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Urban wastewater treatment in Brazil

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Summary

Abstract

The major focus of this report is the description and critical analysis of the main wastewater treatment processes used in Brazil. Special emphasis is given to small to medium size communities with populations lower than 100,000 inhabitants, which represent approximately 95% of the 5,570 Brazilian municipalities. In terms of coverage, around 40% of the sewage generated in Brazil is treated, with an estimated number of treatment plants in the order of 2,800. Based on a survey of 2,187 treatment plants, the configurations most widely adopted are: anaerobic pond followed by facultative pond; UASB (upflow anaerobic sludge blanket) reactor; activated sludge; ponds followed by maturation ponds; septic tank followed by anaerobic filter. An assessment of the actual performance of 166 treatment plants showed a great variability in the effluent concentrations and in the removal efficiencies, with performances that were usually inferior to those reported in the technical literature. Data on capital cost expenditures indicated values ranging from R$60/inhabitant to R$650/inhabitant, depending on the treatment process employed. Due to the favorable climatic conditions in Brazil, there are no technical limitations for the adoption of biological sewage treatment. Traditional options incorporate stabilization ponds and activated sludge, but the more recent trend involves the adoption of UASB reactors followed by some form of post-treatment.

Resumo

O principal foco deste relatório é a descrição e análise crítica dos principais processos de tratamento de águas residuárias utilizados no Brasil. Ênfase especial é dada às pequenas e médias comunidades, com populações inferiores a 100.000 habitantes, que representam aproximadamente 95% dos 5.570 municípios brasileiros. Em termos de cobertura, cerca de 40% dos esgotos gerados no Brasil são tratados, com um número estimado de estações de tratamento da ordem de 2.800. Com base em uma pesquisa com 2.187 estações de tratamento, as configurações mais amplamente adotadas são: lagoa anaeróbia seguida de lagoa facultativa; reator UASB (reator anaeróbio de manta de lodo e fluxo ascendente); lodos ativados; lagoas seguidas de lagoas de maturação; fossa séptica seguida de filtro anaeróbio. Uma avaliação do desempenho real de 166 estações de tratamento mostrou uma grande variabilidade nas concentrações efluentes e nas eficiências de remoção, com performances usualmente inferiores às reportadas na literatura. Os custos de construção variam de R$60/habitante a R$650/habitante, dependendo do processo de tratamento empregado. Devido às condições climáticas favoráveis no Brasil, não há limitações técnicas para a adoção do tratamento biológico dos esgotos. Opções tradicionais incorporam lagoas de estabilização e lodos ativados, mas a tendência mais recente envolve a adoção de reatores UASB seguidos por alguma forma de pós-tratamento.

Executive summary

The major focus of this report is the description and critical analysis of the main wastewater treatment processes used in Brazil, with special emphasis on small to medium size communities with populations lower than 100,000 inhabitants. No industrial wastewater treatment is addressed here, but solely urban wastewater or domestic sewage.

Because the population component is important in this report, it starts with a geographical overview followed by a description of the Brazilian population structure and its distribution according to size, since this influences the selection of the treatment system to be adopted. Due to its vast territorial dimensions, Brazil presents considerable regional diversities in economic and climatic conditions, what can influence the selection and adoption of wastewater treatment processes.

Most of the population is located in towns and cities that are situated within less than 1,000 km from the Atlantic coast. Within this area, the Northeast region has exceptional climatic conditions for the adoption of natural treatment systems, and temperature and sunlight decrease towards the South of Brazil, but still keeping favorable conditions for biological treatment processes. The inverse occurs in terms of economic conditions, with the South and Southeast regions showing better indicators, what is reflected in terms of the coverage of the sanitation infrastructure.

Regarding the distribution of the population according to size, from the 5,570 Brazilian municipalities, around 25% of them have populations lower than 5,000 inhabitants, about 70% have populations with less than 20,000 inhabitants and approximately 95% of the municipalities have populations lower than 100,000 inhabitants. Therefore, the vast majority of municipalities in Brazil are small to medium-sized, and the selection of wastewater treatment process needs to take this into account.

In terms of coverage of sanitation services in Brazil, approximately half of the population is connected to a sewage network collection system and approximately 70% of the sewage collected in networks is treated. In terms of flow, only around 40% of the sewage produced is treated.

It is estimated that, from the total of 5,570 municipalities in Brazil, around 1,900 (34%) have WWTPs (wastewater treatment plants). The total number of WWTPs in Brazil is estimated to be around 2,800 plants.

A survey being conducted in 2015 in Brazil by ANA (National Water Agency), with data (still preliminary and subject to change) obtained from 2,187 WWTPs, indicates the following major points:

- The treatment configurations most widely adopted in terms of number of treatment plants (more than 200 treatment plants in each configuration) are, in this order: Anaerobic pond followed by Facultative Pond; UASB (Upflow Anaerobic Sludge Blanket) reactor; Activated sludge; Ponds followed by Maturation ponds; Septic tank followed by Anaerobic filter.

- The treatment configurations that dominate in terms of population equivalent (greater than 3 million inhabitants in each configuration) are, in this order: Activated sludge; Anaerobic pond followed by Facultative pond; UASB followed by Polishing pond; UASB followed by Activated sludge; UASB followed by Trickling filter; Aerated pond; UASB reactor.

- In terms of groupings of treatment systems, it is observed that: (a) ponds and UASB reactors alone or followed by any form of post-treatment dominate in terms of number of treatment plants, representing almost 80% of the 2,187 treatment plants analyzed; (b) UASB reactors alone or followed by any form of post-treatment, activated sludge and different combinations of ponds treat the largest number of inhabitants, representing 95% of the total population equivalent surveyed; (c) the total population equivalent treated by the 2187 WWTPs analyzed in Brazil is 51,878,930 inhabitants.

- Most of the existing treatment plants have a flowsheet that is compatible with the removal of organic matter. Pathogen removal (by disinfection or maturation ponds) is implemented in 22% of the treatment plants surveyed, and nutrient (nitrogen and phosphorus) removal is incorporated in a small number of WWTPs.

- The largest number of treatment plants in Brazil are for small towns: from the 2,187 plants surveyed, 25% are for populations lower than 2,000 inhabitants, almost 50% are for populations up to 5,000 inhabitants, and 80% are for populations less than 20,000 inhabitants.

- Ponds are used approximately evenly for population sizes up to 20,000 inhabitants. The number of UASB reactors alone (without post-treatment) decrease with the increase in population size. A similar pattern occurs for UASB followed by post-treatment (even though different post-treatment processes are covered). Activated sludge is evenly distributed in all population ranges, and septic tank followed by anaerobic filter is used mainly for populations up to 5,000 inhabitants.

The regulatory framework established in Brazil for the protection of surface water is presented in the report. The national directives of CONAMA (National Environmental Council) 357/2005 and 430/2011 related to the classification of the water bodies and the specification of quality standards for discharges and receiving water bodies are presented, together with comments applicable to some states in Brazil. This legal framework is very important in the definition of the treatment processes to be adopted, such that the water quality standards are complied with.

A general description of the main wastewater treatment processes used in Brazil is presented, based on the literature. Information is presented in a concise way, with summary tables making a synthesis of important data, such as: (a) average effluent concentrations and typical removal efficiencies of the main pollutants of interest in domestic sewage; (b) typical characteristics of the main sewage treatment systems, expressed in per-capita values; (c) qualitative comparative analysis that covers various relevant aspects in the evaluation of the sewage treatment systems. The aspects of efficiency, economy, process and environmental problems are summarized.

Given the leading role played by Brazil in the utilization of UASB reactors, a brief list of the main constraints and challenges associated with this important treatment process is presented, highlighting the way for future research and improvements.

The major design criteria used in Brazil for the calculation of volumes and areas required by the main reactors and tanks in the liquid line of the main treatment processes are presented in a concise way, with tables summarizing data from the technical literature and from ABNT (Brazilian Association on Technical Standards).

An assessment of the performance of 166 WWTPs located in the states of São Paulo and Minas Gerais (Southeast region of Brazil), comprising six different treatment configurations and six water quality constituents (BOD - biochemical oxygen demand, COD - chemical oxygen demand, TSS - total suspended solids, TN - total nitrogen, TP - total phosphorus and FC - fecal or thermotolerant coliforms) was presented. The major conclusions of this evaluation are:

- A great variability was noticed in the effluent concentrations and in the removal efficiencies, considering all analyzed constituents and all treatment technologies.
- The septic tank followed by anaerobic filter process presented a performance much below the expected one, based on the literature.
- The performance of facultative ponds was lower than expected from the literature, considering COD, TSS and TN removal efficiencies. However, good TP and FC removal efficiencies were achieved.
- Anaerobic ponds followed by facultative ponds showed a good performance in terms of BOD, COD, TP and FC removal, with a significant percentage of WWTPs with efficiencies within and even above the values reported by the literature.
- UASB reactors without post-treatment showed BOD and COD removal efficiencies compatible with those reported in the literature and a poorer performance regarding TSS, FC and nutrients.
- The performance achieved by the UASB reactors followed by post treatment was good and the closest one with the expected values from the literature.
- The performance presented by the activated sludge plants, considering organic matter removal, was the highest among the evaluated systems, although it was below the reported literature range.
- In general, the direct influence of the loading conditions to which the treatment plants were subjected was small and scattered in all the treatment processes.
- A single operational variable or a group of variables could not be used to explain the differentiated performances among all the WWTPs. The contribution and influence of each operational variable seemed to differ from one WWTP to another and, as expected, this is likely to be a combination of multiple design and operational aspects.

Data from a survey of construction costs (CAPEX) of WWTPs built in the Southeast region of Brazil are presented, converted to the base date of October 2015 (USD 1.00 = Brazilian Reais R$ 3.80). The following ranges of typical values (round figures) have been obtained:

- Natural treatment by ponds (facultative or anaerobic followed by facultative) has unit costs between R$135 and R$230/inhabitant, and the inclusion of a pathogen removal stage by maturation ponds increase the total costs by a factor around 2.3 (associated with the larger number of ponds and total area required).
- Treatment by UASB reactors alone represents the cheapest variant, with round unit costs between R$60 and R$180/inhabitant. Several post-treatment options for the UASB effluent are available, from natural to compact systems. Post-treatment by ponds raise the total costs to around between R$285 and R$435/inhabitant, in the case of one or two ponds, and between R$390 and R$650/inhabitant, in the case of three or more maturation ponds. Post-treatment by compact systems such as anaerobic filters and trickling filters have somewhat similar total costs, in the range of R$215 to R$365/inhabitant.
- Treatment by activated sludge has the highest costs among the compact systems (R$360 to R$440/inhabitant).
- Operation and maintenance costs (OPEX) are more difficult to obtain. Data from only one service provider have been obtained, and it is difficult to extrapolate them to other regions in Brazil because the treatment systems employed were predominantly different from those covered in this report.

General comments on operation and maintenance structure are also included in the report. Case studies are provided and the challenges for the effective implementation of wastewater treatment in Brazil are listed.

As a final comment, it is observed that several different sewage treatment configurations are being used in Brazil. The most traditional system involves stabilization ponds, which are present in large numbers for populations up to around 20,000 inhabitants. Variants of the activated sludge process have been used for many population ranges, covering small, medium and large cities in Brazil. UASB reactors represent the main trend for all population ranges, especially when they are followed by a post-treatment stage. Several post-treatment options for the UASB effluent are available, with a special mention to trickling filters, which are being implemented in many locations, especially when land availability is not large, and also polishing ponds. Due to the favorable climatic conditions, technical options for the biological treatment of sewage are plenty in Brazil, and this is a very positive element for the progressive improvement of the coverage of wastewater treatment in the country.

1. Introduction

This report presents an overview of the wastewater treatment practice in Brazil, following the scope detailed in the Terms of Reference specified in the contract between IDB and the author (October 2015).

The major focus is the description and critical analysis of the main wastewater treatment processes used in Brazil, with special emphasis on small to medium communities with populations lower than 100,000 inhabitants. No industrial wastewater treatment is addressed here, but solely urban wastewater or domestic sewage.

Because the population component is important in this report, it starts with a geographical overview followed by a description of the Brazilian population structure and its distribution according to size, since this influences the selection of the treatment system to be adopted. The data used are from IBGE[1] (Brazilian Institute on Geography and Statistics).

After that, the status of coverage in terms of sewerage and sewage treatment in Brazil is presented, based on the last survey (2013) undertaken by SNIS[2] (National System for Information on Sanitation).

The description of the existing status is compleed by the preliminary results of an on-going survey made by ANA[3] (National Water Agency), as part of their elaboration of the Brazilian Atlas on Wastewater Treatment. These data have not been presented yet, and were consolidated in a joint effort of ANA´s team and this author, undertaken specifically for this report. Therefore, the most detailed study done so far on the treatment processes used in Brazil will be summarized here.

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[1] IBGE: Fundação Instituto Brasileiro de Geografia e Estatística

[2] SNIS: Sistema Nacional de Informações sobre Saneamento

[3] ANA: Agência Nacional de Águas

The regulatory framework established in Brazil for the protection of surface water is presented next. The national directives of CONAMA[4] (National Environmental Council) related to the classification of the water bodies and the specification of quality standards for discharges and receiving water bodies are presented, together with comments applicable to some states in Brazil. This legal framework is very important in the definition of the treatment processes to be adopted, such that the water quality standards are complied with.

A general description of the main wastewater treatment processes is then presented. Information is presented in a concise way, with summary tables making a synthesis of important data.

Given the leading role played by Brazil in the utilization of UASB (Upflow Anaerobic Sludge Blanket) reactors, the next section covers specific aspects of this important treatment process, emphasizing the main challenges associated with the process.

The major design criteria used in Brazil for the main treatment processes are presented next, with summary tables highlighting data from the technical literature and from ABNT[5] (Brazilian Association on Technical Standards).

The actual performance of existing full-scale treatment plants is covered by surveys that investigated monitoring data from more than 200 treatment plants, discretized by treatment process.

Typical ranges of capital costs for the implementation of treatment systems are presented based on survey of data obtained from consulting firms and water and sanitation companies. Operating costs are more difficult to obtain in Brazil, but data from a specific service provider is included.

General comments on operation and maintenance structure are also included. Case studies are provided and the challenges for the effective implementation of wastewater treatment in Brazil are listed.

Finally, overall conclusions are presented.

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4. CONAMA: Conselho Nacional de Meio Ambiente
5. ABNT: Associação Brasileira de Normas Técnicas

2. Contextualizing brazil: population distribution and climate

2.1. Population distribution in Brazil

Brazil is the largest country in South America (Figure 1), with a surface area of 8,515,767 km^2. It is divided into 26 states and 1 federal district, with a total of 5,570 municipalities. Associated with these continental dimensions is a diversity in economic, social, cultural and climatic conditions. Some of these factors, especially related to demography and climate, may influence the sewerage system and the wastewater treatment processes to be adopted in each case.

Fig. 1. Brazil and South America

Source: Wikipedia (en.wikipedia.org, accessed 23/Nov/2015)

Fig. 2. Brazil, states and regions

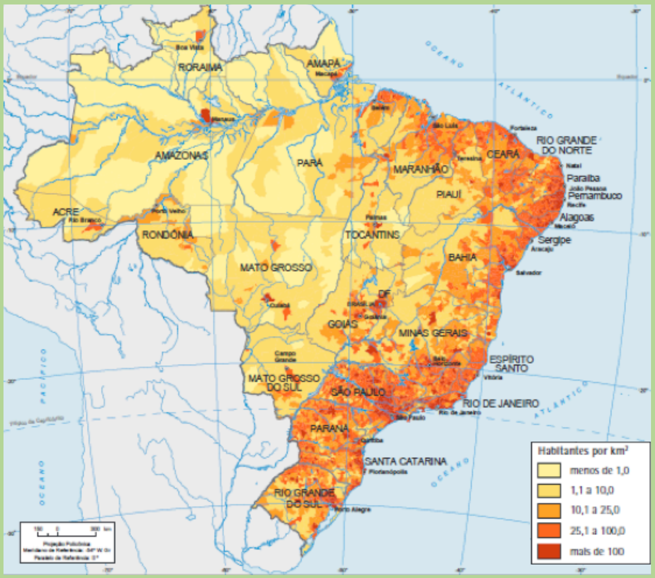
Source: adapted from https://en.wikipedia.org/wiki/Regions_of_Brazil

Many references about Brazil specify their main regions (Fig. 2), with each of them encompassing its own identity in geographical, climatic, social and economic terms. The selection of sewage treatment processes may also vary for region to region.

In the last official counting of the Brazilian population (Demographic Census, undertaken by IBGE) in the year **2010**, the total population was **190,732,694 inhabitants** (IBGE, 2015b). In July **2015**, based on population samples, the total population was estimated as **204.450.649 inhabitants** (IBGE, 2015c). In the last year, the growth rate was estimated to be 0.87%.

