for the Waterharmonica would be as a water provider, not only water, but water with high natural values that could be used to preserve and aggregate more nature to these parks.

Moreover, for the uses proposed above, in the Waterharmonica system is still possible to build and operate educational centres or activities, focused to show the importance of preservation of the wetlands and that it's possible to combine both natural and human systems, taking advantages from both of them.

8.7. Costs

The costs of Waterharmonica system are divided into its construction costs, management and maintenance costs. The construction costs include the cost of the land, costs related to the construction of ponds, reed ditches and banks with some linking structures. The maintenance of a Waterharmonica system is quite simple, and consists in the annual or biennial mowing of the reed and the dredging and removal of aquatic plants, besides removing sludge and other contaminants that tend to settle in the bottom of the ponds. (Kampf & Boomen, 2013b).

The costs of construction of a Waterharmonica System may have big variations. Rough costs for more complex Waterharmonicas (such as Everstekoog, Grou and Land van Cuijk) can be estimated at approx. €175,000 per hectare (Dutch price level 2012), while the cost of simpler systems (such as Sint Maartensdijk) can be kept down to approx. €75,000 per hectare. In the Netherlands the management, including basic monitoring, costs an average of approx. € 7,500/ha/year. While in Swedish Waterharmonica systems the management and maintenance costs vary between € 1,000 and € 7,000/ha/year. (Kampf & Boomen, 2013b).

The earnings of a Waterharmonica are amazing in return for these costs. The conversion of 'dead water' to 'living water' (increasing biodiversity), the balance of peaks in concentrations of pollutants, natural disinfection which does not require chemicals or consume energy, and a recreational area which can be used for education, are some of the benefits provided by the Waterharmonica, which are difficult to quantify in money. Besides that, combinations of functions such as water storage, combating desiccation, recreation and biomass production can deploy other financial sources and the extra costs of a Waterharmonica can be kept down. (Kampf & Boomen, 2013b).

In order to show the cost-effectiveness of Waterharmonica system, Kampf & Boomen, (2013b), compiled the costs of investment, management and maintenance of several purification technologies, including the Waterharmonica, as can be seen in the table 40.

However the calculations of the costs for the designs of the Waterharmonica System in Brazil couldn't be done, since the costs mentioned above are based in European projects, and the price of the lands in the different neighbourhoods and municipalities in the MRSP were not available online.

Table 40. Comparison between conventional sewage treatment techniques with the Waterharmonica costs, per cubic meter treated. Source: (Kampf & Boomen, 2013b).

Treatment Technologies	Cost
STP (Basic treatment)	approx. € 1.00/m³
Ultrafiltration	approx. € 0.35/m³
UV disinfection (pathogens)	approx. € 0.20/m³
Coagulation and (bio)filtration (N and P)	approx. € 0.20/m³
Slow Sand filter (Leidsche Rijn)	approx. € 0.10/m³
Waterharmonica	approx. € 0.05/m³

It's evident that a Waterharmonica has a much lower price, compared to other treatment techniques, but not only that, a Waterharmonica will bring several improvements in exchange for these costs, that the other techniques listed above doesn't bring, what represents another good reason for the development of Waterharmonica Systems not only in the MRSP, but in Brazil in general.

