A review of seventeen years of bank filtration in Brazil: results, benefits and challenges - Part 1: state of Santa Catarina

Revisão de dezessete anos de estudos em filtração em margem no Brasil: resultados, benefícios e desafios - Parte 1: Estado de Santa Catarina

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Abstract

This work is the first part of a national review about Bank Filtration (BF) that began in 2003, in Brazil. These studies were conducted in the laboratory and in the field with water and natural sediment from the study regions, showing how BF has been efficient worldwide for the treatment of water for public supply as an alternative treatment. It aims to show the synthesis of results to date and point out its main benefits and challenges; that is, the state of the art at the national level. The review is concentrated in Santa Catarina (part 1), Pernambuco and Minas Gerais (part 2). BF demonstrates efficiency in reducing parameters such as turbidity and coliforms (total and fecal), pesticides and toxins. However, BF showed low capacity in reducing parameters such as salinity and true color. BF is highly dependent on local geological conditions, so parameters such as iron, manganese, fluorine, alkalinity, hardness, and chlorides can be added to the treated water.

Keywords: Water Treatment. Bank Filtration. Public Supply Systems. Natural Sediment. Water Quality.

Resumo

Este trabalho é a primeira parte de uma revisão nacional sobre Filtragem em Margem (FM), iniciada em 2003 no Brasil. Os estudos foram realizados em laboratório e em campo com água e sedimentos naturais das regiões estudadas, mostrando como a FM tem sido eficiente mundialmente no tratamento alternativo de água para abastecimento público. Tem como objetivo mostrar a síntese dos resultados até o momento e apontar os principais benefícios e desafios; isto é, o estado da arte em nível nacional. A revisão está concentrada nos Estados de Santa Catarina (parte 1), Pernambuco e Minas Gerais (parte 2). A FM demonstra eficiência na redução de parâmetros como: turbidez e coliformes (total e fecal), pesticidas e toxinas. Entretanto, a FM apresentou baixa capacidade de reduzir parâmetros como: salinidade e cor verdadeira. A FM é dependente das condições geológicas locais assim, parâmetros como ferro, manganês, flúor, alcalinidade, dureza e cloretos podem ser adicionados à água tratada.

Palavras-chave: *Tratamento de água; Filtração em Margem, Sistemas de Abastecimento Público; Sedimento Natural; Qualidade de Água.*

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1 INTRODUCTION

The increasing industrialization of Brazil in recent years has brought incalculable damage to the environment, especially to surface waters, where deterioration has brought technical challenges to water treatment technologies already employed. Thus, water pretreatment technologies have been widely studied to ensure that treatment plants meet national potability standards.

Bank Filtration (BF) is a water treatment technology that has been used for over 140 years throughout Europe (RAY et al., 2003; SOARES, 2015). In Brazil, this technology has been studied for 17 years, limited to small-scale field studies, with no reports on this technology implementation in full scale. BF consists of the use of natural materials from the bank itself and from the bottom of the source as a filtering medium. It occurs through the positive, natural or induced hydraulic gradient (through pumping) in wells with hydraulic connection, built near the banks of the surface well (Fig. 1).

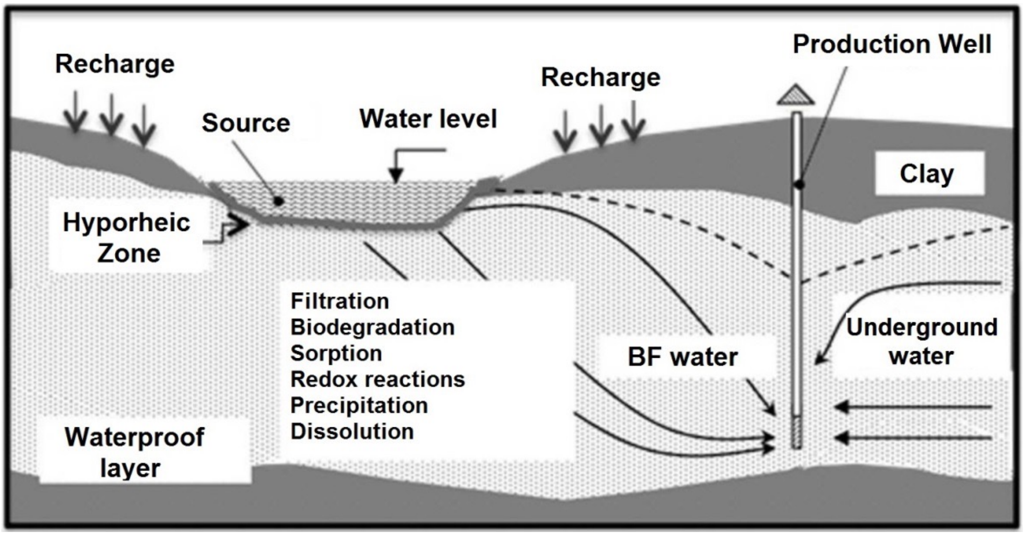

Figure 1 - Operation diagram of Bank Filtration
Source: Esquivel et al. (2012), adapted from Hiscock and Grischek (2002) and Sens et al. (2006)

This gradient induces the water flow through the soil, which removes or attenuates the contaminants present in the surface water in the source-production well route. Captured water is a mixture of both aquifer and surface water percolated by the bank. The proportion of filtered well water captured from wells depends on a number of factors, including bottom depth and permeability, water viscosity, stock elevation, and pumping rates.

According to Donald and Grygaski (2002) apud Sens et al. (2006), the BF system location requires important information about local soil characteristics, such as:

1. Hydraulic conductivity: it is recommended that the value is at least 1 to 2 m/d.

2. Porosity: the larger the grain size and its porosity value, the greater the specific porosity or specific flow of the aquifer.

3. Particle size analysis: the larger the grain size, the larger the pore size.

4. Organic matter content: the presence of soil layers or pockets with OM can give water undesirable characteristics, such as color, taste, and odor.

In addition to physical retention, several other phenomena occur during the water flow towards the well, since the bank soil contains microorganisms that can act in certain substances (pesticides, toxins, organic matter, among others), promoting water quality improvement. Thus, BF works as a low-cost pretreatment in the production of high-quality water supply and can perform as the only treatment before disinfection (MONDARDO, 2009).

BF has been applied in Europe to produce water for supply, most often along the Rhine, Elbe and Danube rivers (RAY et al., 2003). In the United States, interest has grown because it is a low-cost, complete or alternative treatment for filtration systems to remove waterborne pathogens, such as Giardia, Cryptosporidium and viruses (SENS et al., 2006).

The first known BF use for water supply purposes was from a company in the United Kingdom (Glasgow Waterworks), which built a drainage pipe parallel to the Clyde River in 1810 to extract filtered water from the riverbank. In the mid-nineteenth century, BF was officially adopted in Europe to produce drinking water. In Western Europe, one of the first BF facilities was built in Germany on both sides of the Rhine River due to limited groundwater resources in the region. Due to an outbreak of the cholera epidemic in Hamburg, Germany, in 1892, caused by the direct use of the waters of the Elbe River for public supply, the use of artificial or natural passages of underground river water as a new form of water abstraction for human consumption has become essential. Statistical data from 1998 showed that, among sources used for water supply by members of the Rhine River Sanitation Association (German and Dutch side), 49% corresponded to BF and groundwater recharge (RAY et al., 2003).

Some BF facilities on the Danube have been operating for over a century, near the cities of Vienna, Austria, and Bratislava in the Slovak Republic. Other important BF projects can be found in Budapest, and in the city of Belgrade in Yugoslavia (SENS et al., 2006). In Brazil, BF has been used for some time, without being named, in the Upper Itajaí Valley - Santa Catarina State, through wells of 1.2 to 1.5 m in diameter, built along the rivers of Itajaí do Sul, Itajaí do Oeste and Itajaí do Norte (tributaries of the Itajaí Açu River) (SENS et al., 2006).