The geographic distribution of the Brazilian population is also variable. Figure 3 presents the demographic densities and Figure 4 the distribution of Brazilian cities. It can be seen that most of the population is settled in a range of less than 1,000 km from the coastline. There are metropolitan areas with millions of inhabitants and scattered populations in localities of different sizes. The areas taken by the Amazon forest and the Pantanal wetlands have lower population densities and fewer human settlements.

Fig. 3. Brazil. Demographic densities in 2010



Source: IBGE (2015d)

Fig. 4. Brazil. Population distribution in urban areas in 2010

Source: IBGE (2015e)

The distribution of the population according to size is an important factor for the technological solutions to be adopted for sewage collection, transportation and treatment. Figure 5 presents pie charts of the number of municipalities and number of inhabitants in each population range, based on the 2010 Demographic Census.

The following points can be seen from Fig. 4 (top):

- Around 25% of the Brazilian municipalities have populations lower than 5,000 inhabitants.
- About 70% of the municipalities have populations with less than 20,000 inhabitants.
- In terms of the cut-off point proposed by IDB for this report (100,000 inhabitants), it can be seen that 95% of the Brazilian municipalities are below this limit.

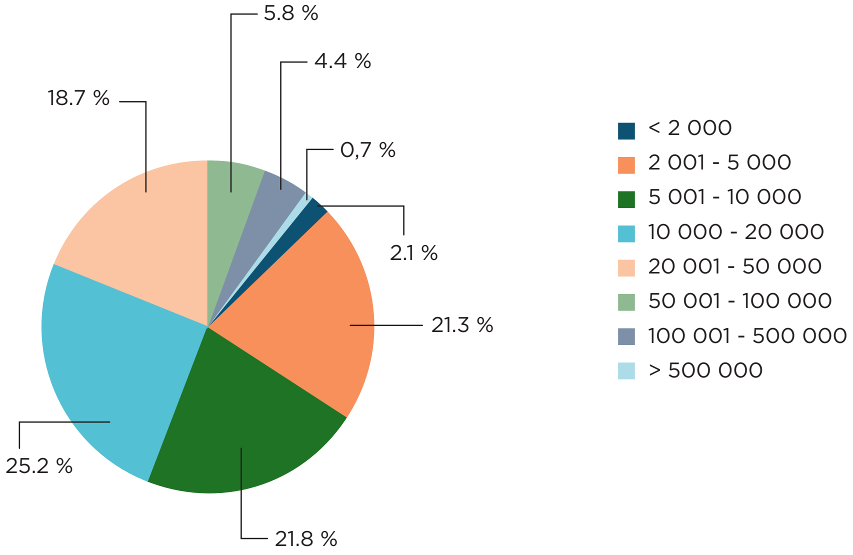
This points out to the strong need of addressing the sewage treatment needs of the population of small towns.

Even though most of the Brazilian municipalities have small population sizes, Fig. 4 (bottom) shows that:

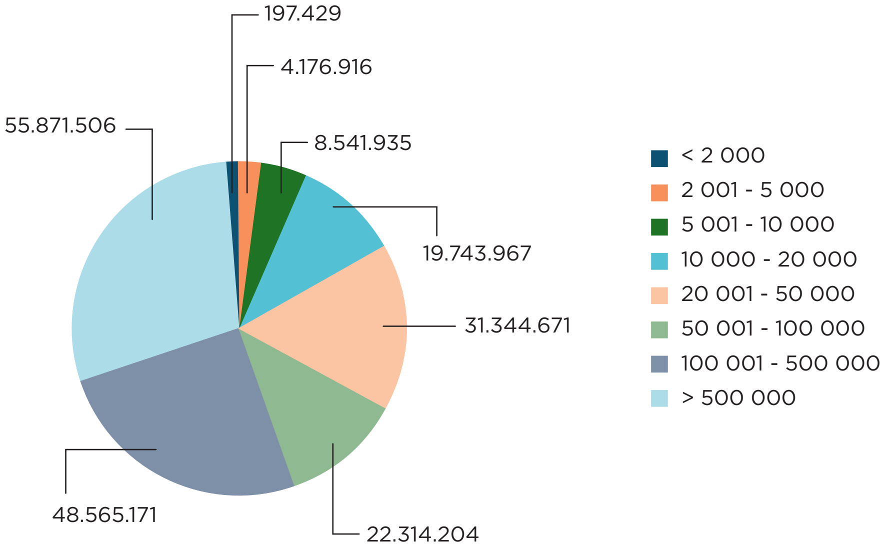
- Only 17% of the population live in towns with less than 20,000 inhabitants
- 45% of the population is established in cities with less than 100,000 inhabitants.

Fig. 5. Top: percentage of municipalities per population range. Bottom: population distribution per municipality size

Percentage of municipalities per population size (%)



Population distribution per municipality size (inhabitants)



Source: IBGE Synopsis Census 2010

2.2. Climate in Brazil

Climate is an important factor for biological wastewater treatment. Brazil has very favorable conditions in terms of high temperatures and sunlight radiation. High temperatures are important for natural treatment systems, because this reduce land requirements of these extensive systems, in comparison with regions under temperate climates. Also, anaerobic digestion is feasible for the treatment of liquids with low concentration of organic matter, such as domestic sewage, what is difficult to be achieved in cold temperatures. Sunlight radiation is important for treatment systems based on algal (photosynthetic) activity, such as facultative and maturations ponds. As will be shown in Section 4, stabilization ponds and anaerobic reactors play a decisive role in wastewater treatment in Brazil, being the two most widely used treatment configurations in Brazil.

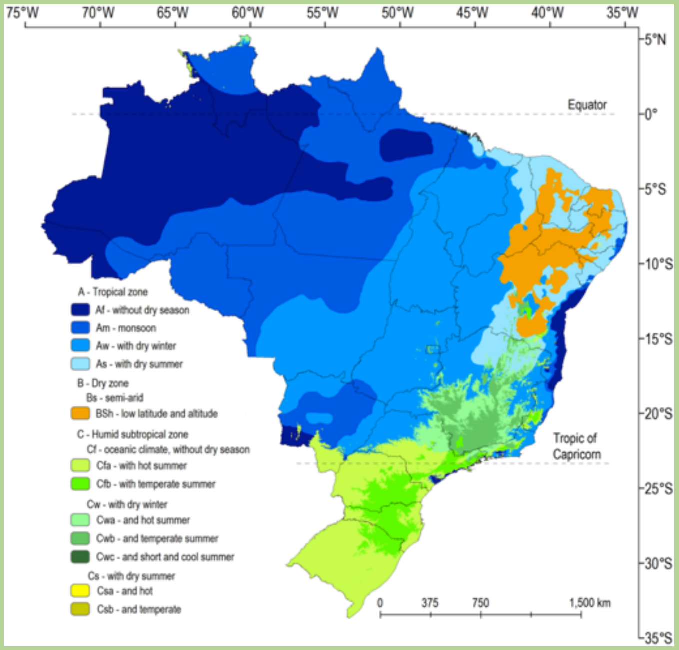


Fig. 6. Climatic regions of Brazil, according to Köppen classification

Source: https://en.wikipedia.org/wiki/Climate_of_Brazil

Most of Brazil is situated in the Southern Hemisphere, with only a small fraction above the Equator line. Latitudes range from 4° N to 34° S (see Figure 6).

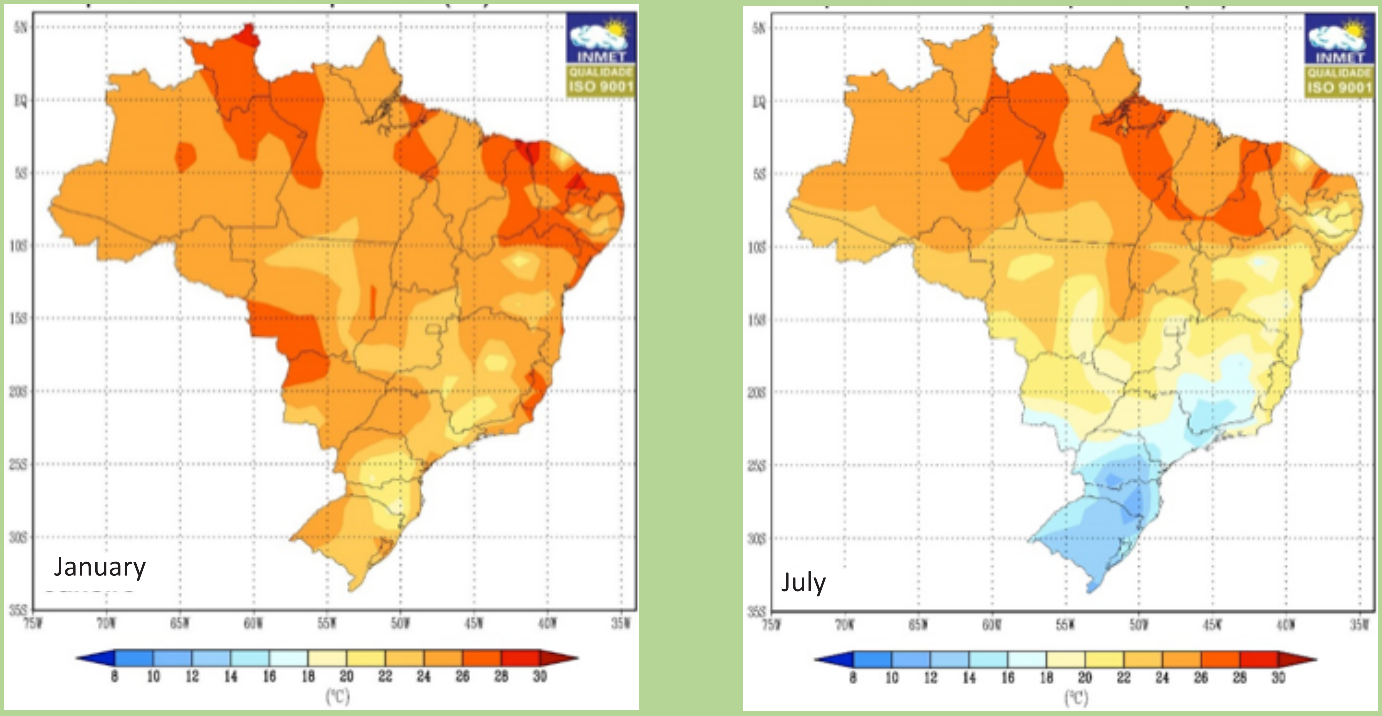
Figure 6 also shows the Brazilian climatic regions, according to Köppen classification. The major regions are A - tropical, B - dry, C - humid subtropical. Due to the large area of the country, there are several subdivisions, which are detailed in the map.

Figure 7 presents in the top part the mean monthly temperatures in warm (January) and cold (July) months. It can be seen that high temperatures prevail during summer (as exemplified by January) and even at the winter (exemplified by July). North and Northeast Brazil, which are closer to the Equator, have less annual variations. On the other hand, Southeast and South Brazil present a wider amplitude, but never reaching very low temperatures, typical of cold and temperate climates in the Northern hemisphere.

Sunlight is abundant in many regions in Brazil, especially in the Northeast, as it can be seen in Figure 7 (bottom). On the other hand, rainfall is low in this region, which is defined as a semi-arid area, with water scarcity and several intermittent watercourses.

Even though sewage treatment may be facilitated in regions where temperatures are high and sunlight is abundant, the coinciding factor that usually these are regions with low dilution capacity in the receiving water bodies bring a challenge in terms of water quality management.

Mean temperatures in warm month (January)   Mean temperatures in cold month (July)



Total hours of sunlight (hours/year)   Total rainfall (mm/year)

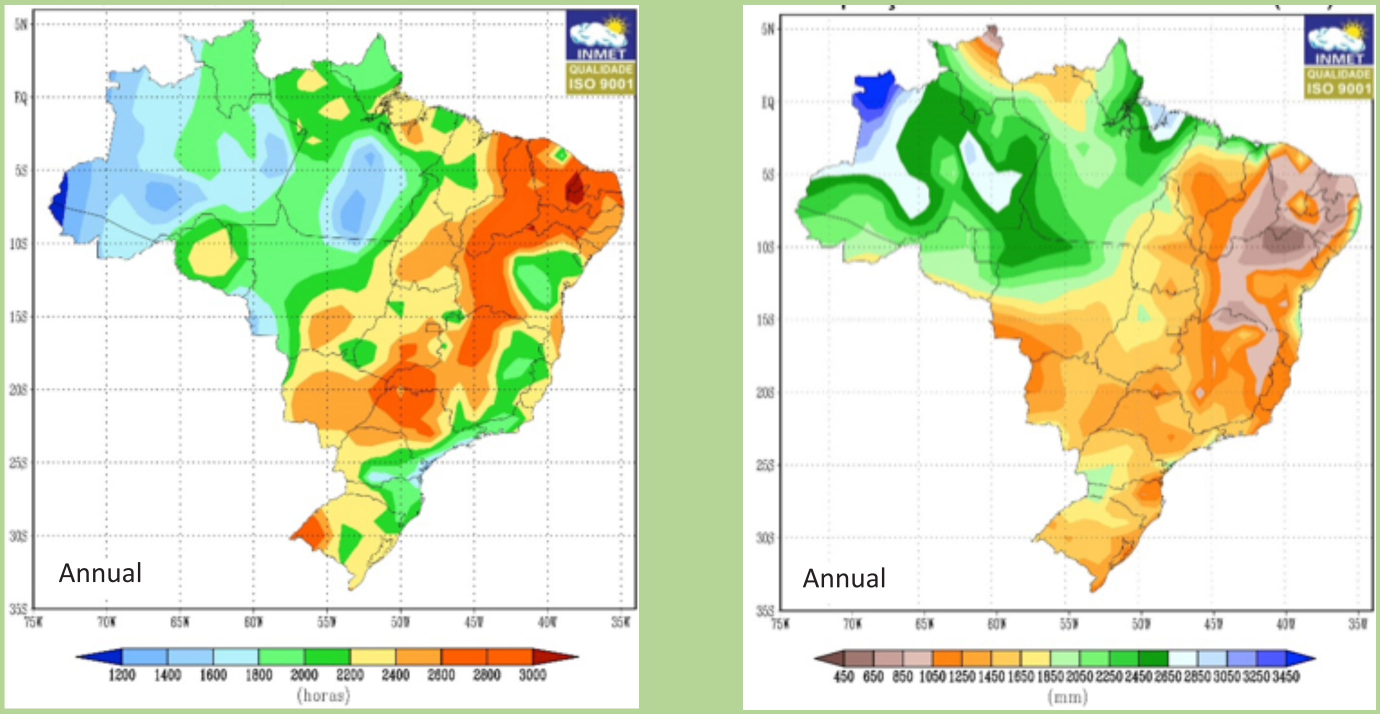


Fig. 7. Top: mean monthly temperatures in warm and cold months in Brazil.
Bottom: total hours of sunlight and total yearly rainfall in Brazil

Source: INMET[6] (2015)

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[6] INMET: Instituto Nacional de Meteorologia

F8. Main catchment areas in Brazil

Source: https://pt.wikipedia.org/wiki/Regi%C3%B5es_hidrogr%C3%A1ficas_do_Brasil#/media/File:Brasil_Bacias_hidrograficas.svg

2.3. Main catchment areas in Brazil

In Brazil, the main route of discharge of treated or untreated wastewater is in surface fresh waters. The main basins (catchment areas) in Brazil are shown in Figure 8. The Amazon and Tocantins-Araguaia are large basins, with large influents and main watercourses. The basins situated in Northeast Brazil have low water availability, and many streams are intermittent. The São Francisco basin is importance in the sense that it crosses several states in Brazil, from the Southeast up to the Northeast. The basins situated in South Brazil mostly run to neighboring countries.

3. COVERAGE IN TERMS OF SEWAGE COLLECTION AND TREATMENT IN BRAZIL

The most frequent surveys on the coverage in terms of sewage collection and treatment in Brazil are provided by SNIS (National System for Information on Sanitation), an official publication from the Ministry of the Cities. Yearly reports are provided, and the latest one is related to data from 2013, and published in December 2014 (SNIS, 2014).

The data are provided by the service providers as a response to standard questionnaires. Even though inconsistencies may exist because of the method used for data gathering, the system is becoming every time more robust and wide reaching. For the year 2013, 67% of the municipalities replied to the questionnaire related to sewerage, amounting to approximately 91% of the population.