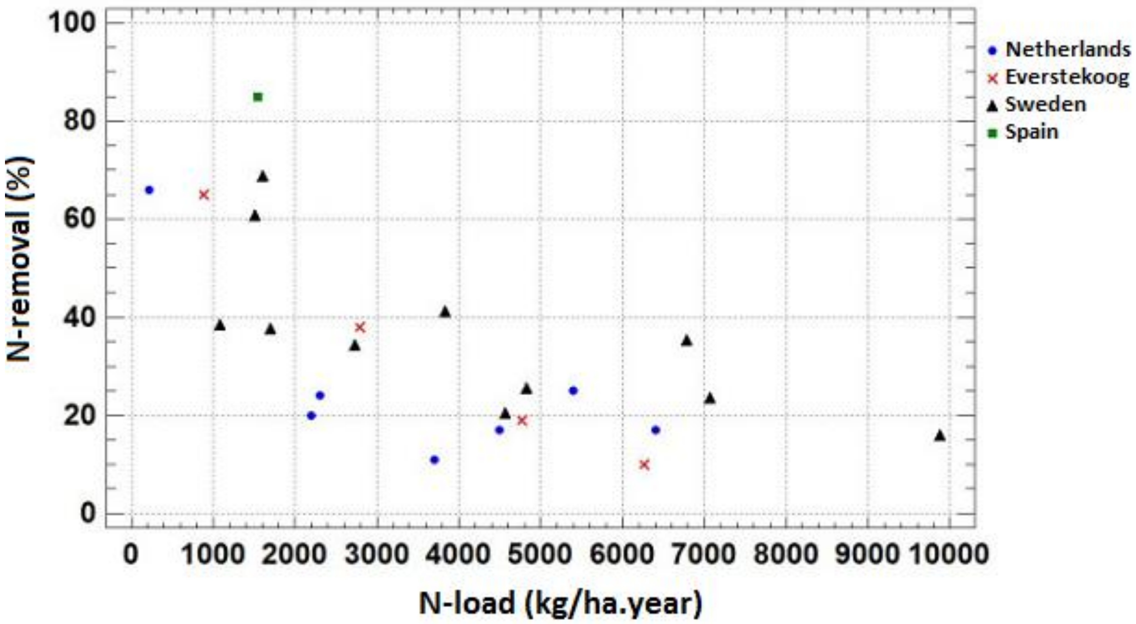
9. Improvements in the effluent quality

9.1. Nitrogen and Phosphorus removal

In most Waterharmonica systems in The Netherlands the nitrogen removal is about 10-25% (Andersson & Kallner, 2002). While in some Waterharmonica Systems in Sweden, the efficiency of nitrogen removal ranges between 25-50% even with higher concentrations, as it can be seen in figure 8. (Flyckt, 2010).

In order to obtain a substantial removal of Nitrogen, its concentration in the effluent must be less than 2000 kg/ha.year, as shows figure 23, with the loads of nitrogen and its removal rates in several Waterharmonicas systems, present in Sweden, Netherlands and Spain.

Figure 23. Nitrogen loads and removal rates for different Waterharmonica systems in Europe. Source: (Kampf & Boomen, 2013a, p. 61)



In the Everstekoog Waterharmonica system the removal of nitrogen exceeds 60% due to long retention times. While in Empuriabrava, Spain, the nitrogen removal is much more effective than the Dutch systems, reducing in 82% at a load of 1,550 kg N/ha/year. (Sala & Kampf, 2011).

Based on figure 23, it's possible to roughly estimate the nitrogen removal, based on the nitrogen load. First is necessary to adjust the points on Figure 23 to a line equation (via linear regression), the result is Equation I, where "x" represents the nitrogen load (in kg/ha.year) and the "y", to be calculated, represents the expected removal in percentage, the expected removal is inversely proportional to the load.