This work is a national review in the field of bank filtration technology that shows the results obtained over 17 years of studying BF in Brazil to date and point out the main benefits and challenges of the technique; that is, the state of the art at the national level. It was divided into two parts for a better understanding and organization of the content on bank filtration: Part 1 describes the researches performed in the state of Santa Catarina, and Part 2 describes the researches performed in the states of Pernambuco and Minas Gerais. This first part was compiled on a result matrix, from which tables were created containing physical, chemical, biological and specific contaminant parameters. For each grouping of results, there was a discussion of the elaborated table.

Figure 2 - Map of Brazil indicating the three federative states involved in BF research: Santa Catarina, Minas Gerais and Pernambuco states
Source: Authors

A bibliographic search was performed in national and international databases, including articles, theses, dissertations, book chapters and course conclusions, totaling 53 documents that indicated that research on the subject is concentrated in the States of Santa Catarina, Pernambuco and Minas Gerais (Fig. 2).

2 STUDIES CARRIED OUT IN THE STATE OF SANTA CATARINA

The first studies in Brazil using the BF technique were performed in 2003 in Peri Lake, located in the south of Florianópolis island, in the state of Santa Catarina (SC), located in southern Brazil (SENS et al., 2006). Another study location in the city of Florianópolis took place in the Barra da Lagoa region (BURGARDT, 2017). The state of Santa Catarina had two other study sites as well: the city of Ituporanga, in an aquaculture lake (SOARES, 2009) and the Itajaí do Sul river (MICHELAN, 2010), and the city of Orleans, in the Belo River (GUEDES, 2018). The study sites in the state of Santa Catarina are shown in Fig. 3.

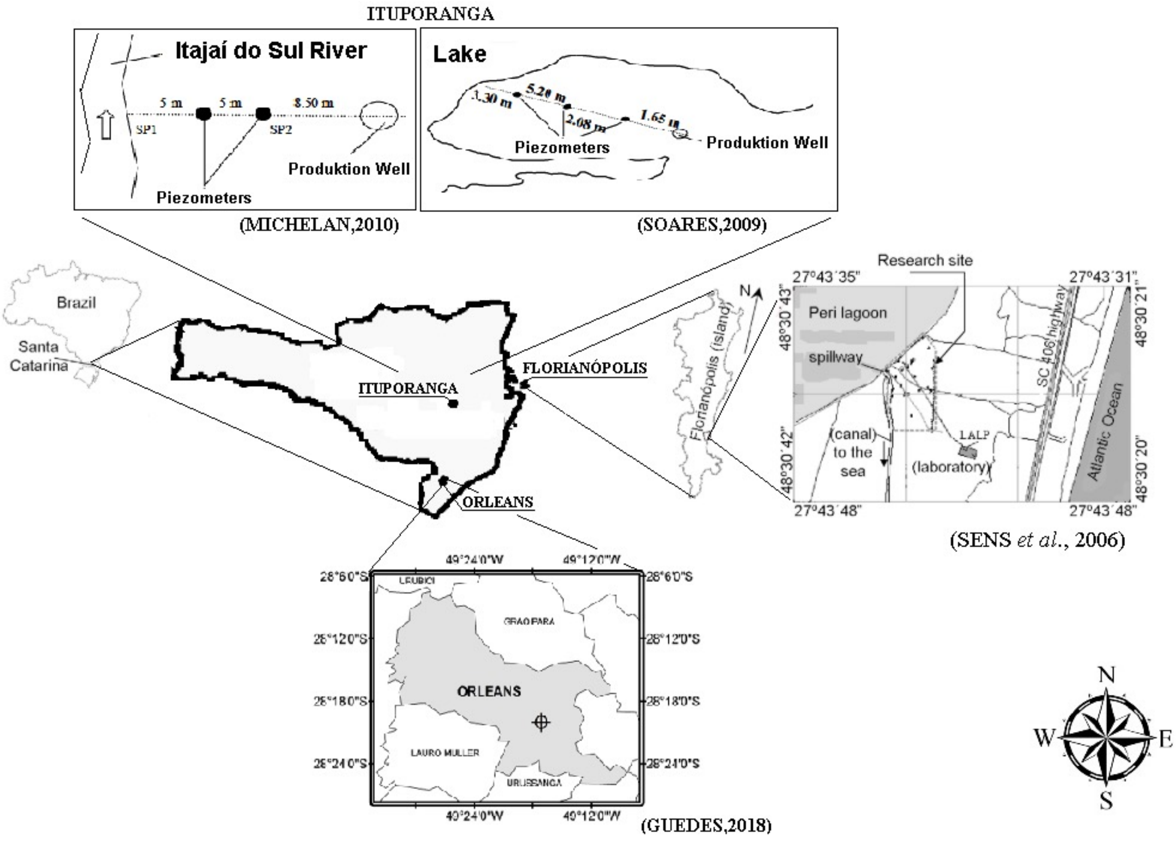

Figure 3 - Location of the study points of the BF technique - Santa Catarina, Brazil
Source: Adapted by the authors from Sens et al. (2006), Soares (2009), Michelan (2010) and Guedes (2018)

2.1 Peri Lake - Florianópolis (SC): Lake bank characterization

Peri Lake is located in the southern region of Florianópolis island. The lake has approximately 5.0 km^2 (SILVA, 1999), an average depth of 4.2 m, its deepest part reaches 11 m (SIMONASSI, 2001). The aquifer has an average depth of 20 m, a hydraulic conductivity of 1x10^{-4} m/s and an effective porosity of 25% (ESQUIVEL et al., 2012). The lake water is approximately 3 m above sea level with no saline wedge intrusion (CAMPOS, 2012). The studies were conducted in an area with marine deposits (SANTOS et al., 1989; OLIVEIRA, 2002). The design of the production well (P1) began in 2003 at 20 m from the shore of the lagoon (SENS et al., 2006). In 2011, this well was replaced by a new one with a smaller diameter (P2), keeping the same distance from the lake (ESQUIVEL et al., 2017).

The sediment analysis carried out from the bottom of the lake, near the wells, showed the presence of 85% of fine sand in the bottom of the Peri Lake (in the first 50 cm), and 13% medium/coarse sand, with little depth variation, and detection of 4% clay (MONDARDO, 2009; ESQUIVEL et al., 2012; SOARES, 2015; SOARES et al., 2019). The presence of organic matter (OM) was also found in the order of 27% in the first 30 cm depth (SENS and DALSASSO, 2007).

The effective diameter values (d10) in Peri Lake were similar in the first 50 cm, indicating hydraulic conductivity from 1.7×10^{-4} to 2.9×10^{-4} m/s (RABELO, 2006; ESQUIVEL et al., 2012; SOARES, 2015; SOARES et al., 2019). The sediment site also has a low curvature coefficient (mean CC of 1.0) and a low uniformity coefficient (mean CU 1.4), indicating uniformity of grains and sediments with grain size tending to homogeneity (ESQUIVEL et al., 2012; SOARES, 2015; SOARES et al., 2019). The low specific porosity, ranging from 25% to 26%, is attributed to the organic deposition of compounds and/or presence of retained gases in the medium (physical and biological clogging) (ESQUIVEL et al., 2012).

Through soil evaluation to a large extent, marine sediments were identified in its composition, with dark sand (since there is OM) up to about 1 m deep, fine sand (also containing OM) from 1 to 4 m deep, fine white sand between 4 and 18 m, and clay between 18 and 23 m. The presence of fine sand falls on a scale of 80 to 99% in the first 5.5 m depth (SENS et al., 2006; SENS and DALSASSO, 2007; ESQUIVEL et al., 2016).