The coverage of the service providers (water and sanitation company or utility) may be of the following types:

- Regional (typically a company in each state of the federation)
- Micro-regional (only three in Brazil)
- Local (typically covering a municipality)

The juridical nature of the service providers may be:

- Direct administration (belonging to the municipality; very frequent in Brazil)
- Autarchy (acting in the municipality, but as an autonomous service; also very frequent in Brazil)
- Society with mixed economy (predominant in almost all state companies)
- Public enterprise (only five cases in Brazil)
- Private enterprise (not very representative, but responsible for one state, three micro-regional and 63 local companies)
- Social organization (very small in Brazil)

From the 1,385 service providers that responded to the questionnaires, the vast majority is distributed according to the following categories:

- Local / direct administration: 72% of the questionnaires
- Local / autarchy: 30% of the questionnaires
- Regional / mixed economy: 24 out of the 28 regional companies, operating a very large number of water supply and sanitation systems in the municipalities

Another important source of information in Brazil is provided by IBGE (Brazilian Institute on Geography and Statistics) in the PNSB[7] (National Survey on Basic Sanitation). The methodology is different, because data is gathered based on a census approach. The last survey was carried out in 2010. Because the SNIS data is more recent, it will be used in this report.

Table 1 summarizes the data obtained in the 2013 survey by SNIS. These data will be presented graphically in the figures to follow, where they will be discussed.

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6. PNSB: Pesquisa Nacional de Saneamento Básico

Table 1. Main indicators associated with sewage collection and treatment in Brazil, based on the 2103 survey by SNIS

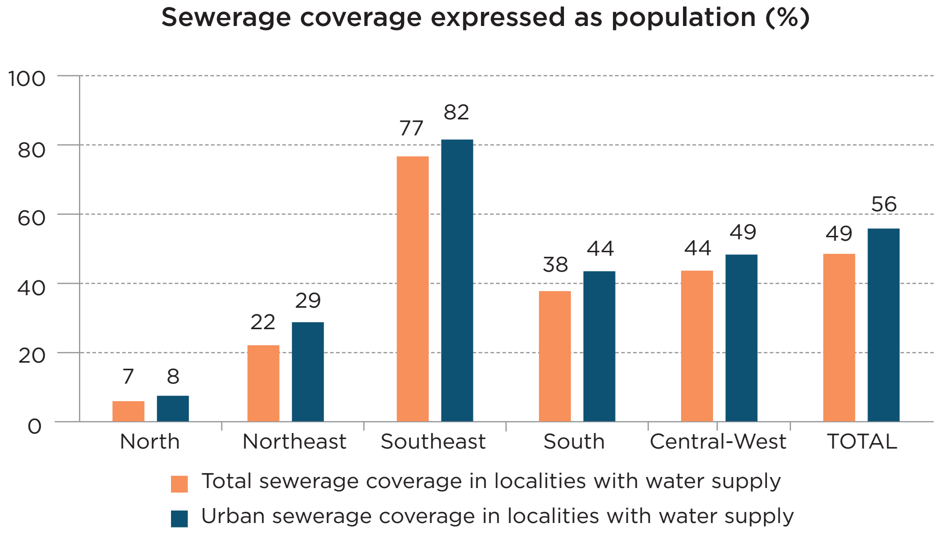
Region	Total sewerage coverage in localities with water supply	Urban sewerage coverage in localities with water supply	Volume sewage collected over volume water consumed	Volume sewage treated over volume sewage collected	Volume sewage treated over volume water consumed
-	%	%	%	%	%
North	6.5	8.2	16.6	85.3	14.7
Northeast	22.1	29.3	34.2	78.1	28.8
Southeast	77.3	82.2	66.0	64.3	43.9
South	38.0	44.2	43.1	78.9	35.1
Mid-west	44.2	48.6	49.9	91.6	45.9
TOTAL	**48.6**	**56.3**	**54.2**	**69.4**	**39.0**

The data in Table 1 reflect the coverage in terms of the population and volume associated with sewage collection in 2013 in Brazil, based on the questionnaires received by SNIS. It should be noted that the data are related only to sewage collection by sewerage network of pipes, and do not cover on-site sanitation. On-site sanitation can be improved or unimproved, according to the World Health Organization classification, but this is not addressed here. The aim of this report is to evaluate treatment systems in small communities, and this type of treatment is associated with sewage collection by pipelines that are responsible for the wastewater that is conveyed to the treatment plants. Therefore, on-site sanitation is not covered in this report.

Figure 9 shows the coverage in terms of the **population** (total and urban) that has **sewage collection** in the municipalities that have water supply. The logic behind this is that if there is no water supply in the locality, there will be no sewage production. Since Brazil is predominantly an urban country, it can be seen that the averages for the total and urban populations are not substantially different and, naturally, the numbers in terms of urban population are slightly better. The data on urban coverage is also shown in the map in Figure 10.

Regional asymmetries can be seen, with low coverages in the North and Northeast regions in Brazil. In these regions, on-site or individual solutions play an important role. The best indices are in Southeast, in which the development level is more favorable. For Brazil as a whole, it is seen that **approximately half of the population is connected to a sewage collection system**.

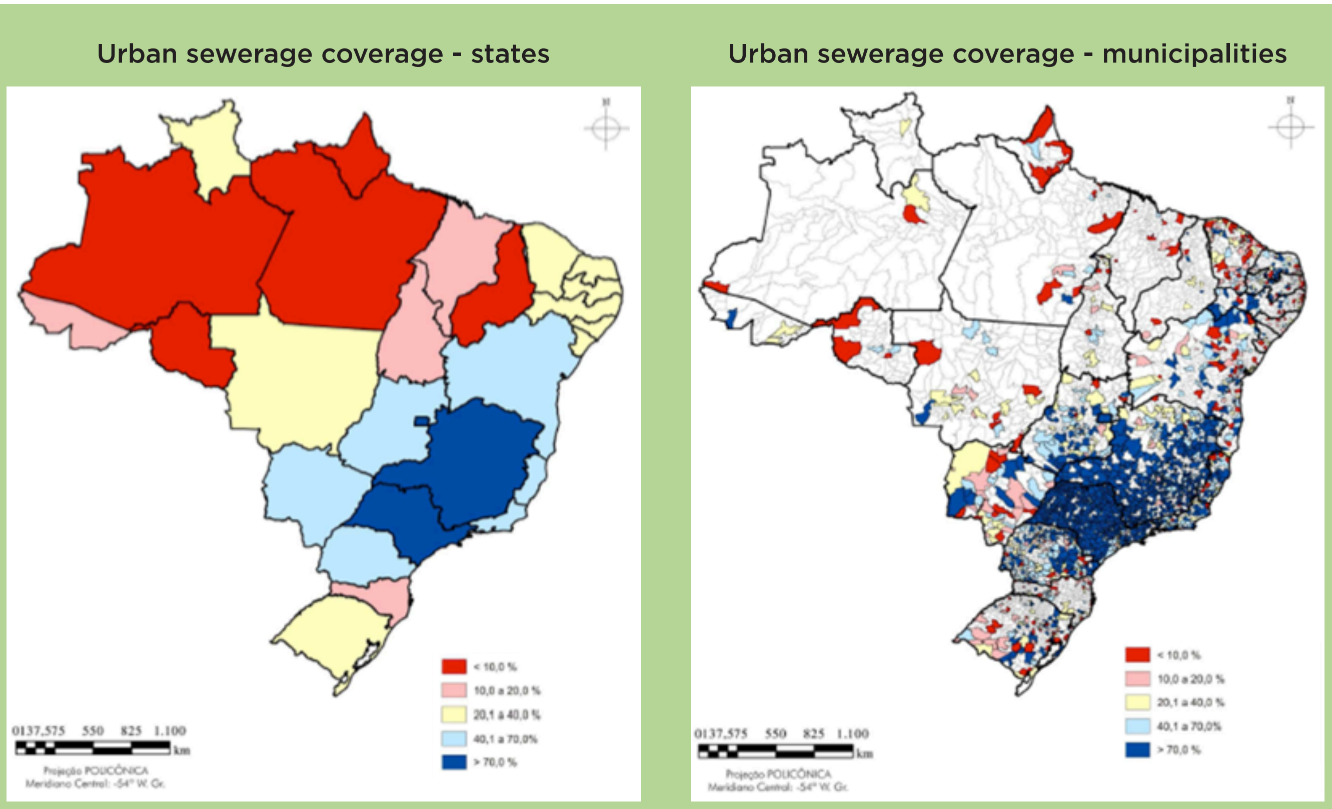
Fig. 9. Percentage of population (total and urban) connected to a sewage collection system, according to region and in Brazil, as a whole, in 2013



Left bars: total population connected to sewers divided by total population in municipalities that have water supply
Right bars: urban population connected to sewers divided by urban population in municipalities that have water supply

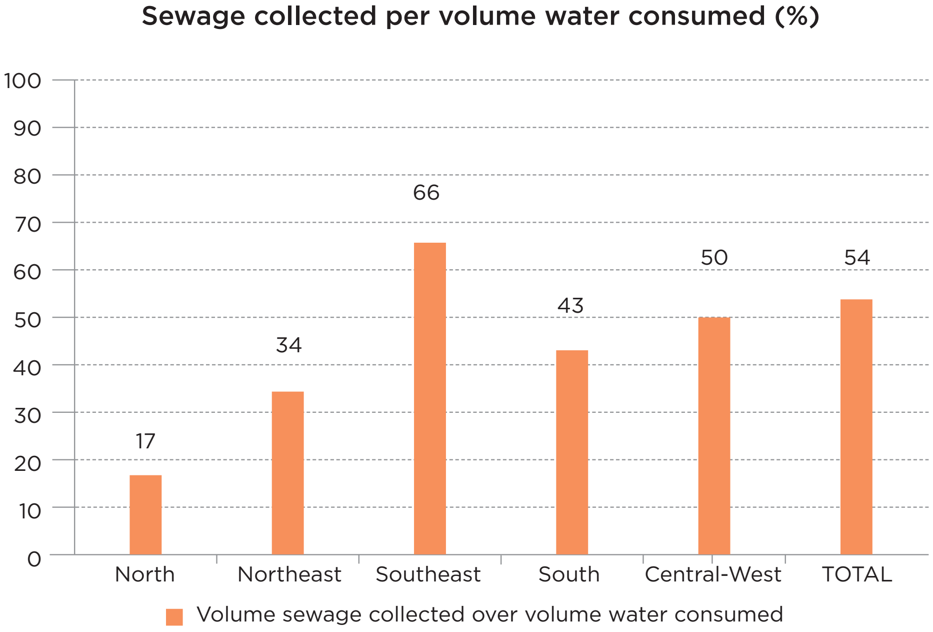
Source: graph made with data from SNIS (2014)

Fig. 10. Percentage of urban population connected to a sewage collection system, according to region and in Brazil, as a whole, in 2013



Top: statistics per state of the federation
Bottom: statistics per municipalities. Municipalities in white: no response to the questionnaires
Source: adapted from SNIS (2014)

Figure 11 presents other statistics of coverage of sewage collection, but this time expressed as **volume of sewage collected** divided by volume of water consumed. The rationale seems to be that sewage production could be approximately estimated by the volume of water consumed, assuming a return coefficient (including infiltration) close to 1.0. Therefore, a reasonable estimate of the volume of sewage collected per unit volume of sewage produced can be obtained. The numbers and comments are somewhat similar to those in Figure 9, for urban population. The same comment on the regional asymmetries can be made, and that the **overall coverage in Brazil is that slightly more than half of the sewage produced is collected in sewerage networks**.



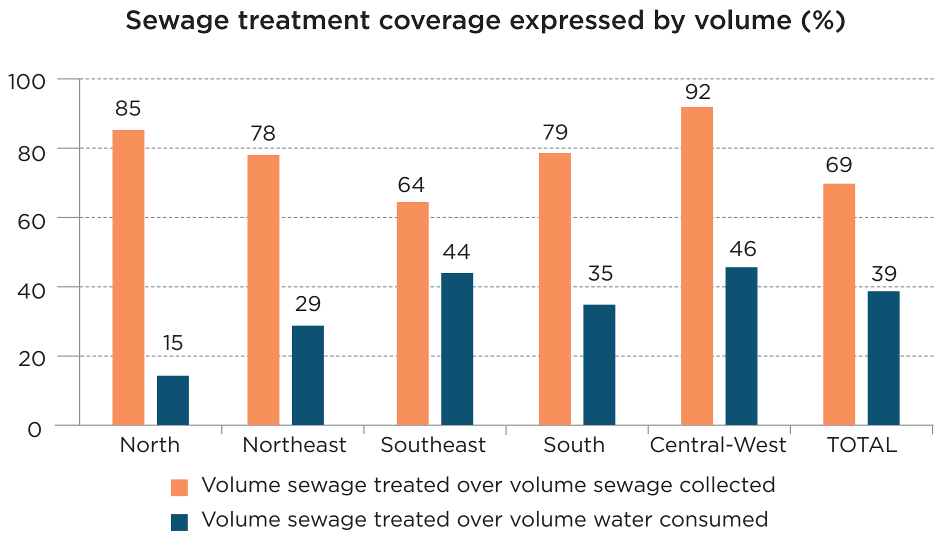
Source: graph made with data from SNIS (2014)

Fig. 11. Volume of sewage collected divided by volume of water consumed, according to region and in Brazil, as a whole, in 2013

Figure 12 addresses the **coverage in terms of sewage treatment**. Two statistics are shown. One relates the volume of sewage that is treated in comparison with the volume of sewage that is collected. The other one expresses the volume of sewage that is treated in comparison with the volume of water that is consumed, or approximately the volume of sewage that is generated. For Brazil, as a whole, it can be said that **approximately 70% of the sewage collected in networks is treated**, but only **around 40% of the sewage produced is treated**.

This analysis points out to the large regional differences in Brazil, but reinforce that fact that, even in the more developed regions, the coverage in terms of sewage treatment is far from desirable. A very large effort is necessary in order to enhance these indices. Even though improvements have been achieved in the past years, reality is still very far away from what is required.

Fig. 12. Percentage of sewage treatment in terms of volume of sewage collected and volume of water consumed, according to region and in Brazil, as a whole, in 2013



Left bars: volume of sewage treated divided by volume of sewage collected
Right bars: volume of sewage treated divided by volume of water consumed

Source: graph made with data from SNIS (2014)

4. TREATMENT SYSTEMS USED IN BRAZIL. A SURVEY FROM THE NATIONAL WATER AGENCY

4.1. Brazilian Atlas on Urban Wastewater Treatment

The National Water Agency (ANA) is undertaking a very important and unprecedented survey on the status of urban wastewater treatment in Brazil. Data on the volumes of sewage produced, collected and treated in each of the Brazilian municipalities are being gathered. On the towns that have wastewater treatment, a characterization of the treatment system is made, including the specification of the treatment line adopted.

These data have not yet been published (the final report is due at 2016), but ANA authorized the author to have access and present the preliminary findings for this IBD report. The author and ANA worked together in the consolidation of a simplified classification system for the treatment processes, and these results are presented below. It should be reminded that these data, although very advanced, are still preliminary, and may be subject to adjustments.

As of 13 July 2015, the general numbers of municipalities and wastewater treatment plants (WWTP) in ANA´s survey are:

- Total number of municipalities in Brazil: 5570
    - Municipalities with WWTPs: 1899
        - Municipalities with characterized WWTPs: 1519
        - Municipalities with WWTPs that have not yet been characterized: 380
    - Municipalities without WWTPs: 3671
- Total estimated number of urban WWTPs in Brazil: 2785
    - WWTPs identified and with data characterization: 2187
    - WWTP identified, but without data characterization: 218
    - WWTP not yet identified: 380

The number of existing WWTPs is greater than the number of municipalities with sewage treatment because some municipalities have more than one treatment plant. These data do not include privately owned treatment plants for small and specific applications, such as in condominiums, resorts, restaurants, hotels, hospitals etc, and, as mentioned before, treatment plants in industries.

The data presented below are based on the **2187 WWTP that have been fully characterized**.

4.2. Number of WWTPs according to process type

The 2187 existing treatment plants have been classified according to one of the categories presented in Table 2.

Table 2. Names and acronyms of the treatment processes identified in ANA´s survey

Simplified identification of the treatment process	Acronym
Aerated pond	AerP
Anaerobic pond	AnP
Facultative pond	FP
Pond + Maturation pond	P+Mat
Upflow anaerobic sludge blanket reactor	UASB
Aerated biofilter	AerBF
Overland flow (land disposal)	OF
Anaerobic filter	AnF
Trickling filter	TF
Physical-chemical treatment	PC
Polishing pond (facultative or maturation, after a previous treatment stage)	PP
Activated sludge	AS
Septic tank	ST
Other treatment process (different from above)	Others

These treatment processes are typically combined into the flowsheets listed in Table 3.