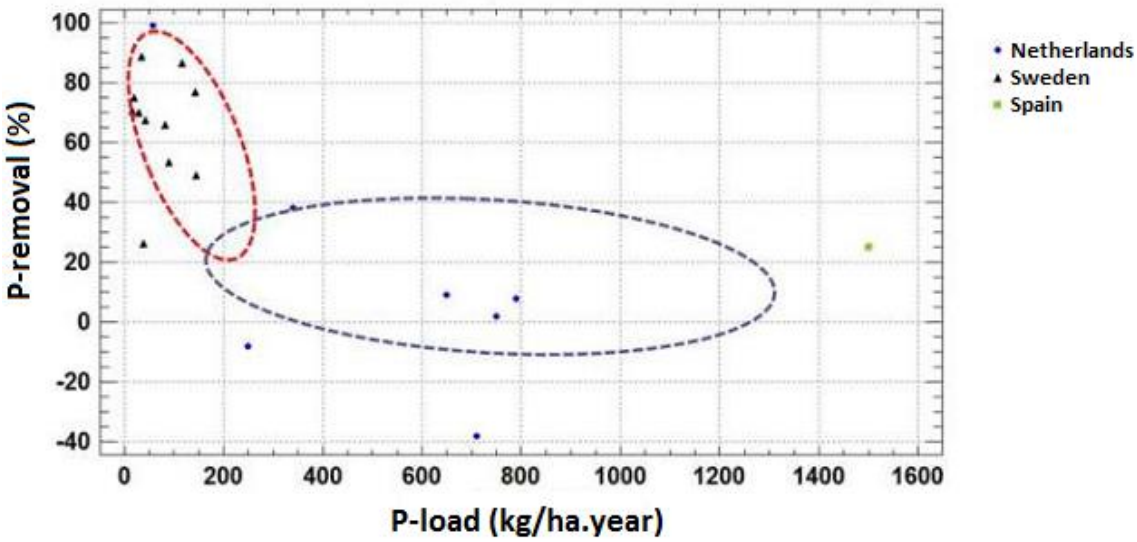
$y = -\ 0{,}006x + 57{,}563$ (Equation I)

However, the removal of nitrogen is not only related to its load on the Waterharmonica system, the retention time plays an important role as well (Figure 26) , this way, it's hard to estimate with great accuracy the actual nitrogen removal. Nevertheless, it's known that with a low nutrient load, very good returns and a far-reaching removal rate is expected. (Kampf & Boomen, 2013b)

Now, related to phosphorus removal, in the Dutch systems the removal rates of phosphate are up to - 40% to + 40%, however, at Klaterwater which uses a combination of a sand filter, a vertical reed bed with subsequent ponds, it can reach P-levels of 0.01 to 0.02 mg/L, which shows a removal efficiency of 99% (Kampf & Boomen, 2013b). In Sweden, removal rates of more than 60% are common, resulting in P-levels of 0.10 until 0.06 mg/L, it's due to lower flow rates and relatively not high nitrogen and phosphorus loads. (Flyckt, 2010).

The Figure 24 shows the removal of phosphorus in Waterharmonicas in Netherlands, Sweden and Spain. As can be seen, the removal of phosphorus is also inversely proportional to its load in the Waterharmonica system, some studies show that with long retention times, far-reaching removal of nutrients takes place (Kampf & Boomen, 2013b).

Figure 24. Phosphorus loads and removal rates for different Waterharmonica systems in Europe. Source: (Kampf & Boomen, 2013a, p. 62)



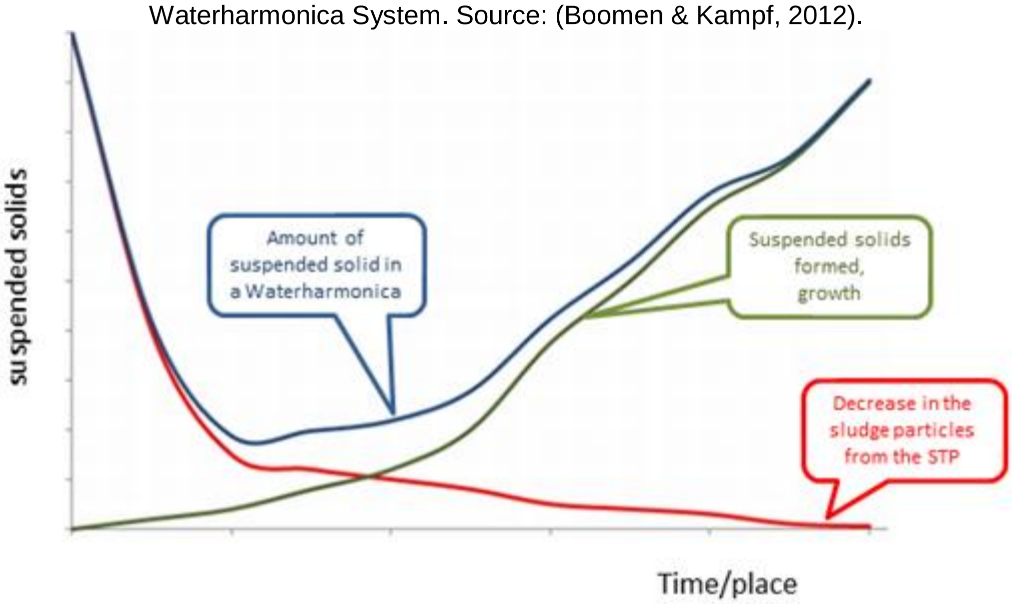
The nutrient removal should largely take place in the STP, then, the Waterharmonica will lower the remaining N and P levels. However, the nutrient removal in a Waterharmonica depends on the concentration and as said above and it decreases, the greater the load. So, for an acceptable nutrient removal, a Waterharmonica with a low to an extremely low load (< 0.1 m/day) is required or an effluent with better quality and lower P-levels.