Sens et al. (2007) built P1 with 100 mm in diameter, 12 m deep and the filter in the last 4 m, approximately 20 m from the lake. Monitoring studies have indicated that the flow naturally proceeded towards the main well (SENS and DALSASSO, 2007; MONDARDO, 2009). Two protection wells were also built on each side of P1 to ensure that the water infiltrated preferably came from Peri Lake (SENS et al., 2006). When P2 was built, with 50 mm in diameter and 12 m deep, 20 m from Peri Lake and a 2 m filter, P1 was decommissioned (ESQUIVEL et al., 2017). Seven piezometers were drilled, four of them 12 m deep, located at 8, 40, 55 and 57 m from the bank, and the remaining at 4, 5, and 6 m deep, 1 m from the bank (ESQUIVEL et al., 2012, 2016, 2017). The quality of bank filtered water in P1 and P2 are discussed in Table 1. The saturated aquifer layer (D) was defined as roughly 18 m, with effective porosity (ne) corresponding to 20% (SENS et al., 2006; SENS and DALSASSO, 2007; ESQUIVEL et al., 2012). The pumping flow (Q) in the first study corresponded to 24 m^3/d (approximately 0.26 L/s), obtaining hydraulic conductivity (K) of 1.49×10^{-5} m/s, and 1.5×10^{-4} m/s, and the vertical conductivity (Kv) obtained was 1.42×10^{-5} m/s and horizontal (Kv), 1.42×10^{-4} m/s (SENS et al., 2006; SENS and DALSASSO, 2007; ESQUIVEL et al., 2012). After 48 h of pumping, the well lowered about 0.6 m (SENS et al., 2006; SENS and DALSASSO, 2007). The water's travel time from the lake to the well was about 10 days for the 5.5 m deep well, and 14 days for P1 with a depth of 12 m (SENS and DALSASSO, 2007).

2.1.1 *Water quality characterization: physical, chemical and biological parameters*

Table 1 shows raw water physical parameters (RW - water from the source - Peri Lake) and filtered water (FW - water in production wells - P1 or P2) between the years 2004 and 2017 (SENS et al., 2006; SENS and DALSASSO, 2007; MONDARDO, 2009; CAMPOS, 2012; ESQUIVEL et al., 2012, 2016, and 2017).

As observed, BF was very effective in turbidity removal, in both P1 and P2, (94 and 97% average removal, respectively) and consequently, apparent color (89 and 93% removal, respectively). Not as expressively, advantageous BF results in true color removal were noted as well. In production well P1 (SENS et al., 2006; MONDARDO, 2009), the total dissolved solids (TDS) increased at an average of 3.2 times. The authors pointed out that the increase in TDS was due to the presence of calcium sediment at the site, which was also related to the increase in P1 conductivity (3 times), total hardness (7 times) and total alkalinity (11 times) as per Table 2. Moreover, it was considered that TDS variation was caused by the leaching of existing compounds in the soil.

Table 1 - Results of the physical parameters obtained in Peri Lake.

	Apparent color (Pt–Co Units)	**True color (Pt–Co Units)**	**Turbidity (NTU)**	**TDS (mg/L)**	**Temperature °C**
Ref.	(ESQUIVEL et al., 2017; MONDARDO, 2009; SENS and DALSASSO, 2007; SENS et al., 2006)	ESQUIVEL et al., 2017; MONDARDO, 2009; SENS and DALSASSO, 2007; SENS et al., 2006)	ESQUIVEL et al., 2017; MONDARDO, 2009; SENS and DALSASSO, 2007; SENS et al., 2006)	(MONDARDO, 2009; SENS et al., 2006)	ESQUIVEL et al., 2017; MONDARDO, 2009; SENS and DALSASSO, 2007; SENS et al., 2006)
RW	56 to 78	5 to 9.5	5.64 to 7.24	36 to 36.4	20.5 to 25.5
FW (P1)	2 to 10	2 to 5	0.22 a 0.4	111 to 121.6	21.4 a 24.4
% average removal	**89**	**47**	**94**	**x**	**x**
FW/RW removal	**x**	**x**	**x**	**3.2**	**x**
	Apparent color (Pt–Co Units)	**True color (Pt–Co Units)**	**Turbidity (NTU)**	**TDS (mg/L)**	**Temperature °C**
Ref.	(CAMPOS, 2012; ESQUIVEL et al., 2012, 2016, and 2017)	x	(CAMPOS, 2012; ESQUIVEL et al., 2012, 2016, and 2017)	x	(CAMPOS, 2012; ESQUIVEL et al., 2012, 2016, and 2017)
RW	61 to 90	NA	6.7	NA	20.7
FW (P2)	6 to 6.5	NA	0.19	NA	22.3 to 22.35
% average removal	**93**	**x**	**97**	**x**	**x**

RW- raw water (source-Peri Lake); **FW-** filtered water (production well); **FW/RW average** - average increment of parameter in FW; **NA-** Not analyzed; **NTU-** Turbidity Unit; **TDS-** Total Dissolved Solids.

Source: Adapted by the authors from Sens (2006), Sens and Dalsasso (2007), Mondardo (2009), Campos (2012) and Esquivel (2012, 2016, and 2017)

The RW chemical analysis allowed identification and quantification of polysaccharides (18.8%), humic substances (39.5%), block-built humic substances (15.5%), low molecular weight acids (8.4%) and 12% neutral substances (ESQUIVEL et al., 2017). Regarding the water's chemical quality for the BF system (SENS et al., 2006; SENS and DALSASSO, 2007; MONDARDO, 2009; CAMPOS, 2012; ESQUIVEL et al., 2012, 2016, and 2017), there was a significant increase in alkalinity in P1 and P2, with respect to the supply (10 and 14 times, respectively) and total hardness (7 and 9 times, in P1 and P2, respectively) as observed in Table 2.

There was also a 3- to 4-fold increase in electrical conductivity in both wells. Esquivel et al. (2017) mentioned that the increase of these parameters after BF is justified by the interaction with the aquifer, which has leached minerals in its composition. However, even with the increase of these parameters, as well as total hardness, Ca hardness and Mg hardness in FW, they were within the potability standards effective in 2012 (Ministry of Health Ordinance 2914, current Annex XX of Consolidation Ordinance Nº 5).

In P2, the hardness results in calcium and magnesium showed an increase of 11 and 2 times, respectively. In this well, there was also a small increase of manganese and little variation of iron in relation to the source. In terms of the source, the chloride variation in both wells was not significant either. Similar concentrations of chloride in RW and wells P1 and P2 indicated that most of the filtered water comes from the lake (ESQUIVEL et al., 2017). The pH of the source varied slightly over the 13 years of the study, not exceeding 0.6 pH units. Table 2 shows a small increase in pH in both wells in relation to the source, which agrees with the observed increase in alkalinity and total hardness.

Table 2 - Results of chemical parameters obtained in Peri Lake.