Table 3. Main flowsheets (combination of treatment processes)

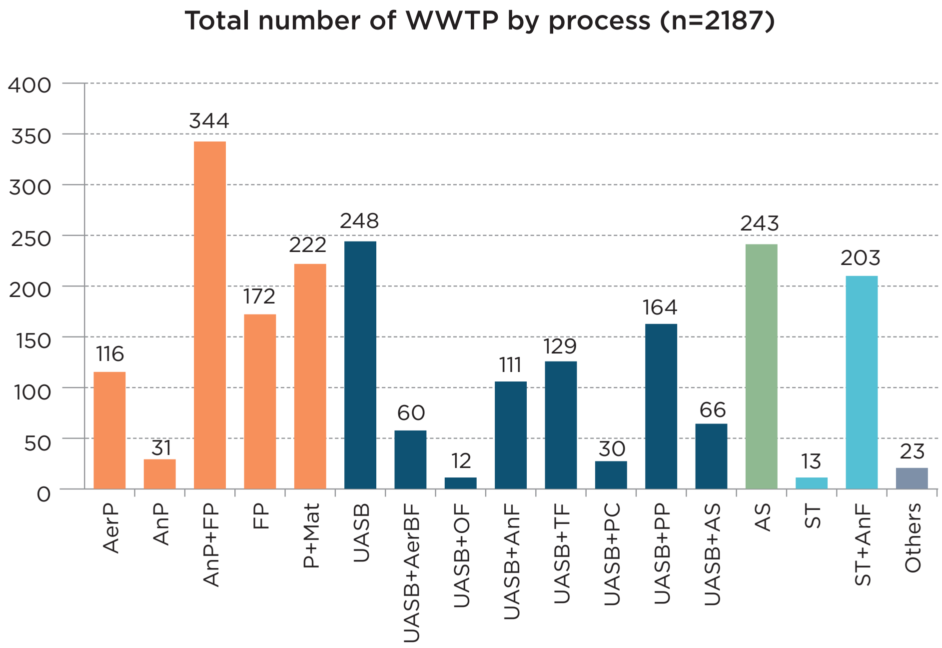
Simplified identification of the treatment process	Acronym	Major category
Aerated pond	AerP	Pond
Anaerobic pond	AnP	
Anaerobic pond + Facultative pond	AnP+FP	
Facultative pond	FP	
Pond (system or facultative) + Maturation pond	P+Mat	
Upflow anaerobic sludge blanket reactor	UASB	UASB + Post treatment
UASB + Aerated biofilter	UASB+AerBF	
UASB + Overland flow (land disposal)	UASB+OF	
UASB + Anaerobic filter	UASB+AnF	
UASB + Trickling filter	UASB+TF	
UASB + Physical-chemical treatment	UASB+PC	
UASB + Polishing pond (facultative or maturation)	UASB+PP	
UASB + Activated sludge	UASB+AS	
Activated sludge	AS	Activated sludge
Septic tank	ST	Septic tank + Anaerobic Filter
Septic tank + Anaerobic filter	ST+AnF	
Other treatment combinations	Others	Others

In order to simplify the analysis, no subdivisions of treatment systems in terms of loading rates or operating modes have been adopted. For instance, "activated sludge" accounted for all variants, including conventional activated sludge, extended aeration, sequencing batch reactors, activated sludge with biological nutrient removal etc. On the other hand, it was necessary to be more specific on the ponds, because the four pond types adopted (aerated, anaerobic, facultative, maturation) are very different from each other and accomplish different functions.

Fig. 13 presents the distribution of the 2187 WWTPs according to the process flowsheets listed in Table 3. **The treatment configurations most widely adopted** (more than 200 treatment plants in each) are:

- Anaerobic pond + Facultative Pond
- Ponds + Maturation pond
- UASB reactor
- Activated sludge
- Septic tank + Anaerobic filter

Fig. 13. Distribution of the number of WWTPs according to processes combinations (flowsheet)

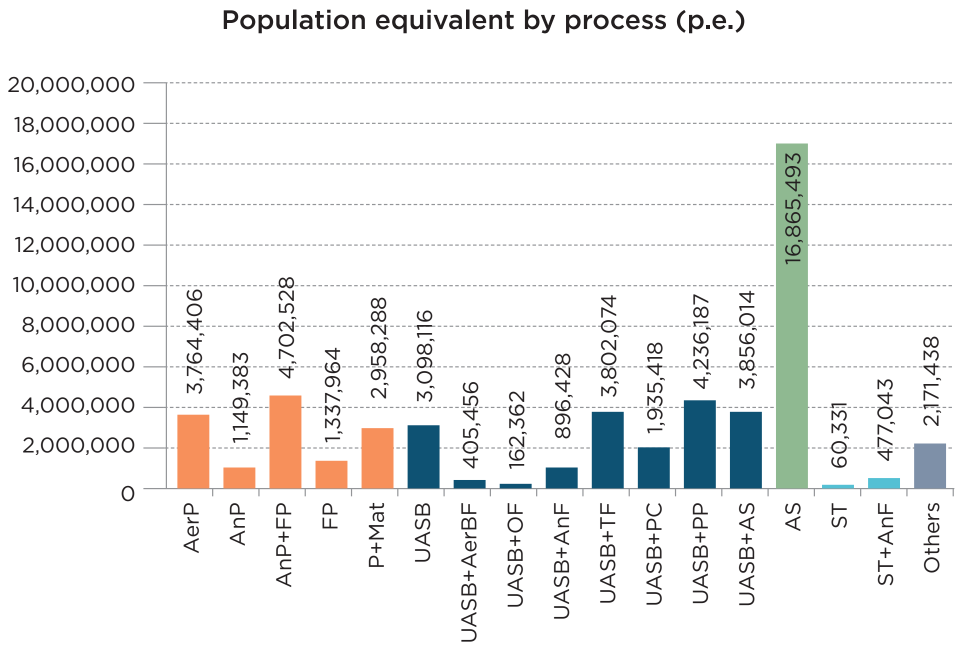


Source: graph prepared with data provided by ANA (Brasil, 2015)

Figure 14 presents the population equivalent of each of the treatment configurations listed in Table 3. The interpretation is different from that in Figure 13. Activated sludge dominates largely, since it is widely adopted in many large cities, therefore accounting for a large population equivalent. The **treatment configurations that dominate in terms of population equivalent** (greater than 3 million inhabitants) are, in this order:

- Activated sludge
- Anaerobic pond + Facultative pond
- UASB + Polishing pond
- UASB + Activated sludge
- UASB + Trickling filter
- Aerated pond
- UASB reactor

Fig. 14. Population equivalent (inhabitants) per processes combinations (flowsheet)

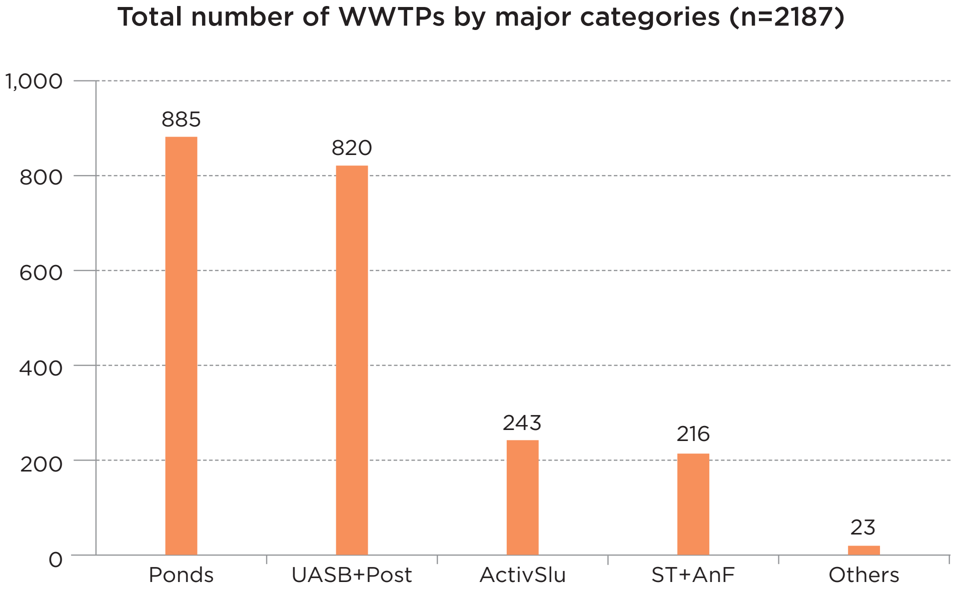


Source: graph prepared with data provided by ANA (Brasil, 2015)

Grouping the treatment configurations into major categories (as detailed in Table 3) leads to Figures 15 and 16, which present the number of treatment plants and the population equivalent for these main categories. From these two graphs, it can be said that:

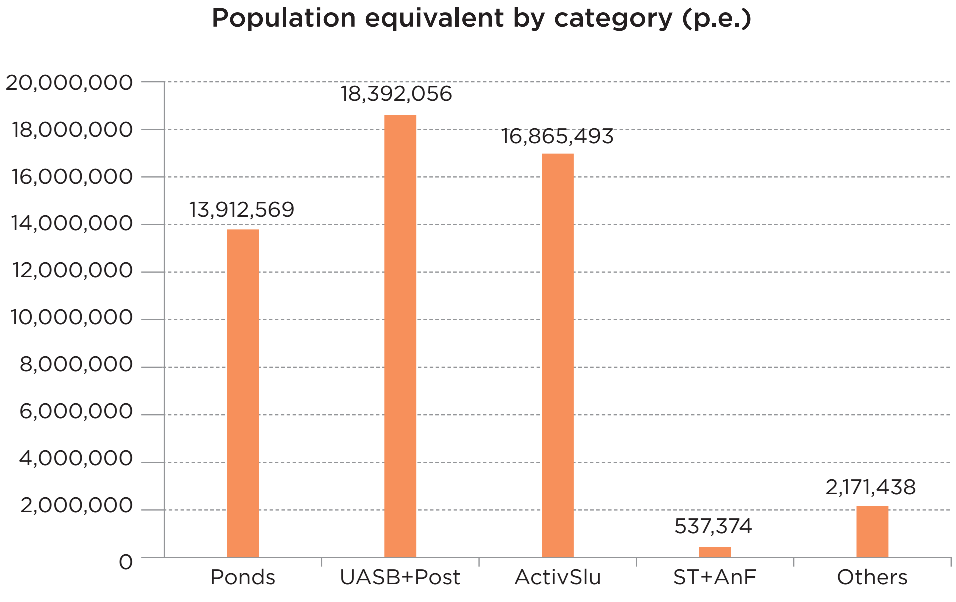
- Ponds and UASB reactor alone or followed by any form of post-treatment dominate in terms of number of treatment plants, representing almost **80% of the treatment plants analyzed**.
- UASB reactor alone or followed by any form of post-treatment, activated sludge and different combinations of ponds treat the largest population equivalents, representing **95% of the total population equivalent**.
- The total population equivalent treated by the 2187 WWTPs analyzed is **51,878,930 inhabitants**.

Fig. 15. Distribution of the number of WWTPs according to major treatment categories



Source: graph prepared with data provided by ANA (Brasil, 2015)

Fig. 16. Population equivalent (inhabitants) per major treatment category



Source: graph prepared with data provided by ANA (Brasil, 2015)

One specific comment may be made about constructed **wetlands**, which are widely adopted in several countries for the treatment of small communities. It was not easy to include them as a separate group, because they are scattered together with different treatment systems. From the 2187 WWTPs, 32 (1.5%) include a stage with wetlands. It is important to remember that this survey does not include treatment sewage from specific installations (condominiums, resorts, hotels etc), which have a more intense use of wetlands.

From the survey, it is seen that most of the treatment processes aim at removing organic matter (BOD, COD). Regarding additional objectives, the following can be said:

- **Pathogen removal**. From the 2187 WWTPs evaluated, 251 (11.5%) have a disinfection stage, and 225 (10.3%) have maturation ponds. The total number of plants that have a specific stage for pathogen removal is therefore **476 (21.8%)**.
- **Nutrient removal**. Although some plants described a stage for biological nutrient removal (especially involving activated sludge), this information was absent in most of the data collected. No conclusions can be drawn, but it is known that stages for nitrogen and phosphorus removal are not common in the Brazilian treatment plants.

4.3. Distribution of WWTPs according to process and population size

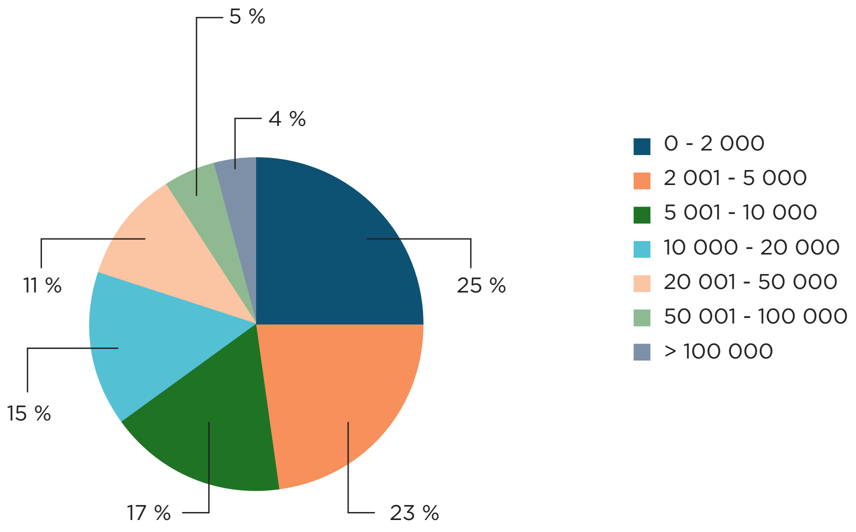
Since one of the objectives of this report is to analyze treatment plants for small towns, with a cut-off point of 100,000 inhabitants, it is important to investigate the distribution of treatment processes per population size.

The distribution of the Brazilian population according to the size of the municipality was presented in Section 2.1, Figure 5. A similar graph with the same population ranges is presented in Figure 17, but now showing the number of treatment plants. It is clear to see that the largest numbers are for small towns: **25% of the WWTPs are for populations lower than 2,000 inhabitants, almost 50% are for populations up to 5,000 inhabitants, and 80% are for populations less than 20,000 inhabitants**.

A sequence of graphs (Figures 18 to 20) are presented, showing the distribution of treatment configurations by population size. The graphs are separated by major categories, to make their visualization easier. It can be seen that ponds are used approximately evenly for population sizes up to 20,000 inhabitants. The number of UASB reactors alone decrease with the increase in population size. A similar pattern is seen for UASB followed by post-treatment (even though different post-treatment processes are covered). Activated sludge is evenly distributed in all population ranges, and septic tank followed by anaerobic filter is used mainly for populations up to 5,000 inhabitants.