9.2. Suspended Solids

As it was stated before, the amount of suspended solids in the effluent entering the Waterharmonica doesn't necessarily decrease after passed the Waterharmonica System. However, the composition of the suspended solids changes drastically, as illustrated in the Figure 25.

Before enter the Waterharmonica, the suspended solids in the effluent are formed mainly by 3 components: organic matter, pathogens and heterotrophic bacteria (from the sludge). In the Waterharmonica, between the daphnia ponds and the reed ditches, there's a reduction in the amount of suspended solids, however, after the reed ditches, there's again an increase and at the end of the Waterharmonica System, the composition of the suspended solids has changed, it reaches a big reduction in the amount of organic matter and pathogens and there's a huge increase in the amount of phytoplankton.

Figure 25. The changes in the suspended solids (SS) in the different sections of the Waterharmonica System. Source: (Boomen & Kampf, 2012).



Again, the amount of suspended solid doesn't decrease, but its composition changes drastically from suspended organic matter and pathogens to phytoplankton organisms, much more common in the natural water systems, as the receiving water bodies of the Waterharmonica discharge.

9.3. Pathogens

The quantity of pathogens decreases logarithmically with the retention time (Figure 27). In order to achieve an appreciable reduction, a minimum retention time of 2.5 days (at dry weather conditions) is necessary. (Kampf & Boomen, 2013b).

In comparison between conventional disinfection methods (like sodium hypochlorite) and Waterharmonica Systems, the Waterharmonica is much more efficient. In Everstekoog the average values of 2.700/100 ml were measured for E. coli, which is much lower than the 11.100/100 ml measured during the period that chemical disinfection with sodium hypochlorite was carried out. (Kampf & Boomen, 2013b).

9.4. Hydraulic retention time

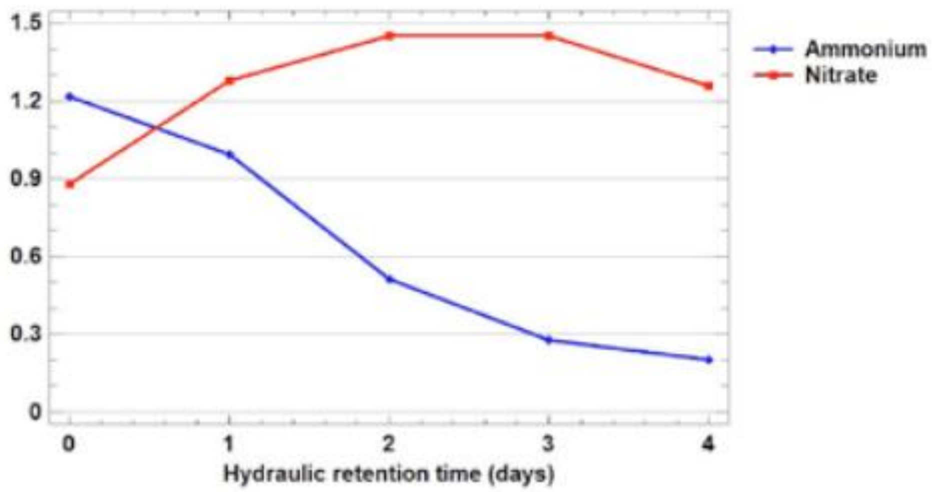
The HRT is the time needed for a given flow to fill the Waterharmonica, which means that low flows and big storage volumes, lead to bigger hydraulic retention times. The Table 41 shows how the effluent flow and the average depth of the Waterharmonica system affect the HRT, where the HRT (in days) is given by the average depth (in meters) divided by the effluent load (in m/day).