	Total Alkalinity (mg $CaCO_3$/L)	**Chlorides (mg Cl^-/L)**	**Electrical conductivity (µS/cm)**	**Hardness Ca (mg/L)**	**Hardness Mg (mg/L)**	**Total Hardness (mg $CaCO_3$/L)**	**Fe^{2+} (mg/L)**	**Mn^{2+} (mg/L)**	**pH**
Ref.	MONDARDO, 2009; SENS and DALSASSO, 2007; SENS et al., 2006)	(ESQUIVEL et al., 2017; MONDARDO, 2009; SENS and DALSASSO, 2007; SENS et al., 2006)	MONDARDO, 2009; SENS and DALSASSO, 2007; SENS et al., 2006)	x	x	MONDARDO, 2009; SENS and DALSASSO, 2007; SENS et al., 2006)	x	x	MONDARDO, 2009; SENS and DALSASSO, 2007; SENS et al., 2006)
RW	7.64 to 9.6	17.0 to 18.15	67.08 to 78	NA	NA	10.5 a 11.45	NA	NA	7.1 to 7.3
FW (P1)	84.9 to 90	17.68 to 19	222 to 226	NA	NA	74.3 to 85	NA	NA	7.6 to 7.88
FW/RW average	**11**	**x**	**3**	**x**	**x**	**7**	**x**	**x**	**x**
	Total Alkalinity (mg $CaCO_3$/L)	**Chlorides (mg Cl^-/L)**	**Electrical conductivity (µS/cm)**	**Hardness Ca (mg/L)**	**Hardness Mg (mg/L)**	**Total Hardness (mg $CaCO_3$/L)**	**Fe^{2+} (mg/L)**	**Mn^{2+} (mg/L)**	**pH**
Ref.	(CAMPOS, 2012; ESQUIVEL et al., 2012, 2016, and 2017)	(CAMPOS, 2012; ESQUIVEL et al., 2012, 2016, and 2017)	(CAMPOS, 2012; ESQUIVEL et al., 2012, 2016, and 2017)	(CAMPOS, 2012; ESQUIVEL et al., 2012, 2016, and 2017)	(CAMPOS, 2012; ESQUIVEL et al., 2012, 2016, and 2017)	(CAMPOS, 2012; ESQUIVEL et al., 2012, 2016, and 2017)	(CAMPOS, 2012; ESQUIVEL et al., 2012, 2016, and 2017)	(CAMPOS, 2012; ESQUIVEL et al., 2012, 2016, and 2017)	(CAMPOS, 2012; ESQUIVEL et al., 2012, 2016, and 2017)
RW	7.4 to 8	11.9 to 12	64 to 74	7.8 to 7.86	4.2	10.2 to 11.53	0.013 to < 0.03	to < 0.007 to 0.02	6.83 to 7.38
FW (P2)	105.5	14 to 14.7	235	85 to 85.6	10 to 10.5	95.8 to 96	0.01	0.094	7.86
FW/RW average	**14**	**x**	**4**	**11**	**2**	**9**	**x**	**x**	**x**

RW- raw water (source-Peri Lake); **FW-** filtered water (production well); **FW / RW average -** average increment of parameter in FW; **NA-** Not analyzed

Source: Adapted by the authors from Sens (2006), Sens and Dalsasso (2007), Mondardo (2009), Campos (2012), Esquivel (2012, 2016, and 2017)

In isolation, Esquivel et al. (2017) also analyzed bromides in RW and FW in well P2, not observing variations. Furthermore, 3.1 and 34 mg/L of calcium and 1 and 2.4 mg/L of magnesium were obtained in RW and FW, respectively. The increase in the values of these parameters aligns with the increase of total hardness.

Changes were observed in alkalinity, total hardness and conductivity conditions in FW, as evidenced by studies performed in P1 (Table 2), as well as complementary chemical aspects of FW (Table 3). These changes were justified by Sens et al. (2006), who attributed them to the presence of calcium sediments in the geological profile, observing fragments during well drilling. Nevertheless, the authors considered that there was a great influence of sediments on the increase of the electrical conductivity from the lake. The same chemical behavior aforementioned was observed in P2.

Regarding the evaluation of nitrate ions, Mondardo (2009) observed the appearance of 1.24 mg/L in P1. The other authors did not detect variations between the source and the production well (SENS et al., 2006; SENS and DALSASSO, 2007; ESQUIVEL et al., 2012, 2016, and 2017) except Sens et al.(2006), who noted a small 1.25-fold increase in nitrate ions in FW (1.93 mg/L), the appearance of ammoniacal nitrogen (between 1.2 and 1.9 mg NH_3^-N/L) (SENS et al., 2006; SENS and DALSASSO, 2007), and the removal of 100% of chlorophyll in well P1 (SENS and DALSASSO, 2007). There was no evaluation of these parameters in P2. Some authors (CAMPOS, 2012; ESQUIVEL et al., 2016) observed a 2-fold increase in the concentration of hydrogen sulfide in P2 as well (Table 4).

Table 3 shows the absorbance 254 nm results, which indicates a considerable removal of dissolved organic matter (DOM) in P1 (66%) and 29% in P2. In addition, there was a significant decrease in total organic carbon (TOC) and dissolved oxygen (DO) in P1 and 98% of DO decrease in P2.

Table 3 – Results of complementary chemical parameters.

	Absorbance 254 nm (cm^{-1})	**DOC (mg/L)**	**TOC (mg/L)**	**DO (mg O_2/L)**	**Orthophosphate (mg PO_4^{-3}/L)**
Ref.	MONDARDO, 2009; SENS and DALSASSO, 2007)	x	(MONDARDO, 2009; SENS and DALSASSO, 2007)	(MONDARDO, 2009; SENS and DALSASSO, 2007; SENS et al., 2006)	MONDARDO, 2009; SENS and DALSASSO, 2007; SENS et al., 2006)
RW	0.116 to 0.14	NA	7.1 to 7.27	6.82 to 7.36	0.05 to 0.66
FW (P1)	0.019 to 0.067	NA	1.8 to 1.93	2.48 to 2.64	0.46 to 0.49
% average removal	**66**	**x**	**74**	**64**	**2**
	Absorbance 254 nm (cm^{-1})	**DOC (mg/L)**	**TOC (mg/L)**	**DO (mg O_2/L)**	**Orthophosphate (mg PO_4^{-3}/L)**
Ref.	(CAMPOS, 2012; ESQUIVEL et al., 2012)	CAMPOS, 2012; ESQUIVEL et al., 2012, and 2017)	(CAMPOS, 2012; ESQUIVEL et al., 2012, and 2017)	(CAMPOS, 2012; ESQUIVEL et al., 2012, 2016, and 2017)	x
RW	7.8	3.42 to 4.2	5.4 to 6	8.6 to 8.64	N.A.
FW (P2)	5.5	3.32 to 3.6	4.3	0.02 to 0.22	N.A.
% average removal	**29**	**11**	**26**	**98**	**x**

RW- raw water (source-Lagoa do Peri); **FW-** filtered water (production well); **NA-** Not analyzed; **DOC-** Dissolved Organic Carbon; **TOC-** Total Organic Carbon; **DO-** Dissolved oxygen.

Source: Adapted by the authors from Sens (2006), Sens and Dalsasso (2007), Mondardo (2009), Campos (2012), Esquivel (2012, 2016, and 2017)

Concerning the chemical aspects related to the degradation dynamics of OM, Esquivel (2012) mentioned that the process begins with the rapid consumption of DO, leading to an increase in nitrate ion (due to ammonium oxidation and the onset of OM degradation), and elevated manganese, iron, and sulfide values as the travel time increases. Even with the low OM reduction observed by the DOC analysis (Table 3), the removal of DOM (through absorbance results at 254 nm) responsible for the formation of trihalomethanes (THM) stands out (CAMPOS, 2012).

Campos (2012) and Esquivel et al. (2012, and 2016) highlight that the DO decrease indicates the occurrence of anoxic conditions, which is in agreement with the low oxide-reduction potential obtained in P2 (ORP in RW = 52 in FW = -307) (ESQUIVEL et al., 2012) according to Table 4. With the low oxygen in the medium, microorganisms continue to use other electron-accepting species such as OM.

Esquivel et al. (2012 and 2017), in a more in-depth study, observed that the lake water presented around 8.6 mg O_2/L. Through P2 monitoring, redox conditions were identified in the first meters of infiltration, where practically all oxygen, nitrate and sulfate were consumed. Iron and manganese dissolved, and the odor confirmed the presence of hydrogen sulfide. There was a gradual decrease of iron (II) and sulfide ions with increasing distance and depth to P2, where pyrite (FeS_2) formation occurs, as well as possible precipitation of iron carbonate ($FeCO_3$). The concentration of manganese ions (II) increased as it approached P2.