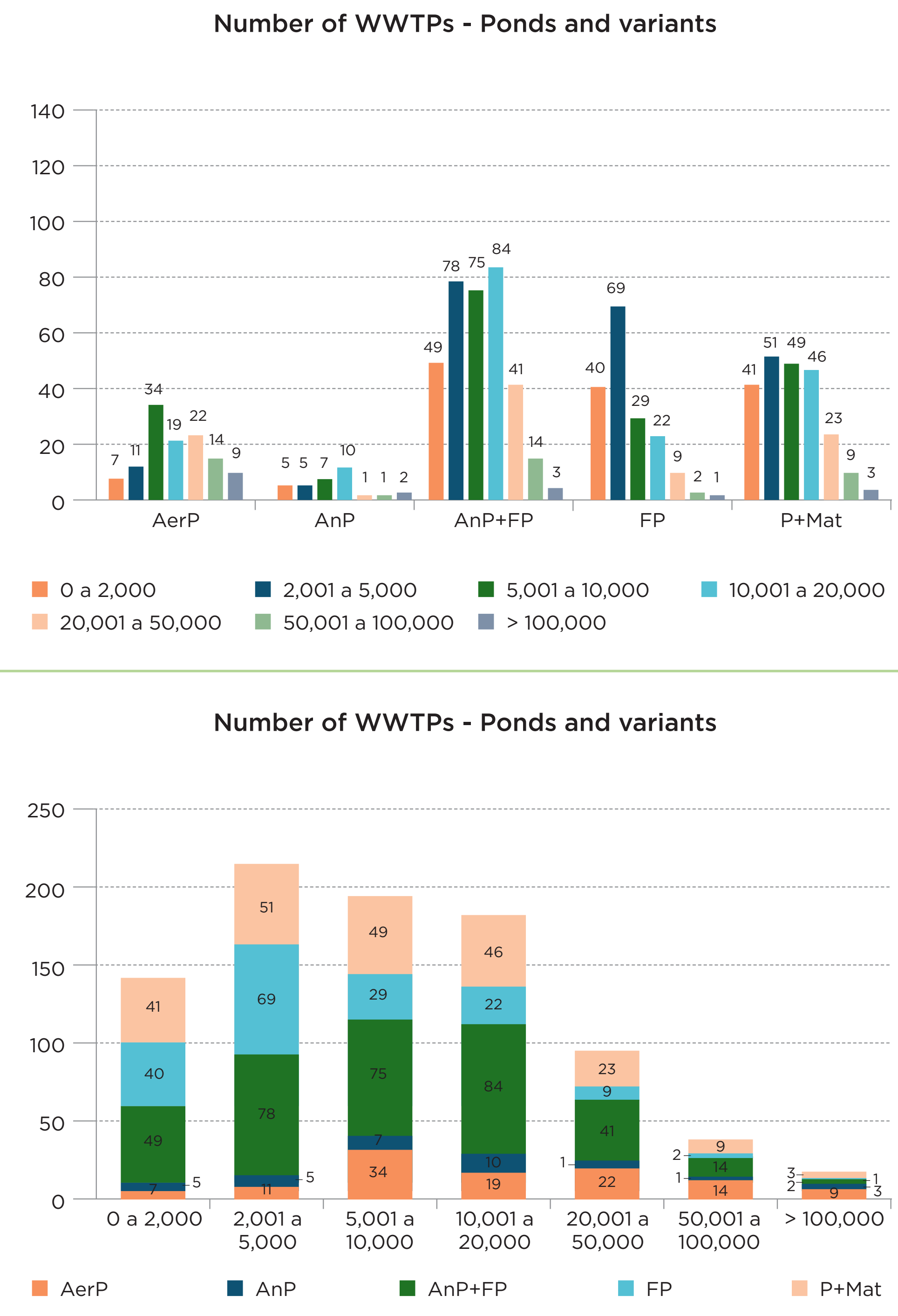
Fig. 17. Number and percentage of WWTPs per population range (inhabitants)

Distribution of number of WWTPs by population range

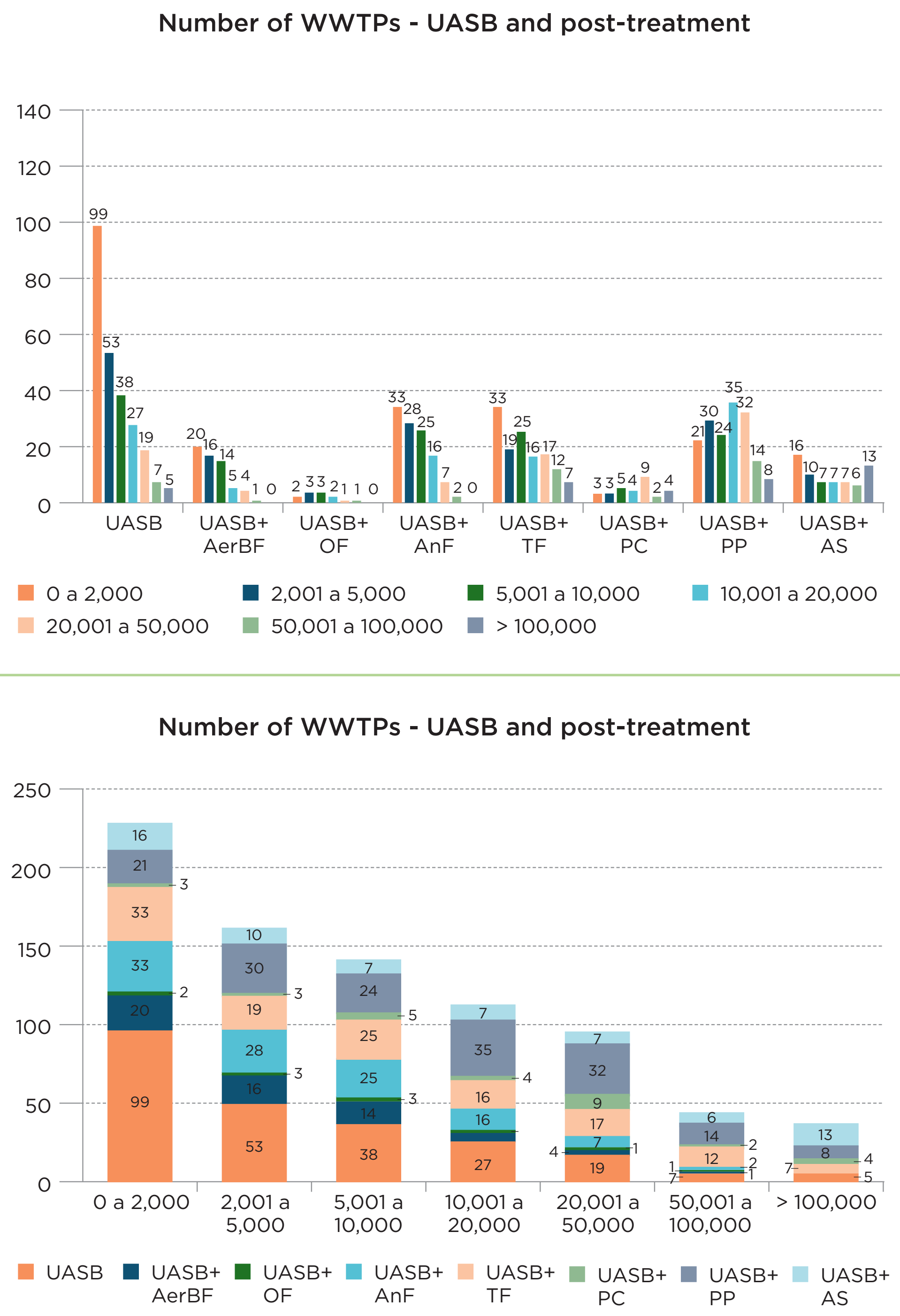


Source: graph prepared with data provided by ANA (Brasil, 2015)

Fig. 18. Number of treatment plants (ponds and variants) separated by population range and treatment configuration. Top: separation by treatment configuration. Bottom: separation by population range configuration. Bottom: separation by population range



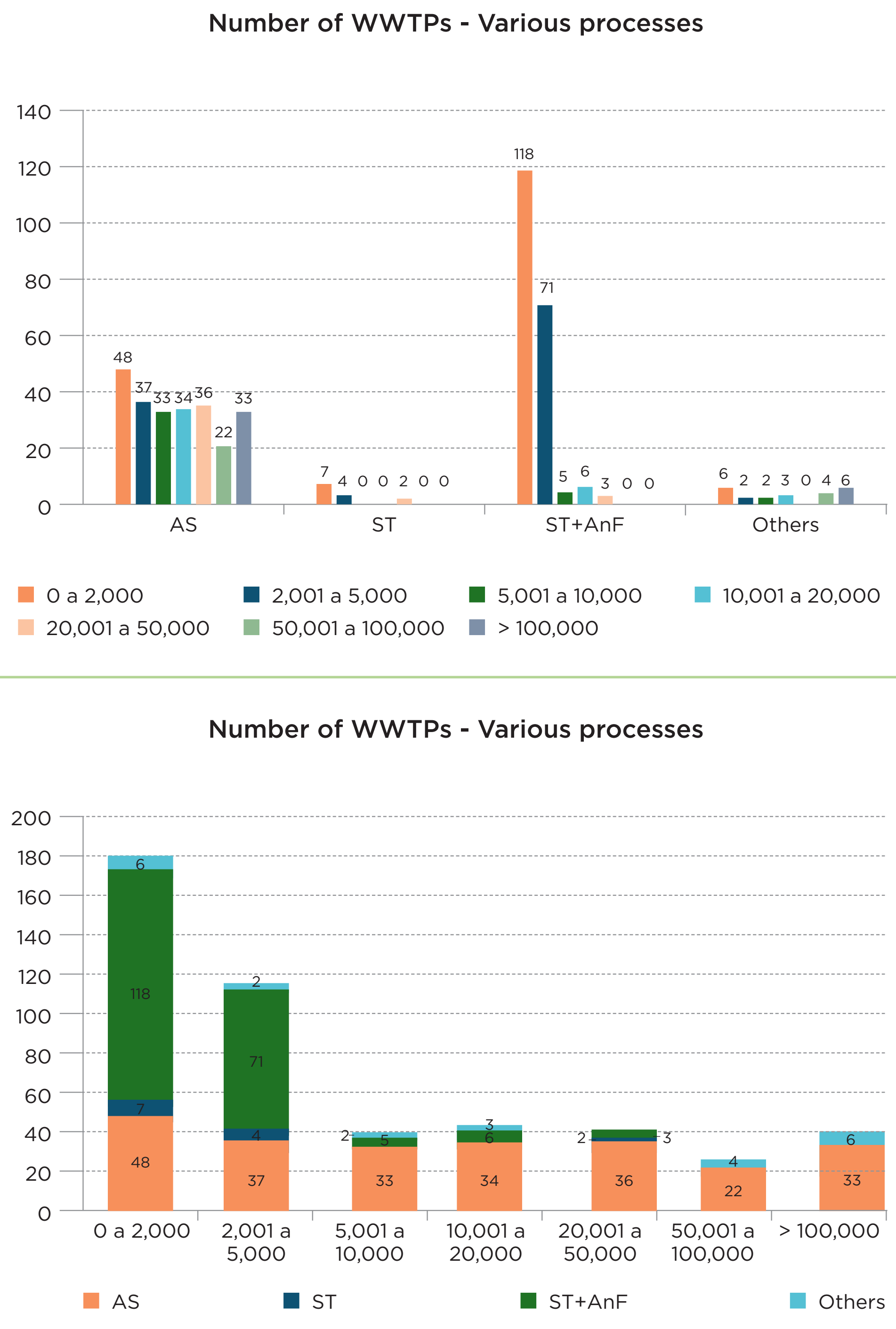
Source: graph prepared with data provided by ANA (Brasil, 2015)


Number of WWTPs - UASB and post-treatment

Number of WWTPs - UASB and post-treatment

Source: graph prepared with data provided by ANA (Brasil, 2015)

Fig. 19. Number of treatment plants (UASB reactor and post-treatment) separated by population range and treatment configuration. Top: separation by treatment configuration. Bottom: separation by population range



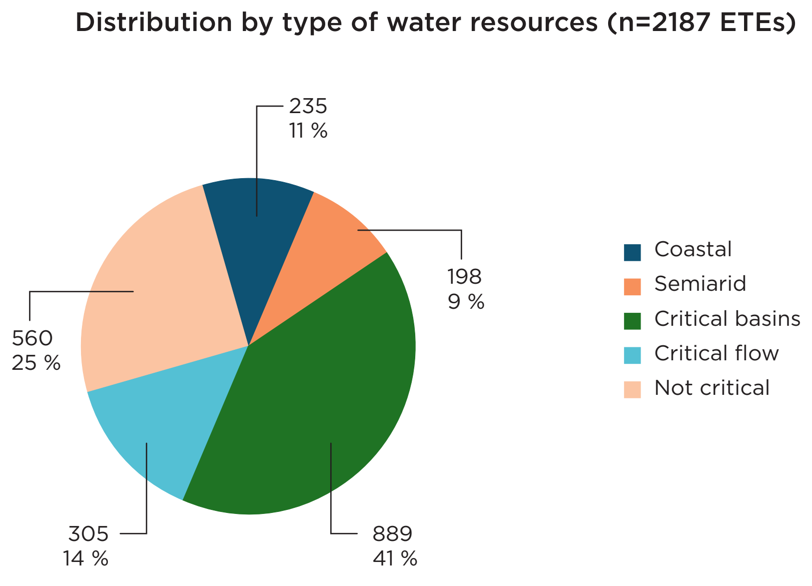
Source: graph prepared with data provided by ANA (Brasil, 2015)

Fig. 20. Number of treatment plants (various configurations) separated by population range and treatment configuration. Top: separation by treatment configuration. Bottom: separation by population range

4.4. Destination of the discharged effluent

ANA´s survey also includes an evaluation of the destination of the discharged effluent. This will not be detailed in this report, but a simple indication is given in Figure 21. Discharge to coastal waters via submarine outfall usually involve simple treatment schemes, and this destination accounts for 11% of the WWTPs. The remaining treatment plants discharge to fresh waters. Discharges at the semiarid region are complex, because of the low dilution capacity, which can be even nihil in intermittent streams. ANA adopted specific criteria for classifying a basin as critical, depending on population size and other factors. It can be seen that most of the discharges (41%) take place at these critical basins. Discharge at basins with critical flow (small dilution capacity, because of several factors) account for 14% of the total number. Finally, 1/4 of the discharges are made in basins that do not show any critical factor.

Fig. 21. Number and percentage of treatment plants discharging to specific water bodies



Source: graph prepared with data provided by ANA (Brasil, 2015)

4.5. Most widely used treatment processes in Latin America

Although not connected with ANA´s survey in Brazil, it is interesting to analyze at this stage the results from a survey undertaken by Noyola et al (2012) in wastewater treatment in some countries in Latin America. The sample considered 2734 WWTPs divided as follows: 702 facilities in Brazil (estimated total facilities in their study: 2985), 177 in Chile (estimated total facilities: 263), 139 in Colombia (unknown estimated total facilities), 32 in Guatemala (estimated total facilities: 87), 1653 in Mexico (estimated total facilities: 1833), and 31 in Dominican Republic (estimated total facilities: 56). As in ANA´s survey in Brazil, the sample and the estimated total facilities did not consider very small private plants (hotels, shopping malls, residential buildings, etc.).

Figure 22 (top) presents the number of WWTPs according to treatment configuration. The number of treatment processes is higher than the number of WWTP (2933 vs. 2734) due to the existence of 199 facilities using two processes (two types of treatment technologies in series, as pre- and post-treatment). Figure 22 (bottom) presents the same treatment processes, but now reporting the total flow (m^3/s) treated by each process.

These data are to be compared with Figures 13 and 15, which are specific to Brazil, and based on ANA´s survey. The overall trends are similar, with a large utilization of stabilization ponds, activated sludge and UASB reactors. The largest number of plants are represented by stabilization ponds, but the highest accumulated flow is associated with activated sludge.

Wastewater treatment in Latin America (plants surveyed by Noyola et al, 2012).

Brazil
702 facilities

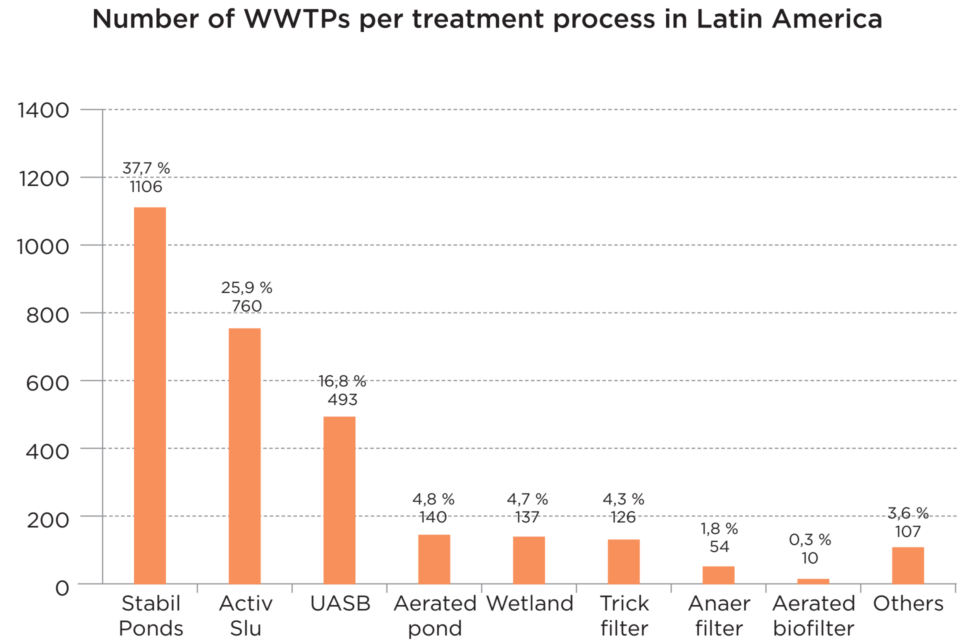
Chile
177 facilities

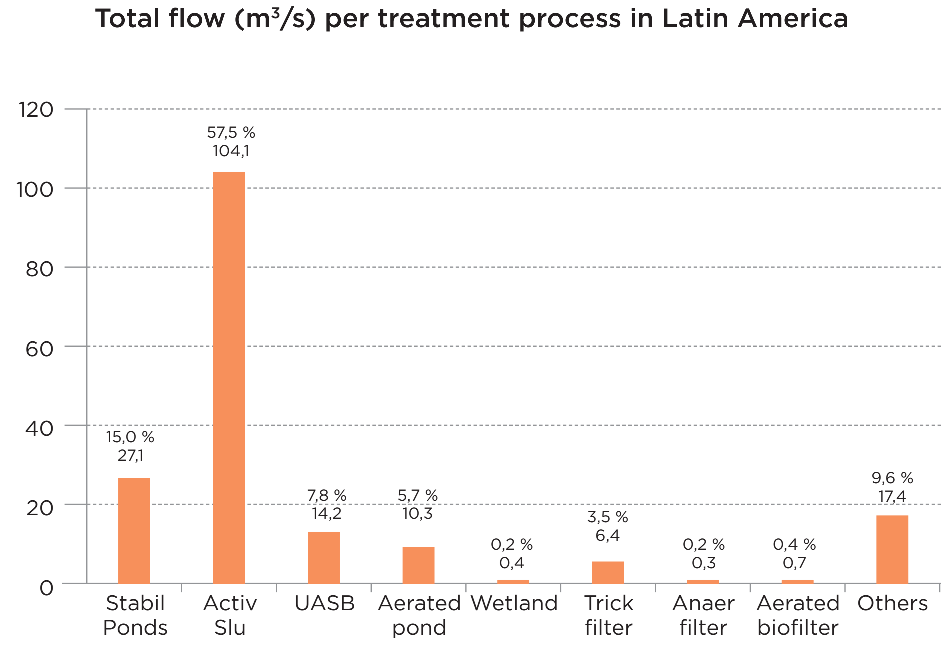
Colombia
139 facilities

Guatemala
32 facilities

Mexico
1653 facilities

Dominican Republic
31 facilities





Source: data from Noyola et al (2012)

Fig. 22. Distribution of treatment processes in selected Latin-American countries (absolute numbers and percentages). Total number of processes: 2,933

5. LEGISLATION RELATED TO WATER BODIES PROTECTION AND EFFLUENT DISCHARGES IN BRAZIL

5.1. Conama Directive 357/2005 for the protection of water bodies

As was shown in Section 2, Brazil is a federative union, divided into states. Setting up and controlling the environmental legislation is at the federal level a task of the National Environmental Council (CONAMA[8]) and its executive branch (IBAMA[9]). The federal law applies at national level. Each state has also a state environmental council and an executive agency. Besides dictating the state environmental policy, the council has the responsibility of licensing and controlling polluting activities, with the technical support of the environmental agency.