Table 41. Hydraulic retention time and its relation with the effluent load entering the Waterharmonica and the Waterharmonica depth.

Effluent load (m/day)	Average Waterharmonica depth (m)			HRT
	0.5	0.75	1.00	
0.05	10	15	20	HRT in days
0.1	5	7.5	10	
0.2	2.5	3.75	5	
0.3	2	2.5	3	

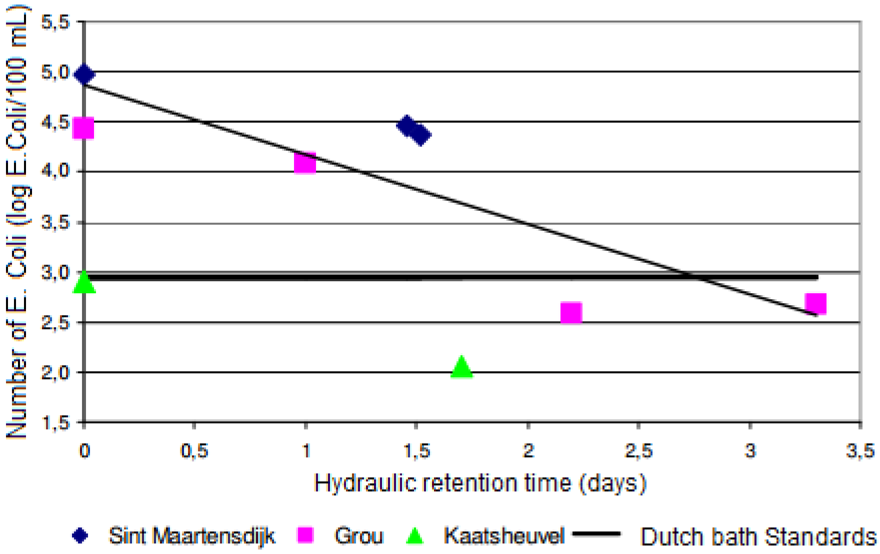
For instance, Waterharmonicas designed to reduce suspended solids and BOD tend to have longer hydraulic retention times (i.e. Põltsamaa in Estonia with HRT of 10 days). Nitrogen removal processes in short HRT is due to denitrification and ammonia escape while in longer HRT the removal is attributed to capture by plants which leads to higher N-removal rates. (Kampf, 2008). The relation between the HRT and nutrients removal is illustrated in the Figure 26.

Figure 26. Hydraulic retention time and its relation with the levels of Nitrogen and Phosphorus compounds in mesocosm experiments, adjacent to the Grou Waterharmonica. Source: (Kampf & Boomen, 2013b).



Another aspect of the importance of the HRT is related to pathogens removal, since the amount of pathogens decrease logarithmically with the retention time, as shows Figure 27. In order to achieve bathing water standards (in the Netherlands), a minimum retention time of 2,5 days is required. Now, if the emphasis of the Waterharmonica System is only on disinfection, the HRT is the most significant design parameter (Kampf & Boomen, 2013b).

Figure 27. Hydraulic retention time influence on the number of pathogens in a number of full-scale Waterharmonicas.
Source: (Boomen & Kampf, 2012), adapted.



Longer retention times also contribute to change on biodiversity found in the Waterharmonica, because it acts increasing the number of and shifting to cleaner species. However, long HRTs may cause algae bloom in some cases. (Kampf & Boomen, 2013b).