Regarding the Trihalomethane Formation Potential (THMFP), Esquivel (ESQUIVEL et al., 2012) perceived a seasonal behavior, with a higher THMFP concentration at higher temperature periods, possibly due to the desorption/dissolution of natural organic matter (NOM). The decrease in UV-254 nm absorbance values in the systems and the reduction of specific ultraviolet absorption (SUVA), as shown in Table 4, demonstrated that the water infiltration in the soil, on the well source route, preferentially promotes the THMPF removal in relation to the entire NOM. Esquivel concluded, through a first-order kinetic model, that the removal of NOM and THMFP occurs in the first days of infiltration, and the reduction of easily degradable NOM occurs in less than 2 days. As such, the moderately degradable fraction would need 60 to 90 days of travel to have 95% removal. An increase in travel time to remove slowly degradable NOM, which in practice is non-degradable, would not significantly change the removal achieved in their studies as about 95% of THMFPs are present in the easily degradable OM fraction (ESQUIVEL et al., 2012, and 2017).

Table 4 - Evaluation of chemical parameters by Esquivel studies in P2.

	ORP (mV)	THMFP(µg CHCl3/L)	% oxygen saturation	S^{2-} (mg/L)	H_2S (mg/L)	SO_4^{2-} (mg/L)	SUVA (L/m·mg)
RW	52	73	96 to 96.2	< 0.01	0.007	3.06	2.3
FW	-307	51	2 to 2.25	0.018 to 0.02	0.018	< 0.52	1.9

RW - raw water (source-Lagoa do Peri); **FW**- filtered water (production well); **ORP** - Oxide-reduction potential; **THMFP** - Trihalomethane Formation Potential; **SUVA**- specific ultraviolet absorption.

Source: Adapted by the authors from Esquivel et al. (2012, and 2017).

Microbiological parameters were performed only for P1. The first analyses of BF efficiency for the removal of phytoplankton, including cyanobacteria and, more specifically, *Cylindrospermopsis raciborski*, were performed by Sens et al. (2006), whose results demonstrated 100% removal (Table 5). In later studies of Sens and Dalsasso (2007), Mondardo (2009), Romero et al. (2014), similar results were obtained. Studies also showed improvement in FW quality in P1, which refers to the presence of equivalent saxitoxins, and no traces were found after treatment.

In all studies, none of the parameters in Table 5 were detected: they were either absent or undetected. Laboratory research involving sediments from the lake bank indicated that the removal of phytoplankton, cyanobacteria and *C. raciborski* occurs in the first centimeters of the filter medium, reaching values of 94 to 100% removal. The OM present in the bank sediments, mechanisms of adsorption and degradation, production flow and travel time, were aspects that influenced the biological results (SENS and DALSASSO, 2007). The removal rates of saxitoxins and neosaxitoxins ranged from 40 to 100% (SENS and DALSASSO, 2007; MONDARDO, 2009; ROMERO et al., 2014; SOARES et al., 2019).

Table 5 – Results of biological parameters in Peri Lake.

	Cyanobacteria (cells/mL)	Cylindrospermopsis raciborskii (cells/mL)	Phytoplankton (cells/mL)	Dissolved saxitoxin equivalent (µg/L)
Ref.	(ROMERO et al., 2014; SENS and DALSASSO, 2007; SENS et al., 2006)	(MONDARDO, 2009; ROMERO et al., 2014; SENS and DALSASSO, 2007; SENS et al., 2006)	(MONDARDO, 2009; ROMERO et al., 2014; SENS and DALSASSO, 2007; SENS et al., 2006)	(MONDARDO, 2009; ROMERO et al., 2014; SENS and DALSASSO, 2007; SENS et al., 2006)
RW	$1.3 \cdot 10^6$ to $1.53.10^6$	$9.43.10^5$ to $1.22.10^6$	$1.4.10^6$ to $1.55 .10^6$	3.8 to 6.05
FW (P1)	A or ND	A or ND	A or ND	ND

RW- raw water (source-Peri Lake); **FW-** filtered water (production well); **A -** absent; **ND-** Not detected.

Source: Adapted by the authors from Sens (2006), and Sens and Dalsasso (2007), Mondardo (2009), Romero et al. (2014)

2.1.2 *Modeling*

The implementation of the bank filtration system in Peri Lake provided conditions for the application of simulations and computational modeling that could generate information about the hydraulics of the applied process, as well as confirm the observations obtained in the field. New scenarios and conditions could be explored using models 1 (ESQUIVEL et al., 2012), 2 (SOARES, 2015) and 3 (VARELA et al., 2018), according to Table 6.

Table 6 - Synthesis of the models elaborated from field research.

Modeling	Hypotheses	Scenarios	Main Results
1 (ESQUIVEL et al., 2012)	Estimate the travel time of the water to the production wells and the natural behavior of groundwater.	1) No pumping	From the bottom of the lake to where the well grooves begin at 20 m from the lake and 9.5 m deep, it was an estimated 190 days.
		2) With pumping	With a flow of 30 m³/d of water, the minimum estimated time was at least 80 days. The water in the lake naturally infiltrates towards the piezometer system.
2 (SOARES, 2015)	Evaluate the behavior of groundwater in different BF pumping scenarios, at flows of 100 L / s and 200 L / s and considering different levels of bank clogging.	1) Natural water availability conditions	The lake feeds the aquifer and the Sangradouro channel, which is also fed by groundwater.
		2) Decreased water level of the lake	The more the surface water level decreases, the more the channel is fed by groundwater, adopting an identity of flow gain and losing the characteristic of influential water body. With an applied flow rate of 100 L/s, under favorable conditions, the infiltration rates in the lake remain constant.
		3) In dry conditions	The flow of groundwater goes to the well gallery, reducing the natural recharge of the lake caused by the infiltration, and the channel suffers water loss due to pumping.
		The 3 scenarios above	With an applied flow of 200 L/s, in all conditions, the infiltration rate in the lake remains constant and the aquifer suffers a decrease, being even greater in periods of drought, where the channel does not receive water from the aquifer and provides flow loss (worst scenario).
3 (VARELA et al., 2018)	Define the best water catchment scenario on the banks of Peri Lake.	1) Possible flows	Maximum exploitation supported by the 15 m³ / h (4.17 L/s per well).
		2) Number of possible wells	Maximum quantity of 15 wells, totaling a maximum flow of 62.5 L/s. 15 wells operating at 15 m³/h would not generate saline wedge intrusion.
		3) Possibility of approaching the water treatment station (Casan).	15 wells with a flow of 15 m³/h allocated closer to the water treatment station, would generate impairment in 4 wells due to the saline wedge coming from the proximity to the sea.

Source: Adapted by the authors from Esquivel, et al. (2012), Soares (2015) and Varela et al. (2018).

2.2 Barra da Lagoa – Florianópolis (SC): Study site characterization

Barra da Lagoa is a neighborhood located in the eastern region of Florianópolis island, as shown in Fig. 3. The location has the UTM coordinates of 753835.29 m E and 6948108.09 m S, zone 22. The saline water catchment station is located approximately 50 m from the sea (BURGARDT, 2017). The soil in Barra da Lagoa corresponds to a sedimentary aquifer composed of elements that vary from coarse to fine sand and may present small amounts of silt and clay (GUEDES JÚNIOR, 2005).

The angular filtration system, where the production well is tilted at an angle between -20° and -45° with the soil level used by Burgardt (BURGARDT, 2017; BURGARDT et al., 2017; BURGARDT and SENS, 2018), aimed at improving the characteristics of sea water for subsequent referral to the reverse osmosis process.