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[8] CONAMA: Conselho Nacional de Meio Ambiente

[9] IBAMA: Instituto Brasileiro de Meio Ambiente e dos Recursos Naturais Renováveis

Whereas the environmental control policies are established as a function of political boundaries (states), water resources management follows geographical limits (river basins). If the river basin is completely confined within one state of the union, its water resources are managed by the state water resources council, which may assign a river committee and agency for the basin. However, river basins that cross two or more states or national boundaries are managed by a federal agency (ANA - National Water Agency). There are no fixed rules for defining the minimum size of the basin that is required for having a committee. Basin committees, together with the state water resources council, define the general policies of water resources management in the catchment area, including establishment of classes of use for the water body, licensing for water abstraction and wastewater discharge and the definition of the application of the revenue arising from the user-polluter-pay principle. The basin agencies are the executive branch of the committee. These principles are set by the National Water Resources Policy (Law 9433 of 1997).

This section, based on von Sperling (2008), describes and comments on the major points of the Brazilian national standards for water quality and effluent discharge (CONAMA Directive No. 357/2005). These standards are used as a basis for licensing new polluting activities, since they are a reference for Environmental Impact Assessment (EIA) studies. A permit may only be issued if has been demonstrated by EIA that the legislation will be complied with. In addition, for existing polluting activities, enforcement based on the legislation may be put into practice by the state environmental councils. It should be recognized, however, that putting these principles into real practice is a difficult task and a challenge for many state environmental systems. A closer control on private polluters (industries) seems to be easier to apply than on public polluters (municipalities).

The Federal directive CONAMA (National Environmental Council) No. 357/2005 updated a directive that was established in 1986 (CONAMA Directive 20/1986). Both structures are similar, but the 2005 legislation revised water uses, classes, constituents and parameter values. Besides the federal legislation, there are also state legislations. Each state must comply with the federal law, and has also the option in the state legislation of including specific parameters or more stringent standard values.

CONAMA Directive 357/2005 divided the waters in the national territory into fresh (salinity $\leq$ 0.05 %), brackish (0.05 % < salinity < 3 %) and saline (salinity $\geq$ 3%) waters. For each of these categories, there are different classes. Each class is associated with a grouping of intended uses for the water. For fresh waters there are five classes, for brackish water there are four classes and for saline waters there are four classes. This section concentrates mainly on fresh water, and Table 4 presents a summary of the main potential water uses assigned to each class.

The Special Class is associated with the most important uses, and Class 4 is designated for less critical uses. The Special Class is intended for the preservation of the environment under natural equilibrium. However, abstraction of water for supply is accepted, but no wastewater (even treated) is allowed to be discharged into a Special Class water body. Wastewater discharge may only take place into water bodies with classes 1 to 4.

Each river basin, through its committee and agency, together with the environmental agency, must have their waters classified according to the system shown above. In the absence of any specific classification, the legislation specifies that the water body will automatically remain as Class 2.

Table 4. Classification of fresh waters as a function of their intended uses (CONAMA Directive 357/2005)

Use	Class				
	Special	1	2	3	4
Domestic drinking water supply	X (a)	X (b)	X (c)	X (d)	
Preservation of natural equilibrium of aquatic communities	X				
Preservation of aquatic environment in special protection units	X				
Protection of aquatic communities		X	X		
Recreation with direct contact (*)		X	X		
Irrigation		X (e)	X (f)	X (g)	
Breeding of species (aquaculture) and fishing activities			X		
Amateur fishing				X	
Animal water supply				X	
Recreation with indirect contact				X	
Navigation					X
Landscape harmony					X

(a) water supply after disinfection
(b) water supply after a simple treatment
(c) water supply after conventional treatment
(d) water supply after conventional or advanced treatment
(e) irrigation of vegetables eaten uncooked or low-growing fruits eaten unpeeled
(f) irrigation of fruits and vegetables, and also parks, gardens and sports fields with which the public may have direct contact
(g) irrigation of trees, cereals and fodder

(*) a specific bathing directive applies (CONAMA Directive 274/2001)

The classification of water bodies has already been undertaken for many catchment areas in Brazil, but the majority still remains classified as Class 2.

Because of the grouping of water uses, each of the classes is associated with a certain water quality to be maintained in the water body, expressed in terms of receiving water standards. Besides these, there are general discharge standards, which are independent of the class of the receiving water body. Discharge standards are dealt with in Section 5.2.

The federal standards set by the CONAMA directive are summarized in Table 5 for some of the main water quality constituents that are more directly associated with urban wastewater. The complete list of parameters covered by the directive is of course much larger, and the full legislation should be consulted, if necessary. The setting up of the limiting values is based on international experience, and is driven mainly by the protection of human health and aquatic species. Besides the list of the several parameters and their limit values clearly established in the legislation, the CONAMA directive specifies that the quality of the aquatic environments may be evaluated, when appropriate, by biological indicators using organisms or aquatic communities.

Table 5. Brazilian water quality standards for selected constituents in fresh water bodies according to the class (CONAMA Directive 357/2005)

Parameter	Unit	Fresh water class			
		1	2	3	4
pH	-	6.0 to 9.0	6.0-9.0	6.0-9.0	6.0-9.0
Thermotolerant coliforms	MPN/100mL	200 (a)	1000(a)	(b)	
Biochemical oxygen demand	mg/L	3	5	10	
Dissolved oxygen	mg/L	≥ 6	≥ 5	≥ 4	≥ 2
Total ammonia (pH≤7.5)	mgN/L	3.7	3.7	13.3	
Total ammonia (7.5<pH≤8.0)	mgN/L	2.0	2.0	5.6	
Total ammonia (8.0<pH≤8.5)	mgN/L	1.0	1.0	2.2	
Total ammonia (pH>8.5)	mgN/L	0.5	0.5	1.0	
Nitrate	mgN/L	10.0	10.0	10.0	
Nitrite	mgN/L	1.0	1.0	1.0	
Total P (lenthic environment)	mgP/L	0.020	0.030	0.050	
Total P (intermediate environment and direct influent to a lenthic environment)	mgP/L	0.025	0.050	0.075	
Total P (lotic environment and direct influent to an intermediate environment.)	mgP/L	0.10	0.10	0.15	

Only some parameters, directly linked to urban wastewater, are listed here – for a full list consult the legislation CONAMA 357/2005
Intermediate environment: residence time between 2 and 40 days
(a) See bathing water directive (CONAMA 274/2000)
(b) Class 3 – thermotolerant coliforms: water supply for breeding of animals under confinement: 1000 MPN/100mL; indirect contact: 2500 MPN/100mL; other uses: 4000 MPN/100mL

In addition, the possible interactions of substances and the presence of contaminants not specified in the legislation and that are potentially harmful to living beings must be investigated using toxicological, ecotoxicological or other scientifically recognized methods.

These standards are to be met under the so-called reference flow for the river at the point of the discharge. Reference flow is usually a flow characterizing dry-weather periods and low dilution capacities. Each state environmental agency must decide upon the reference flow to be adopted. Common criteria are: Q90 (flow value expected to be exceeded 90% of the time), Q95 (flow value expected to be exceeded 95 % of the time) and Q7,10 (flow value associated with a minimum of seven consecutive days and a return interval of 10 years).

5.2. Discharge standards in Brazil

In the Brazilian legislation there are two types of standards: water body standards and discharge (effluent, emission) standards. This concept is also adopted in many countries. The main reason is that for the environmental agency it is very difficult to control the river water quality when there are multiple discharges and, in case of infringement of the law, assign responsibilities. As a result, the agencies may concentrate their efforts on a more systematic basis on controlling mainly the discharge standards.

The relationship between both standards is:

- An effluent, besides complying with the general discharge standards, must also allow compliance of the receiving water with the specific standards for its class.
- If the compliance with the receiving water body standards is demonstrated by environmental studies, the polluter may apply for the environmental agency for relaxation of its discharge standards.

In 2011, CONAMA updated its directive with a special focus on discharge standards (CONAMA Directive 430/2011). From the constituents listed in Table 5, only BOD (Biochemical Oxygen Demand) is included. Some parameters of broad interest are not included in the national standards, but are left for possible inclusion in the standards from the states, in order to better reflect local reality.

This CONAMA directive makes a distinction between discharges, in general, and discharges from wastewater treatment plants treating sanitary (municipal, urban) wastewater. The applicable BOD discharge standards at federal level for sanitary wastewater are:

- **Biochemical Oxygen Demand**, 5 days, 20° C: **maximum of 120 mg/L**. This limit can be surpassed in the case the treatment system has a **minimum efficiency of 60%**, or as a result of self-purification studies of the receiving water body that ensure compliance with the standards of its respective class.

These standards are not stringent and were the subject of considerable debate during the elaboration of the 2011 directive. The rationale behind it was to allow implementation of simple and less efficient treatment systems, such as UASB reactors alone, with the expectation that in the future improvements in the treatment plants in Brazil could lead to better effluent qualities. This solved an immediate problem that several new treatment plants based on UASB reactors could not obtain their permit if they did not comply with more stringent standards.

Independently of that, **some states** decided to adopt a more stringent discharge standard. The value of **maximum BOD_5 of 60 mg/L** has been adopted in some states, whereas others adopt progressive values as a function of the population equivalent. Some states allow that the concentration value may be exceeded if the **efficiency of BOD removal** in the treatment is **greater than or equal to 70% up to 85%** (depending on the state). The state of Minas Gerais apply standards for Chemical Oxygen Demand - **COD** (**maximum 180 mg/L or mean efficiency greater than 65%** in the case of sanitary sewage).

For **suspended solids**, some states adopt values of **60 to 100 mg/L**. Few states apply discharge standards for **total nitrogen, phosphorus and coliforms**. The federal standards for **ammonia-N** specify the maximum value of 20 mg/L, but this value is not applicable to sanitary wastewater.

CONAMA Directive 357/2005 includes the concept of “progressive targets”, which can be understood as a stepwise and progressive compliance with water body and discharge standards. This involves “a set of measures and actions, compulsory and progressive, required for the compliance with intermediate and final water quality targets compatible with the class of the water body”.

In terms of **reuse**, in Brazil there is so far no legal framework for specifying the required water quality as a function of the use of the treated effluent (agricultural, urban, industrial etc). Despite several discussions, no official document exists. In a scenario of water scarcity, especially in recent years, the route of reuse has not been implemented on a systematic way, having the absence of a regulatory scheme as one of the main reasons.

6. SHORT DESCRIPTION OF THE MAIN WASTEWATER TREATMENT PROCESSES ADOPTED IN BRAZIL

6.1. Description of the treatment processes

It is not the purpose of this report to present a detailed description of the functioning of the main wastewater treatment processes used in Brazil. However, in order to have a common background, a succinct description is presented in a table format (Table 6) and with the main flowsheets (Figure 23 to 27). This section is adapted and simplified from von Sperling and Chernicharo (2005), a textbook by the author of this report that can be freely downloaded at the internet[10]. Further details of the treatment processes can be obtained at this reference, plus at several other references that are cited in the textbook.

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[10] Von Sperling, M., Chernicharo, C.A.L. (2005). Biological wastewater treatment in warm climate regions. 1496 pages. Freely downloadable at IWA Publishing: http://www.iwapublishing.com/open-access-ebooks/3567

Table 6 presents a summary of the main secondary level domestic sewage treatment systems. The technology of wastewater treatment has various other processes and variants, but the description below focusses only on the most frequently used systems in Brazil and Latin America, as shown in Section 4. The flowsheets of the systems described in this table are presented in Figures 23 to 27. In all flowsheets, besides going to the receiving water body, the effluent could be reused (agricultural / industrial / other) if conditions so permit. For the sake of simplicity here, only the liquid phase is shown in the figures (and not the solid or sludge line).

Table 6. Summary description of the main biological wastewater treatment systems used in Brazil

STABILISATION PONDS	
Facultative pond	Wastewater flows continuously through a pond especially constructed for wastewater treatment. The wastewater remains in the ponds for many days. The soluble and fine particulate BOD is aerobically stabilized by bacteria that grow dispersed in the liquid medium, while the BOD in suspension tends to settle, being converted anaerobically by bacteria at the bottom of the pond. The oxygen required by the aerobic bacteria is supplied by algae through photosynthesis. The land requirements are high. Sludge may be accumulated at the bottom of the pond for several years.
Anaerobic pond – facultative pond	Around 50 to 65% of the BOD is converted in the anaerobic pond (deeper and with a smaller volume), while the remaining BOD is removed in the facultative pond. The system occupies an area smaller than that of a single facultative pond.
Aerated lagoon	The BOD removal mechanisms are similar to those of a facultative pond. However, oxygen is supplied by mechanical aerators instead of through photosynthesis. In facultative aerated lagoons, the aeration is not enough to keep the solids in suspension, and a large part of the sewage solids and biomass settles, being decomposed anaerobically at the bottom. In the completely mixed aerated lagoons, the biomass stays in suspension and a subsequent sedimentation pond is required to remove suspended solids.
Maturation ponds	The main objective of maturation ponds is the removal of pathogenic organisms. In maturation ponds prevail environmental conditions that are adverse to these organisms, such as ultra-violet radiation, high pH, high DO, lower temperature (compared with the human intestinal tract), lack of nutrients and predation by other organisms. Maturation ponds are a post-treatment stage for BOD-removal processes, being usually designed as a series of ponds or a single-baffled pond. The coliform removal efficiency is very high.

LAND DISPOSAL	
Overland flow	Wastewater is distributed in the upper part of vegetated slopes, flows over the slopes and is collected by ditches at the lower part. Treatment occurs in the root-soil system. The application is intermittent. Distribution of wastewater may be by high-pressure sprinklers, low-pressure sprays and gated or perforated pipes or channels.
Constructed wetlands	While the former systems are land-based systems, these are aquatic-based systems. The systems are composed by shallow basins or channels in which aquatic plants grow. The system can be of free-water surface (water level above ground level) or subsurface flow (water level below ground level). The subsurface-flow systems can be divided into horizontal or vertical flow systems. Biological, chemical and physical mechanisms act on the root-soil system.
ANAEROBIC SYSTEMS	
Upflow anaerobic sludge blanket reactor (UASB)	BOD is converted anaerobically by bacteria dispersed in the reactor. The liquid flow is upwards. The upper part of the reactor is divided into settling and gas collection zones. The settling zone allows the exit of the clarified effluent in the upper part and the return of the solids (biomass) by gravity to the system, increasing its concentration in the reactor. Amongst the gases formed is methane. The system has no primary sedimentation tank. The sludge production is low, and the excess sludge wasted is already thickened and stabilized.
Anaerobic filter	BOD is converted anaerobically by bacteria that grow attached to a support medium (usually stones) and also suspended in the void spaces in the reactor. The tank works submerged and the flow is upwards. The system requires a primary sedimentation tank (frequently septic tanks) or a previous UASB reactor. The sludge production is low and the excess sludge is already stabilized.
Anaerobic reactor – post-treatment	UASB reactors produce an effluent that has difficulty in complying with most existing discharge standards. Therefore, some form of post treatment is frequently necessary. The post treatment may be biological (aerobic or anaerobic) or physical-chemical (with the addition of coagulants). Practically all wastewater treatment processes may be used as a post treatment of the effluent from anaerobic reactors. The global efficiency of the system is usually similar to the one that would be obtained if the process were being applied for raw wastewater. However, land, volume and energy requirements are lower. Sludge production is also lower.