As this section shows, the HRT is directly related to the efficiency of the Waterharmonica System, in such way that the planning involving the average depth of the System and the effluent load entering the Waterharmonica, should be carefully defined, since they will directly influence on the System's performance, mainly if effluent changes are required in the Waterharmonicas, such as removal of BOD, Nutrients and Pathogens.

10. Conclusions

The Waterharmonica concept, if applied in the MRSP, would improve the effluent quality from a STP in several ways, such as reducing levels of nutrients (N and P) and pathogens, and changing the composition of the suspended solids, from sludge particles to more natural forms, similar to the ones found in the natural systems.

Besides of using essentially natural processes, by making the post-treatment of the STP effluent in a Waterharmonica, it's possible to turn this effluent into usable surface water. It's due the fact that the Waterharmonica converts the "dead water" coming from the STP to "living water", which means that it brings changes in the oxygen levels and rhythm, it increases the biodiversity of microorganisms in this water from a lot of loose bacteria to microorganisms usually found on the natural water bodies and by reducing the number of pathogens, it also makes the water safer and facilitate its further treatment, in essence, it converts the effluent coming from the STP into an ecologically healthier water.

Furthermore, the Waterharmonica can work storing rainfall water, reducing the risk of floods in the more risky areas of the MRSP. The main system only, would be able to store approximately 1.055.000 m³ of water that could be returned slowly to the water bodies, avoiding to worsen the overflow situation.

Based on the obtained results is possible to realize that a Waterharmonica system can be applied both in the urban areas and urban fringes in the MRSP, however, with different sizes and functions, according to the availability of area and effluent volume.

The Waterharmonica is a good approach, however, before to construct a Waterharmonica system, after find a good place, it's necessary to plan what is going to be the main purpose of the system and the expected loads of nutrients, pathogens and suspended solids, all based on the effluent quality. With these information in hands, the Waterharmonica can be projected and built in a more effective way, to ensure its full potential.

11. Recommendations

In areas with high population density and few available areas, the Waterharmonica is not the best approach to improve the environmental quality of the water bodies, it's due to the great flow of effluent and small available areas, which makes possible to treat only a part of the effluent. For this scenarios the best approach maybe is to build new STPs or increase the size and efficiency of current ones if there is availability of area.

Additionally, with bigger and new STPs, the Metropolitan Region also prepare itself for future increments in its population, in view of that their main system for sewage treatment is not capable to deal with all the sewage already produced by the Metropolitan Region's population at the moment.

In rural areas and municipalities located on the border of the MRSP where there is much more land availability and the population in the cities is not so great, the Waterharmonica may have a bigger potential. In this scenarios with plenty of land and smaller volumes of outputs from the STPs, a great improvement in the effluent quality and consequently in the water quality in general, can be achieved. By treating all the effluent generated by the STPs in the urban fringes, great removals of nutrients, pathogens and suspended solids may be obtained, providing better water for use in the farms or even for river/streams restoration.

The Waterharmonica represents an alternative for increasing the water re-use in the Metropolitan Region as a whole, because if there's a new source of good quality water, that before were just to be discharged, it may alleviate the current degradation of the water bodies and the environmental pressure over them and their surroundings, because less resources would be extracted from them, even increasing their restoration chances.

Furthermore, the application of Waterharmonica was found suitable for application in some parts of the Metropolitan Region of São Paulo, one of the most populated areas in Brazil. Choosing different areas to research, including countryside areas with smaller population density and different sanitary situation, the Waterharmonica concept could be a much more attractive solution to convert some of the value still contained in the sewage into natural values, necessary to keep our ecosystems health.

As a final advice, one must look upstream on the rivers present in the MRSP, to assure the water quality on the rivers flowing over the MRSP, improving nature and protecting drinking water resources for the current and future generations. Upstream there is much more space, less dense population and there are formed the watersheds in the region, with especial attention on the urban fringes, where the development on the following years will probably occur, avoiding future negative impacts.

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