The angular capture system used by Burgardt (2017) was designed with a length of 70 m (being 30 m in the sea), with a pump house and a discharge pipe 4,200 m long. The PVC pipe for suction was 160 mm in nominal diameter (ND) and 200 mm in DN, for the discharge pipe. For the water suction, four sets of motor pumps (4 CV) associated in parallel were used, repressing an average of 41.66 m^3/h (11.57 L/s) (BURGARDT, 2017; BURGARDT et al., 2017; BURGARDT and SENS, 2018). A phytoplankton screen at the entrance of the system prevented the capture points from being blocked by fine sediments such as sand and small solids, as protection, besides, the project had a backwash operation when there was a lower quality of filtered water or less flow (BURGARDT, 2017).

Soil samples at 1 m, 3 m, 4 m and 6 m in depth, as well as sand contained on the surface, were analyzed in order to compare the samples submitted to climatic conditions with samples from the subsoil. The local sand presented, on average, from 1 to 6 m in depth, 0.17 mm and 0.24 mm in effective diameter-D10, and D-60, respectively. The surface sand presented 0.23 mm and 0.28 mm of effective diameter-D10 and D-60, respectively. The uniformity coefficient was, on average, 1.39. This shows that, over the 6 m depth, the characteristics of the filter medium undergo little change, being quite uniform as well. These results give the site the ability to remove impurities (BURGARDT, 2017).

2.2.1 *Water quality characterization: physical and chemical parameters*

Physical and chemical parameters were analyzed weekly between August and September 2016 (BURGARDT, 2017; BURGARDT et al., 2017; BURGARDT and SENS, 2018), and the results are shown in Table 7. The authors observed that the levels of salinity and electrical conductivity indicated that water filtration originated from the ocean, without mixing with fresh groundwater. There was also a considerable decrease in turbidity and apparent color. True color, TDS and DOC did not show a significant decrease in FW, nor did the absorbance at 254 nm.

Table 7 - Results of the physical and chemical parameters obtained in Barra da Lagoa.

	Apparent Color (Pt–Co Units)	True Color (Pt–Co Units)	Turbidity (NTU)	TDS (mg/L)	Temp. (°C)	Absorbance 254 nm (cm^{-1})	DOC (mg/L)	Electrical conductivity (µS/cm)	pH	Salinity (g/kg)
RW	30.6 to 32.77	3.8 to 3.97	2.37 to 2.65	34.200 to 34.474	19.1 to 20.05	0.022 to 0.025	4.43 to 5.23	48.7 to 50.78	8.31	34.5 to 35.39
FW (P1)	5.3	3.23 to 3.6	0.13 to 0.15	33.200 to 34.148	19.1 to 19.95	0.022 to 0.2	3.71 to 4.54	48.2 to 5024	8.11	34.4 to 35.34
% average removal	**83**	**5**	**95**	**3**	**x**	**12**	**13**	**x**	**x**	**x**

RW- raw water (source-Barra da Lagoa); **FW-** filtered water (production well); **Pt-Co-** Color Unit, **NTU-** Turbidity Unit; **TDS**-Total Dissolved Solids; **DOC** – Dissolved Organic Carbon.

Source: Adapted by the authors from Burgardt (2017).

The system also showed a decrease in dissolved organic compounds, but on a smaller scale, considering the results of absorbance 254 nm and DOC. The parameters of pH, salinity and electrical conductivity did not change significantly, showing a simple reduction, while the temperature remained constant (BURGARDT, 2017).

2.3 Aquaculture Lake – Ituporanga (SC): Study site characterization

Ituporanga is a municipality in the state of Santa Catarina, Brazil, which has the UTM coordinates of 638149.00 m E and 6966884.00 m S zone 22. It is located 163 km from the city of Florianópolis, the state capital. The BF facilities used by Soares (2009) were located next to an aquaculture lake on the EPAGRI's premises. The purpose of the system was the treatment of lake water for animal drinking.

The location chosen for drilling showed a higher constitution of coarse sand (32.4%) in the first 1.2 m of depth, followed by fine sand (91%) in the second layer of soil (1.20 to 2.10 m), with low clay and silt content. Subsequent predominance of clay (50%) was observed in the third layer, following up to 4.6 m. The porosity of the second layer corresponded to about 30 to 35%, with hydraulic conductivity (K) of 5.4×10^{-4} m/s. It was observed that the lake shore presented an average hydraulic conductivity around 2.22×10^{-7} m/s, indicating sediment clogging and little potential for infiltration (SOARES, 2009).

A production well was drilled with a depth of 2.8 m and a diameter of 1 m. The well flow at the maximum (dynamic) level corresponded to 0.03 L/s, according to the rainfall conditions of the period, with intermittent pumping. It was observed that, in an average obtained from 100 days of operation, 25% of the water filtered by the well originated from the lake and the rest came from the aquifer. The time taken from the water to the well corresponded to about 70 days (SOARES, 2009).

2.3.1 *Water quality characterization: physical, chemical and biological parameters*

Table 8 shows the physical parameters analyzed in the aquaculture lake between 2009 and 2010. There was an increase in FW of 4 and 5 times of apparent color and turbidity, respectively (SOARES, 2009). A 6-fold increase in turbidity was also observed by Soares (2009) and Romero et al. (2010), who considered the influence of clay and iron in the increase observed in the apparent color and turbidity parameters, with a small true color removal. It was taken into account that such aspects were influenced by rainfall at the site and the leaching capacity of the compounds in the soil as well. The occurrence of iron and manganese in FW could also be correlated with the observed physical results. There was a 100% removal of TDS and 12% of SS (suspended solids), whose low removal was attributed to the accommodation of the soil around the well (SOARES, 2009).

Table 8 - Results of physical parameters obtained in the aquaculture lake.

	Apparent color (Pt–Co Units)	True color (Pt–Co Units)	Turbidity (uNTU)	TDS (mg/L)	SS (mg/L)	Temp. (°C)
RW	136.6	55.3	16.4	10.9	98	27.5
FW	512	42.5	87.2	0.05	86	25.5
% removal	**x**	**23**	**x**	**100**	**12**	**x**
FW/RW	**4**	**x**	**5**	**x**	**x**	**x**

RW- raw water (aquaculture lake); **FW-** filtered water (production well); **FW / RW-** parameter increase in FW; **NTU** - turbidity unit; **TDS-** total dissolved solids; **SS-** suspended solids.

Source: Adapted by the authors from Soares (2009).

Table 9 presents the results of the chemical parameters obtained in the aquaculture lake (SOARES, 2009). The increase of total iron, manganese (II), nitrite and nitrate ions in the FW was observed by Soares (2009). Romero et al. (2010) also observed a 6-fold increase in total iron concentration after BF. These results were related to the clogging of the bottom of the source and long travel time, since the hydraulic permeability at the site proved to be limited (SOARES, 2009). Moreover, oxygen reduction over the course of the journey and the closing of the banks allowed the solubilization of compounds, such as iron and manganese, found in FW after precipitation. Such aspects also influenced the increase in the alkalinity and electrical conductivity observed, in addition to the chemical characteristics of the soil at the site (SOARES, 2009).

Table 9 - Results of the chemical parameters obtained in the aquaculture lake.

	Total Alkalinity (mg $CaCO_3$/L)	Electrical conductivity (µS/cm)	Total iron (mg/L)	Mn^{2+} (mg/L)	pH	Absorbance 254 nm (cm^{-1})	NO_2^- (mg/L)	NO_3^- (mg/L)	DO (mg/L)
RW	19.6	21.2	0.42	0.094	7.5	0.117	0.0065	0.13	9
FW	68.4	101	2.8	0.4	6.03	0.13	0.036	0.22	2.8
% removal	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**69**
FW/RW	**3**	**5**	**7**	**4**	**x**	**1.1**	**6**	**2**	**x**

RW- raw water (aquaculture lake); **FW-** filtered water (production well); **FW / RW-** parameter increase in FW; **DO-** dissolved oxygen

Source: Adapted by the authors from Soares (2009).