ACTIVATED SLUDGE	
Activated sludge	The biological stage comprises two units: aeration tank (reactor) and secondary sedimentation tank. The biomass concentration in the reactor is very high, due to the recirculation of the settled solids (bacteria) from the bottom of the secondary sedimentation tank. The biomass remains in the system longer than the liquid, which guarantees a high BOD removal efficiency. The oxygen supply is done by mechanical aerators or by diffused air. It is necessary to remove a quantity of the sludge (biomass) that is equivalent to what is produced. In the conventional activated sludge, this excess sludge removed needs to be stabilized in the sludge treatment stage. In the extended aeration version, the excess sludge has been already digested aerobically in the aeration tank. In the conventional activated sludge, upstream of the reactor there is a primary sedimentation tank to remove the settleable solids from the raw sewage. Alternatively, a UASB reactor can be used instead of the primary sedimentation tank.
AEROBIC BIOFILM REACTORS	
Trickling filter	BOD is stabilized aerobically by bacteria that grow attached to a support medium (commonly stones or plastic material). The sewage is applied on the surface of the tank through rotating distributors. The liquid percolates through the tank and leaves from the bottom, while the organic matter is retained and then further removed by the bacteria. The free spaces permit the circulation of air. In the low rate system there is a low availability of substrate (BOD) for the bacteria, which makes them undergo self-digestion and leave the system stabilized. Sludge that is detached from the support medium is removed in the secondary sedimentation tank. The system requires a pre-treatment stage by primary sedimentation or UASB reactor.
Submerged aerated biofilter	The submerged aerated biofilter is composed by a tank filled with a porous material (usually submerged), through which sewage and air flow permanently. The airflow is always upwards, while the liquid flow can be downward or upward. The biofilters with granular material undertake, in the same reactor, the removal of soluble organic compounds and particulate matter. Besides being a support medium for biomass growth, the granular material acts also as a filter medium. Periodic backwashings are necessary to eliminate the excess biomass accumulated, reducing the head loss through the medium.

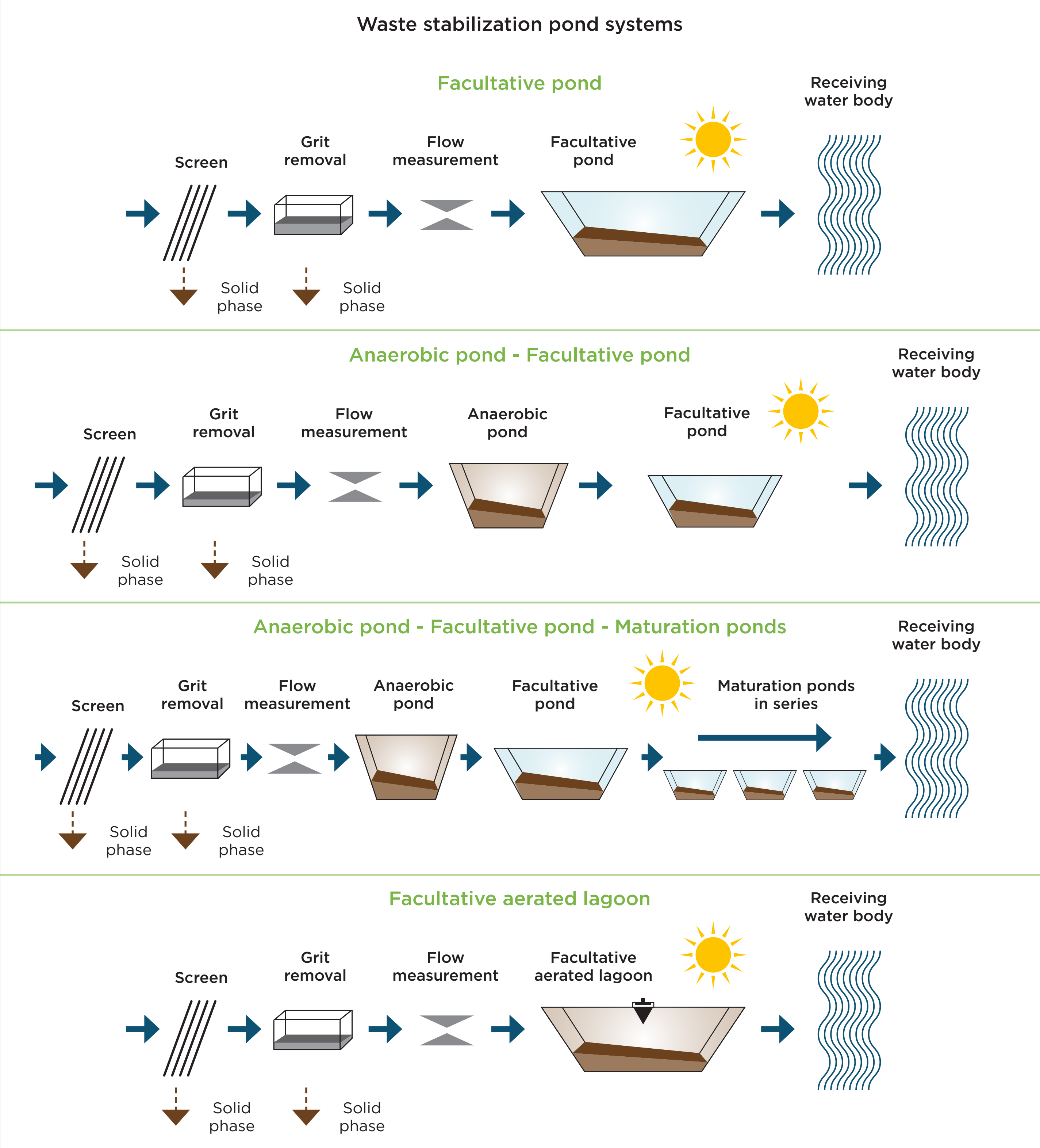


Fig. 23. Flowsheets of stabilization pond systems (liquid phase only)

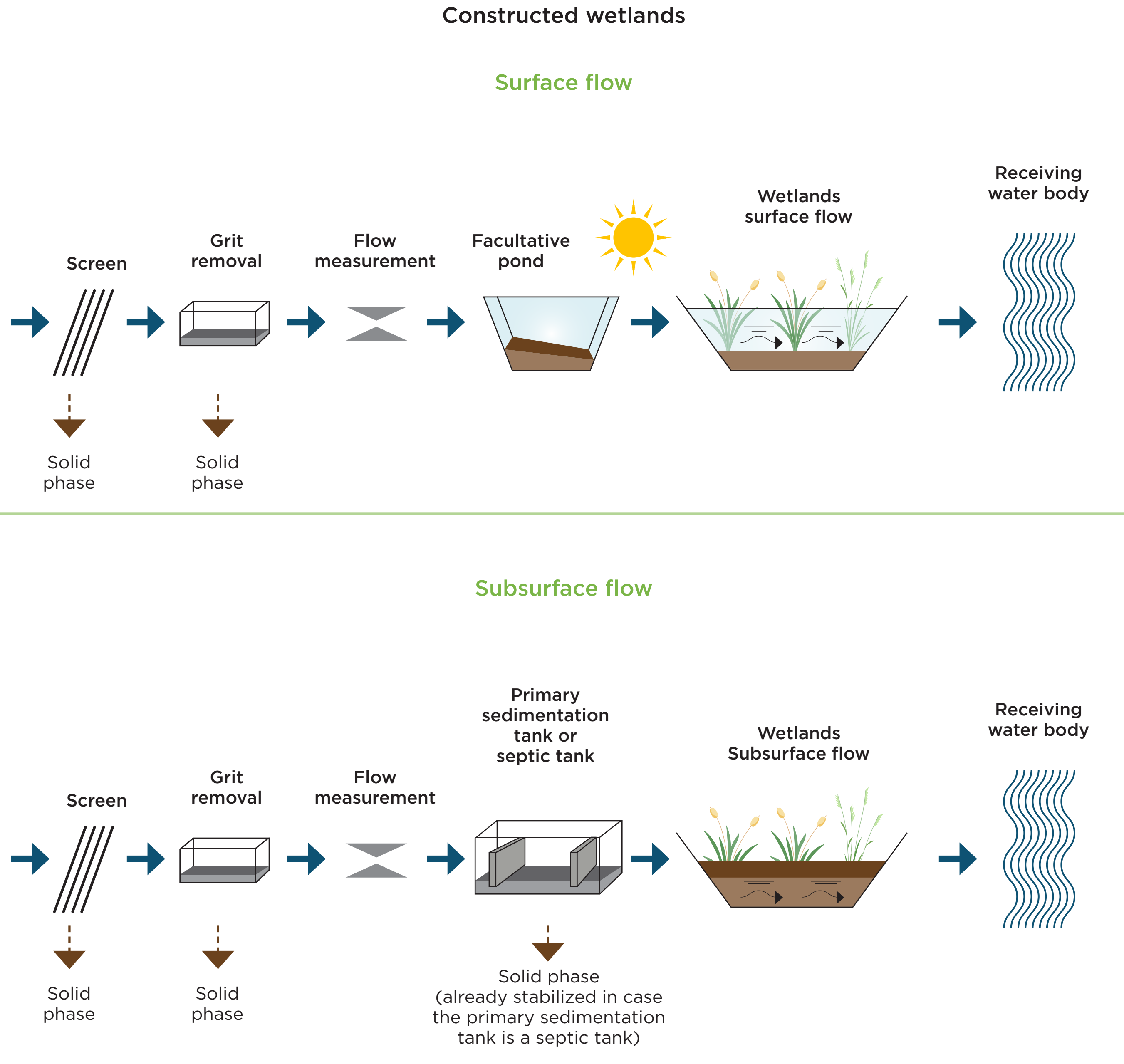
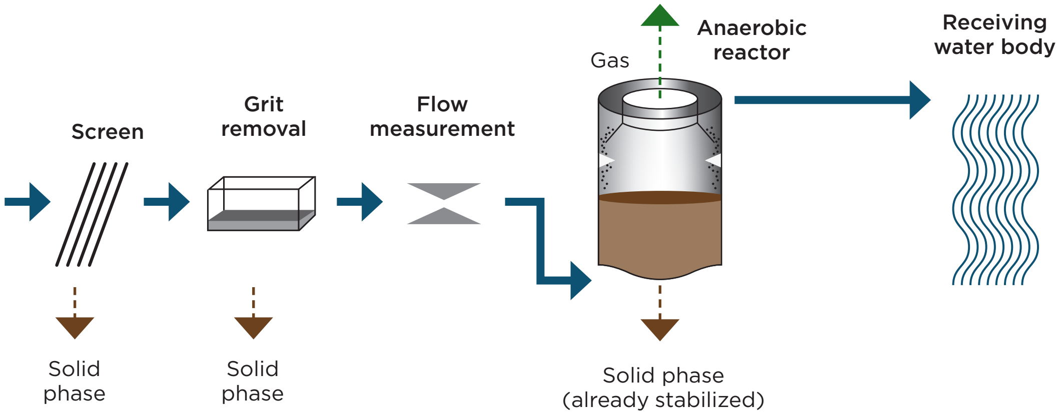


Fig. 24. Flowsheet of constructed wetlands (liquid phase only). Subsurface flow units can have horizontal or vertical flow. Various previous treatment stages can be used (septic tanks, UASB reactors etc). One of the versions of vertical flow wetlands receives raw sewage

Anaerobic systems

Upflow anaerobic sludge blanket reactor



Septic tank - Anaerobic filter

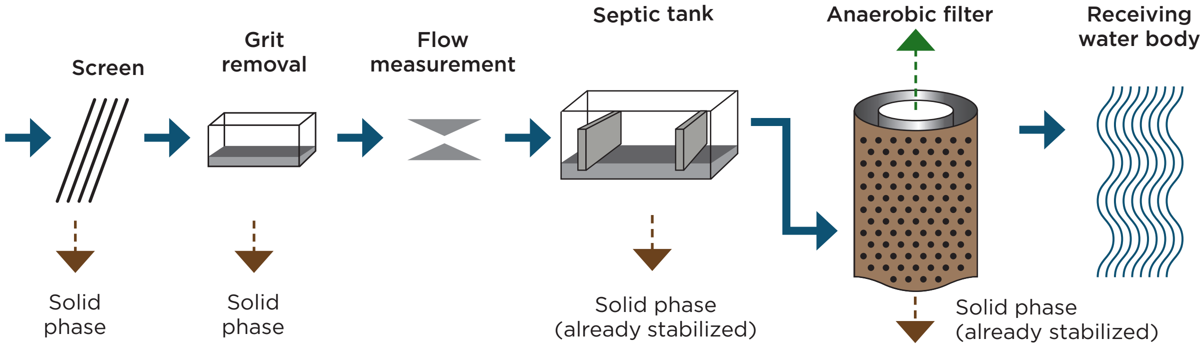
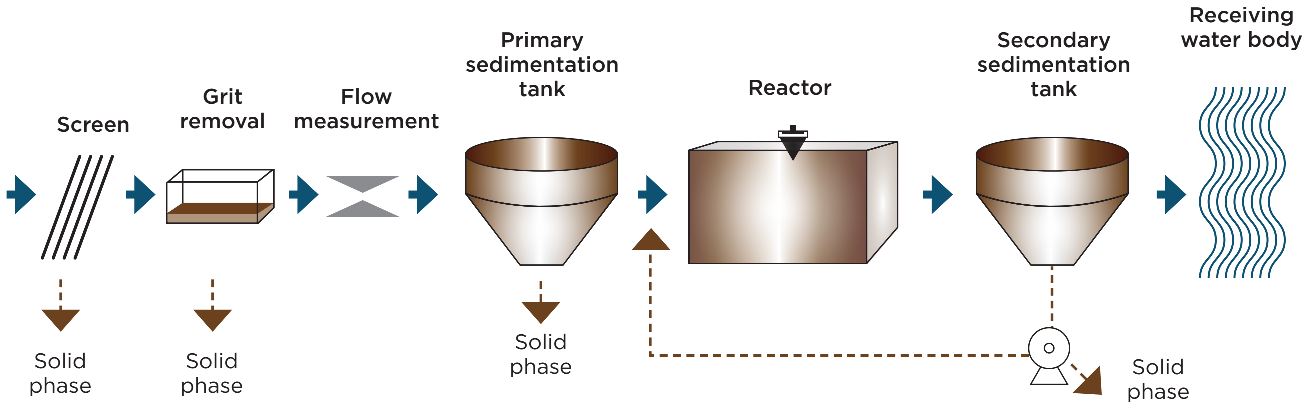


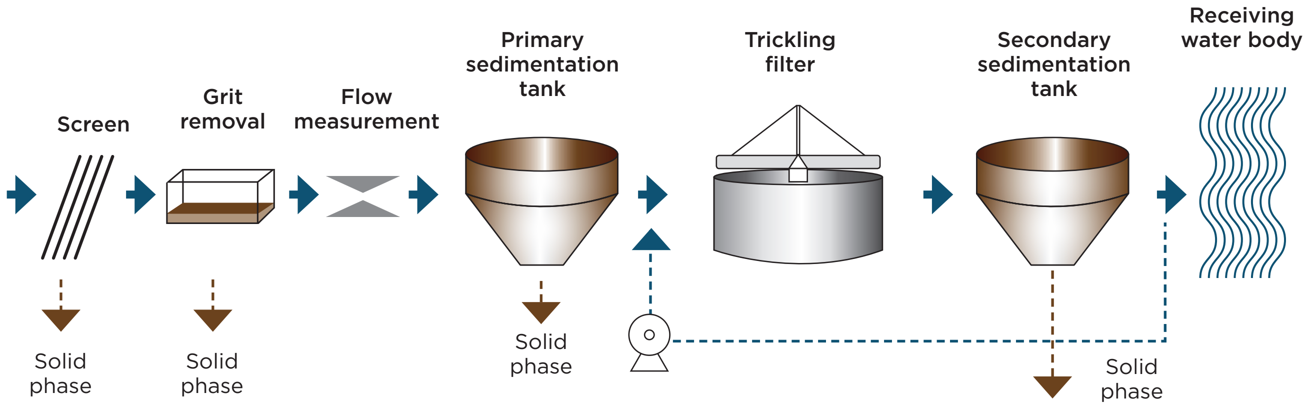
Fig. 25. Flowsheet of anaerobic reactors (liquid phase only)