Table 10 shows that there was a reduction in microbiological parameters (SOARES, 2009; ROMERO et al., 2010), identifying the absence of *E. Coli* and Phytoplankton in the treated water.

Table 10 - Results of biological parameters obtained in the aquaculture lake.

	Total coliforms (MPN/100 mL)		Total phytoplankton (cells/mL)	E. coli (MPN/100 mL)	
Ref.	(SOARES, 2009)	(ROMERO et al., 2010)	(SOARES, 2009)	(SOARES, 2009)	(ROMERO et al., 2010)
RW	12000	10000	8300	160	142
FW	170	1.77 log	A	A	2.15 log
% removal	**98.3**	**97.8**	**100**	**100**	**99.1**

RW- raw water (aquaculture lake); **FW-** filtered water (production well); **MPN** - most probable number; **A**- absent.

Source: Adapted by the authors from Soares (2009) and Romero et al. (2010)

2.4 Itajaí do Sul River - Ituporanga (SC): Study site characterization

Ituporanga is a city located in the central-west region of the State of Santa Catarina. It is located 163 km from the state capital, Florianópolis. The Itajaí do Sul River is the main watercourse in the region, belonging to the Itajaí do Sul sub-basin, which covers 10 municipalities in Santa Catarina, including Ituporanga. The stretch of the Itajaí do Sul River that was part of the study area, belonging to Ituporanga, has the UTM coordinates of 637862.24 m E and 6967007.30 m S, zone 22, altitude of 370 m, annual rainfall ranging from 1,300 to 1,500 mm and precipitation daily maximum of 120 mm. The section of the river studied, 33 m wide on average, was approximately 3 km downstream of agricultural areas and approximately 23 m from the urban perimeter. The position of surface water in relation to agricultural areas was approximately 3 and 10 m (vertical and horizontal distance, respectively) (MICHELAN, 2010; ROMERO et al., 2010; MICHELAN et al., 2011; GUEDES et al., 2018).

The subsoil of the perforated site showed a constitution of clay, silt and fine sand in the first 1.2 m of depth, followed by a layer of silt (58.16%), fine sand (29.61%), clay (6.74 %), medium sand (4%) and coarse sand (1.49%) up to 3.9 meters deep, where the predominance of fine, medium and coarse gravel (50.22%) started. It was considered that the last layer contributed to a hydraulic permeability (K) of 3.0x10-3 m/s. Michelan (2010) obtained a weighted effective porosity of 19%, with a travel time of 15 days while Romero et al.(2010) found 36.2% porosity, with a travel time of 28 days.

The production well, located 18.5 m from the source, was dug in order to measure 4.7 m in depth and 1 m in diameter. The well went into operation with a maximum production flow of 12.76 m³/d (0.15 L/s) (MICHELAN, 2010; ROMERO et al., 2010; MICHELAN et al., 2011; GUEDES et al., 2018).

2.4.1 *Water quality characterization: physical, chemical and biological parameters*

Table 11 shows that there was partial removal of all the studied physical parameters, except in the studies by Romero et al. (2010) where a small increase in TDS of 1.2 times in FW was observed (non-Tabulated result). The turbidity removal was more expressive, on average 68%, with Romero et al. (2010) achieving 84% removal of this parameter.

Table 11 - Results of the physical parameters obtained in the Itajaí do Sul River.

	Apparent color (Pt–Co Units)	True color (Pt–Co Units)	Turbidity (NTU)	TDS (mg/L)	Temp. (°C)
Ref.	(MICHELAN, 2010; ROMERO et al., 2010)	MICHELAN, 2010; ROMERO et al., 2010)	(MICHELAN, 2010; MICHELAN et al., 2011; ROMERO et al., 2010)	MICHELAN, 2010; MICHELAN et al., 2011)	(MICHELAN, 2010; ROMERO et al., 2010)
RW	229 to 231	40 to 44	32 to 36.5	43 to 45	20.7 to 22
FW	120 to 181	49 to 54	6 to 13	34 to 44.2	19.7 to 21
% average removal	**35**	**10**	**68**	**12**	**x**

RW- raw water (Itajaí do Sul River); **FW-** filtered water (production well); **NTU** - Turbidity Unit, **TDS** - Total Dissolved Solids, **FW / RW** - parameter increase in FW.
Source: Adapted by the authors from Michelan (2010), Romero et al. (2010) and Michelan et al. (2011)

Among the chemical parameters analyzed, according to Table 12, the increase in PA of 4 times on average in the total iron concentration stands out (MICHELAN, 2010; ROMERO et al., 2010; MICHELAN et al., 2011; GUEDES i, 2018), a factor associated to Michelan et al. (2010) with a decrease in DO (54%), which causes the compound to solubilize.

Other parameters that suffered an increase in FW were nitrate ions and, mainly, ammonia, with an 11-fold increase in relation to the source. The degradation of organic compounds was also observed through the absorbance results of 254 nm and TOC (MICHELAN, 2010).

Table 12 - Results of the chemical parameters obtained in the Itajaí do Sul River.

	Tot. hardness (mg $CaCO_3$/L)		Tot. iron (mg/L)	pH	Abs. 254 nm (cm^{-1})	TOC (mg/L)	NO_2^- (mg/L)	NO_3^- (mg/L)	NH_3 (mg/L)	DO (mg/L)
Ref.	ROMERO et al., 2010)	(MICHELAN, 2010)	(GUEDES et al., 2018; MICHELAN, 2010; MICHELAN et al., 2011; ROMERO et al., 2010)	GUEDES et al., 2018; MICHELAN, 2010; ROMERO et al., 2010)	MICHELAN, 2010; ROMERO et al., 2010)	(MICHELAN, 2010)	(MICHELAN, 2010)	(MICHELAN, 2010)	(MICHELAN, 2010)	(GUEDES et al., 2018; MICHELAN, 2010)
RW	19.4	20.6	0.42 to 1.26	6.4 to 6.7	0.22 to 0.32	4.4	0.06	0.38	0.6	8.7
FW	12.9	26.4	2.82 to 4.9	5.8 to 6.1	0.078 to 0.079	3.7	< 0.1	< 0.1 to 0.589	6.8	4
% average removal	**33.5**	**x**	**x**	**x**	**71**	**16**	**83**	**x**	**x**	**54**
FW/RW	**x**	**1.32**	**4**	**x**	**x**	**x**	**x**	**1.6**	**11**	**x**

RW- raw water (source-Itajaí do Sul River); **FW-** filtered water (production well); **TOC-** Total organic carbon, **DO-** dissolved oxygen.

Source: Adapted by the authors from Michelan (2010), Romero et al. (2010), Michelan et al. (2011), Guedes et al. (2018)

Regarding microbiological parameters, Table 13 shows the efficiency of BF in the removal of total coliforms (MICHELAN, 2010; ROMERO et al., 2010) and E. coli (MICHELAN, 2010; ROMERO et al., 2010; MICHELAN et al., 2011). In another study, Michelan et al. (2011) mention the removal of 2 logs of total coliforms.

Table 13 - Results of the biological parameters obtained in the Itajaí do Sul River.

	Total coliforms (MPN/100 mL)	*E. coli* (MNP/100 mL)
Ref.	(MICHELAN, 2010; ROMERO et al., 2010	MICHELAN, 2010; MICHELAN et al., 2011; ROMERO et al., 2010)
RW	20000 to 25000	1500 to 3300
FW	140 to 170	3.8 to 5.2
% average removal	**99.3**	**99.8**

RW- raw water (source-Itajaí do Sul River); **FW-** filtered water (production well); **MNP-** most probable number.

Source: Adapted by the authors from Michelan (2010), Romero et al. (2010), Michelan et al. (2011)

2.4.2 2.4.2 Carbofuran removal

The BF removal of the pesticide Carbofuran, frequently observed in the Itajaí do Sul River, was verified. The results show that, on average, it is possible to remove around 69% of the pesticide in FW (MICHELAN, 2010; ROMERO et al., 2010).

For more details regarding carbofuran removal using BF technology, Michelan (2010) carried out a test involving filtration columns whose results showed a travel time of 25 days for the removal of carbofuran in the order of 80%. The half-life of the compound in the system corresponded to 10.5 days at neutral pH.

2.5 Belo River - Orleans (SC): Study site characterization

Orleans is a municipality located in southern Santa Catarina, as shown in Fig. 3, and is 196 km away from the state capital, Florianópolis. The BF system approached by Guedes (GUEDES, 2018; GUEDES et al., 2019) corresponded to the structure located on the Belo River bank, about 2.16 km from the source, inserted in the rural area of Orleans, Santa Catarina, which has the UTM coordinates of 667449.00 m E and 6831854.00 m S zone 22. In addition to the abstraction well, the system was composed of pumping that was performed using photovoltaic energy.

The granulometric composition of the banks of Belo River found coarse sand (34.5%), medium sand (22.4%), fine gravel (21.6%), fine sand (19.7%) and medium gravel (1.4%), in addition to clay and silt (0.89%). The composition of the site showed a flow condition for sediment transport, and the effective soil porosity varied from 29% to 32.5% (GUEDES, 2018; GUEDES et al., 2019).

The geological profile of the land presented clay and silt (up to 2 m deep), basalt rocks and sand (between 2 to 5 m) in addition to coarse sand (5 to 10 m deep), considering the water level of the corresponding groundwater at an average depth of 2.5 m. The hydraulic conductivity of the soil presented an average of 5.2×10^{-5} m/s, typical for sediments composed of coarse and medium sand (GUEDES, 2018; GUEDES et al., 2019).

The production well, called P1, was built 8 inches in diameter, 15 m deep and was located 17 m from the source. The time taken from the water to the well fluctuated between 16 and 32 days, depending on the lowering of the aquifer and the pump used, the pumping being intermittent (GUEDES, 2018). Subsequently, Guedes et al. (2019), in a second production well (P2) 1 m in diameter and 5 m deep, 25 m from the source, also pumped intermittently, as the energy supply system was through photovoltaic cells. It was also possible to identify the hydraulic connection between the water in the wells and the source (GUEDES, 2018; GUEDES et al., 2019).

2.5.1 *Water quality characterization: physical, chemical and biological parameters*

The results in Tables 14, 15 and 16 represent the physical, chemical and biological parameters, respectively, obtained in the production wells P1 (GUEDES, 2018) and P2 (GUEDES et al., 2019). Table 14 shows the excellent efficiency of BF in removing the studied physical parameters, both in P1 and in P2, with removal percentages above 95%.

Table 14 - Results of physical parameters obtained in Belo River.

	Apparent color (Pt–Co Units)	True color (Pt–Co Units)	Turbidity (NTU)
RW	94.5	22.7	23.4
FW (P1)	4.9	0.4	0.3
% average removal	**95**	**98**	**99**
RW	146.1	NA	18.4
FW (P2)	0.8	NA	0.3
% average removal	**99**	**NA**	**98**

RW- raw water (source-Belo River-Orleans); **FW-** filtered water (production well); **NTU** - turbidity unit.

Source: Adapted by the authors from Guedes (2018); Guedes et al. (2019)

In Table 15, it is possible to observe that there was an increase of 1.3 and 1.2 in the electrical conductivity (GUEDES, 2018; GUEDES et al., 2019) due to the chemical characteristics of the sediments, influencing the composition of the leachate materials, such as the release of soil ions. The BF efficiency in the total iron removal was also observed in both wells. There was a DOC reduction, showing the degradation of organic compounds during filtration (GUEDES, 2018) of DO, as well as a decrease in pH, which was much greater in P2.

Table 15 - Results of chemical parameters obtained in Belo River.

	Electrical conductivity (µS/cm)	Total iron (mg/L)	pH	DOC (mg/L)	DO (mg/L)
RW	72.3	0.9	6.8	2.8	7.8
FW (P1)	95.7	0.1	6.3	0.9	5.1
% average removal	**x**	**89**	**x**	**68**	**35**
FW/RW	**1.3**	**x**	**x**	**x**	**x**
RW	66.1	1.2	6.4	NA	7.5
FW (P2)	81.2	0.1	5.2	NA	5.4
% average removal	**x**	**92**	**x**	**x**	**28**
FW/RW	**1.2**	**x**	**x**	**x**	**x**

RW- raw water (source-Belo River-Orleans); **FW-** filtered water (production well); **FW/RW** - increment of the parameter in the FW; **DOC** - Dissolved organic carbon; **DO** - dissolved oxygen.

Source: Adapted by the authors from Guedes (2018); Guedes et al. (2019)

The system's location in a rural area justifies the presence of microbiological contaminants due to the existence of animal husbandry in the region, in addition to the possibility of illegal effluent discharges along the source path. In the data in Table 16, the absence of E. Coli after BF is observed in both wells without, however, eliminating total coliforms (GUEDES, 2018; GUEDES et al., 2019). Nonetheless, 99.99% of removal was obtained.

Table 16 - Synthesis of the biological parameters of the research in Belo River.

	Total coliforms (MPN/100ml)	*E. coli* (MPN/100ml)		Total coliforms (MPN/100 mL)	*E. coli* (MPN/100ml)
RW	110000	6800	**RW**	84000	4900
FW (P1)	15.3	A	**FW (P2)**	4,5	A
% average removal	99.99	100	**% average removal**	100.0	100

RW- raw water (source-Belo River-Orleans); **FW-** filtered water (production well); **MPN** - most probable number.

Source: Adapted by the authors from Guedes (2018); Guedes et al. (2019)

3 FINAL CONSIDERATIONS

From the content prepared for Part 1 of this review, for the correct application of BF, sustainable sources from surface and underground water must be relied on in hydraulic connection with the local aquifer formed by alluvial or unconsolidated materials. The hydrogeology of the aquifer, the hydrology of the water body, the morphology of the river or lake, the composition of its bottom and its quality in addition to the temperature of the surface and groundwater are other local characteristics to consider when applying BF (ESQUIVEL et al., 2016).

As discussed in Burgardt (2017), the BF technique does not remove salinity. In these cases, BF can be at least used as pre-treatment of water desalination plants for supply systems. Regarding carbofuran, Michelan (2010) conducted a test involving filtration columns with results that showed a travel time of 25 days for a removal in the order of 80%.

In all studies carried out, the flow rates applied were low to the point of representing something consistent for the real scale of a public supply system. In the future, it would be interesting to accomplish a study that analyzed quality and quantity (higher flows) to understand what will happen with the travel time and its final quality.

As can be seen in this review, among the parameters involved in the studies presented, the BF technique demonstrates efficiency in reducing parameters such as: turbidity and coliforms (total and fecal), pesticides and toxins. However the technique showed low capacity to reduce parameters, for example: salinity and true color. Parameters such as pH and dissolved oxygen do not change significantly.

It is also important to note that once the technique is dependent on the soil composition inherent to local geological conditions, parameters as iron, manganese, fluorine, alkalinity, hardness and chlorides can be added to the treated water as a function of the redox conditions during runoff as well as through variation flow, changing the contribution of the source and aquifer.

In summary, for public supply systems, BF can be used to make pre-treatment in already consolidated situations, that is, in systems in operation (water treatment plants), which can make the raw water quality reach the beginning of treatment with the same standards of water quality (or better standards, for example: less turbidity) as when the current treatment systems were conceived (start of operation), causing them to have a longer useful life or even a greater flow. The final considerations will be presented in the second part of this review.

4 AUTHORS' CONTRIBUTION

All authors worked equally in the preparation of this scientific article.

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