Aerobic systems

Conventional activated sludge (continuous flow)



Trickling filter



Submerged aerated biofilter

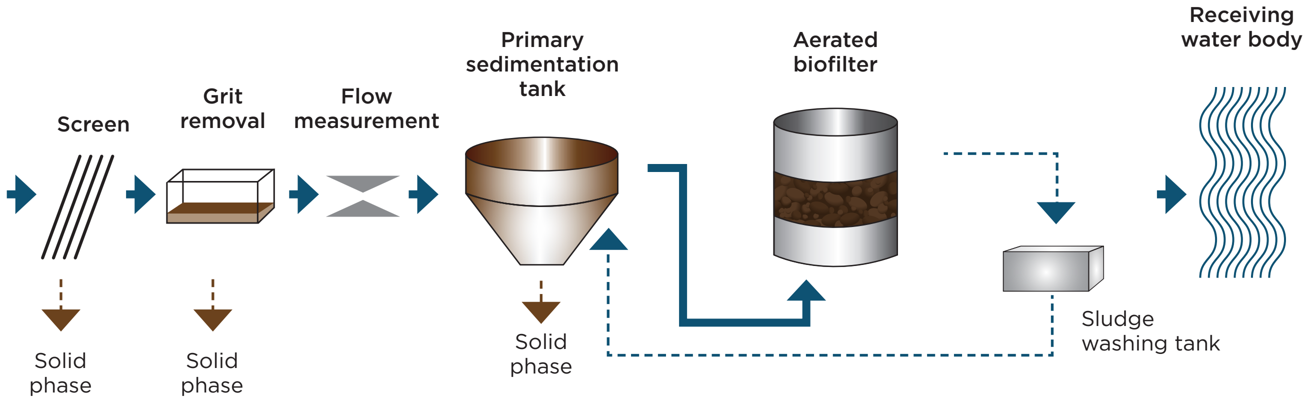
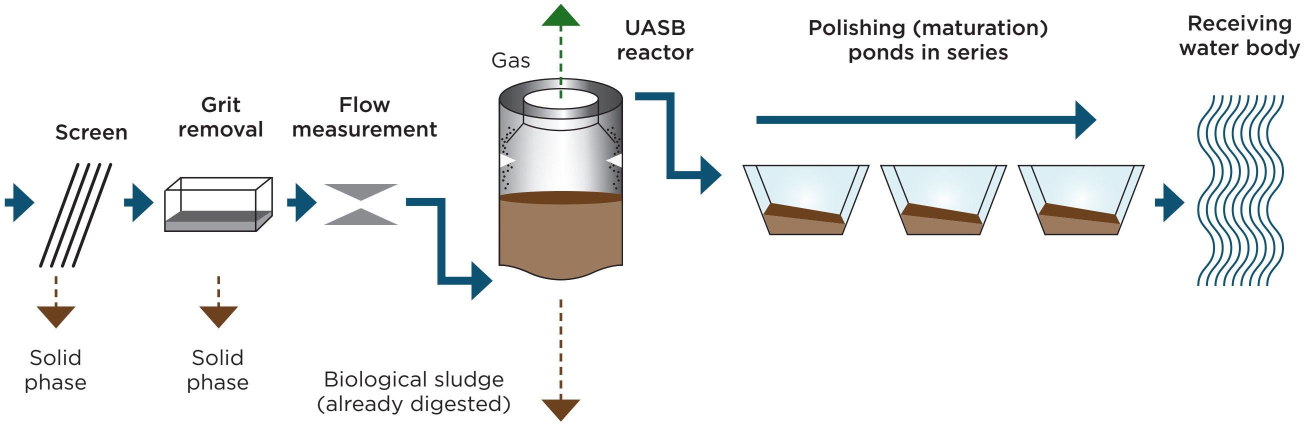


Fig. 26. Flowsheet of aerobic systems (liquid phase only). Example for conventional activated sludge, high rate trickling filter and submerged aerated biofilter.

UASB reactor + Post-treatment

UASB + Polishing ponds (e.g.: Ponds in series)



UASB + Land disposal (e.g.: Overland flow)

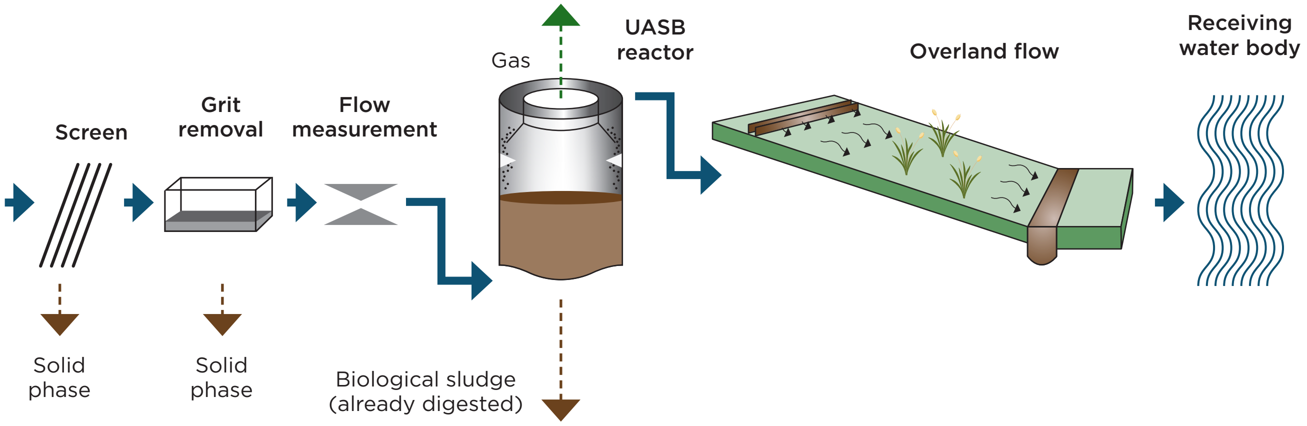
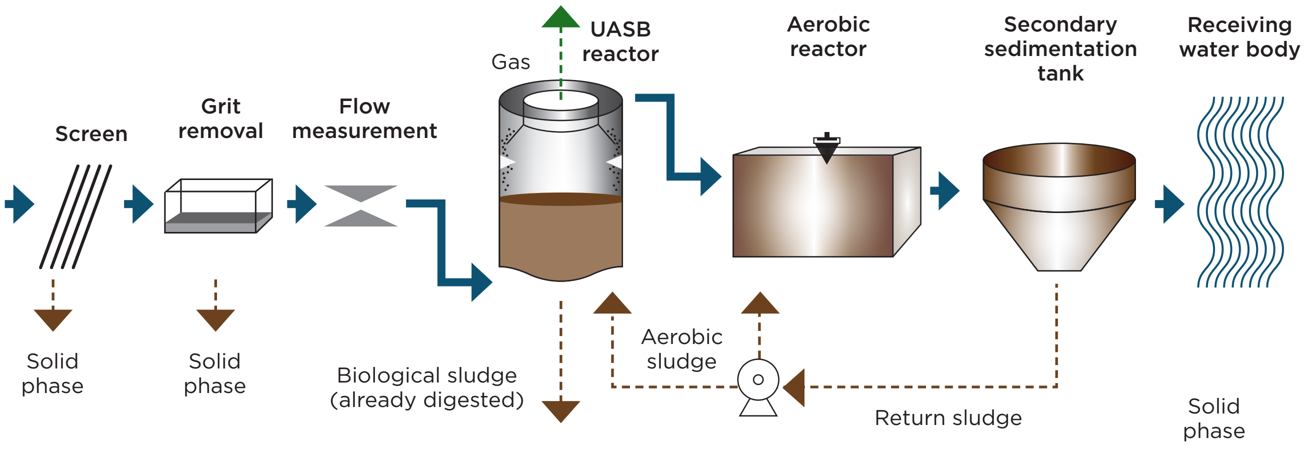


Fig. 27. Flowsheet of UASB reactors followed by post-treatment (liquid phase only)

UASB reactor + Post-treatment

UASB + Suspended - growth reactor (e.g.: Activated sludge)



UASB + Aerobic biofilm reactor (e.g.: Trickling filter)

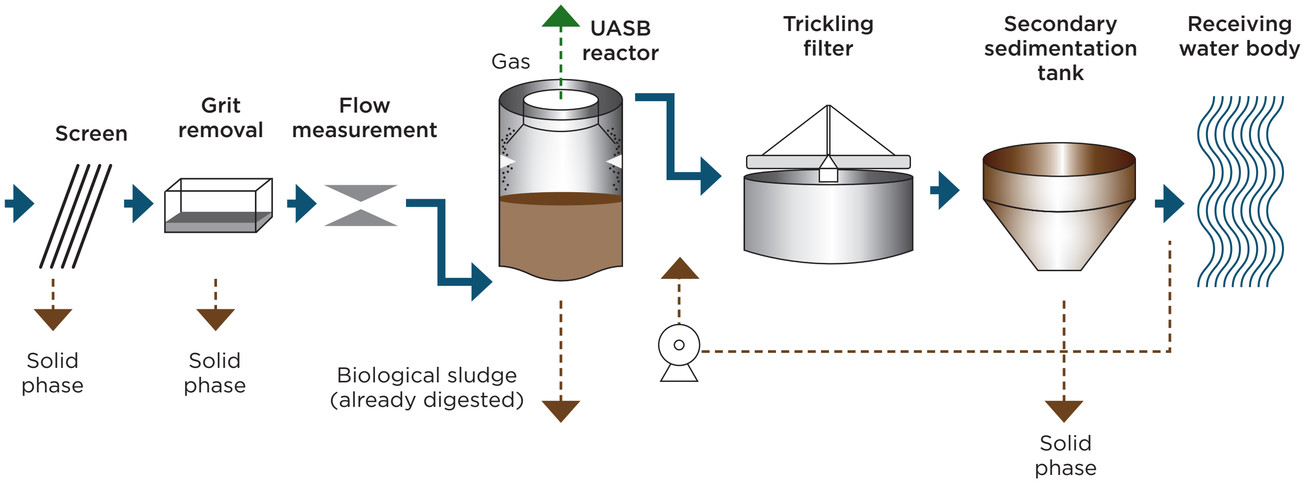


Fig. 27. Flowsheet of UASB reactors followed by post-treatment (liquid phase only)

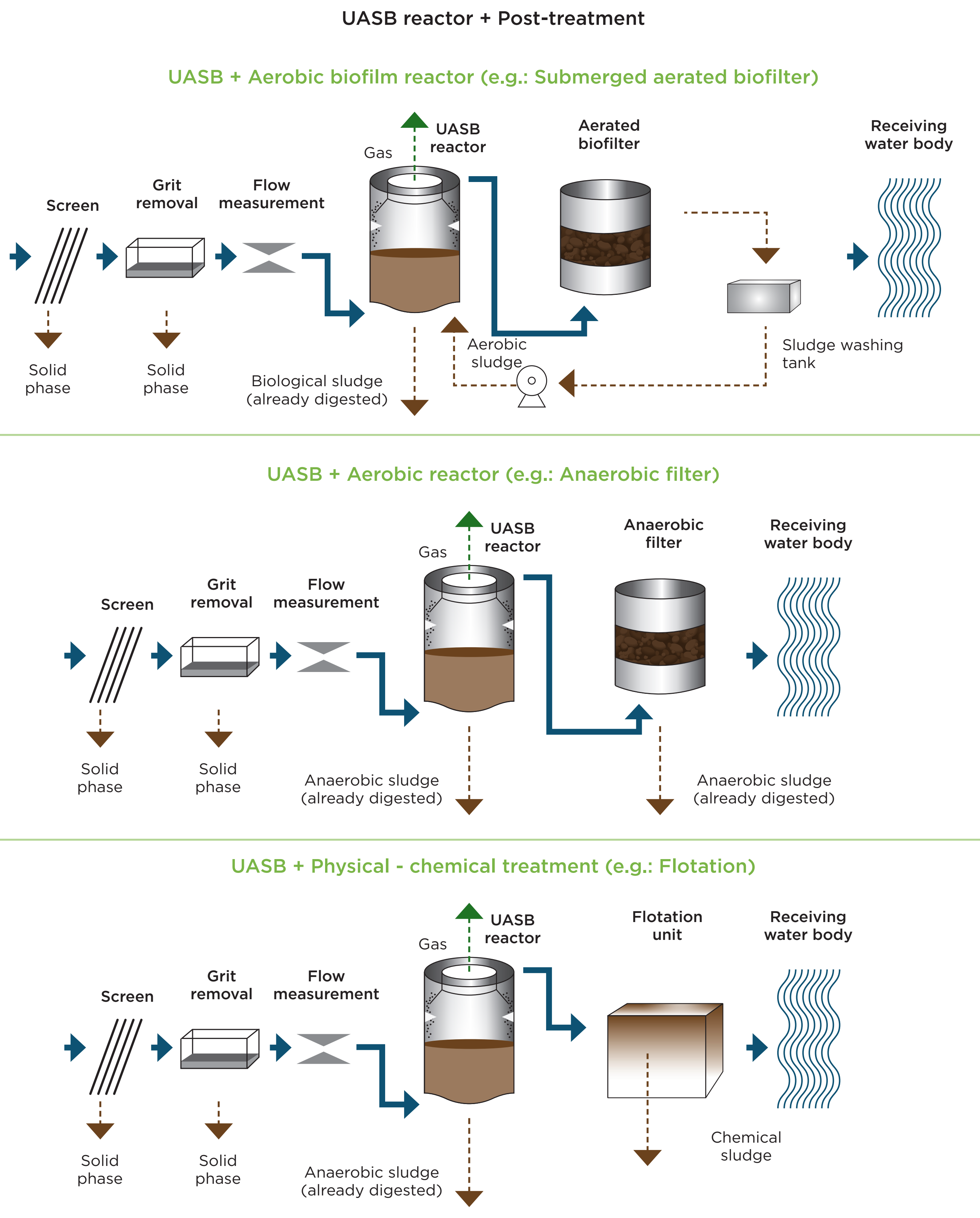


Fig. 27. Flowsheet of UASB reactors followed by post-treatment (liquid phase only)

6.2. Comparison of the treatment processes

The following section is also based, with adaptations and simplifications, on von Sperling and Chernicharo (2005). Further details should be sought at the cited reference. Presented below is a comparative analysis between the main wastewater treatment systems (liquid and solid phases) applied to domestic sewage. The analysis is summarized in various tables and figures:

- *Quantitative comparison* (Table 7): average effluent concentrations and typical removal efficiencies of the main pollutants of interest in domestic sewage
- *Quantitative comparison* (Table 8): typical characteristics of the main sewage treatment systems, expressed in per-capita values
- *Qualitative comparison* (Table 9): a qualitative comparative analysis that covers various relevant aspects in the evaluation of the sewage treatment systems. The aspects of efficiency, economy, process and environmental problems are analyzed.

Of course, any type of synthesis is subject to a degree of uncertainty because of strong influence of the local conditions. The tables present typical values for treatment plants operating under “normal” conditions. As will be shown in Section 9, performance values may vary substantially, depending on a multitude of factors. The synthesis is presented only in order to allow a fast comparison between the treatment process, and the values should not be taken as invariables. Nothing substitutes the specific values obtained in a dedicated design of a particular treatment plant.

Table 7. Expected average effluent concentrations and typical removal efficiencies of the main pollutants of interest in domestic sewage under normal operating conditions

System	Average quality of the effluent								Average removal efficiency						
	BOD_5 (mg/l)	COD (mg/l)	SS (mg/l)	Ammonia (mg/l)	Total N (mg/l)	Total P (mg/l)	ThermoC (FC/100ml)	Helminth eggs (eggs/l)	BOD_5 (%)	COD (%)	SS (%)	Ammonia (%)	Total N (%)	Total P (%)	ThermoC (log units)
Primary treatment (septic tanks)	200-250	400-450	100-150	> 20	> 30	> 4	10^7-10^8	> 1	30-35	25-35	55-65	< 30	< 30	< 35	< 1
Conventional primary treatment	200-250	400-450	100-150	> 20	> 30	> 4	10^7-10^8	> 1	30-35	25-35	55-65	< 30	< 30	< 35	< 1
Facultative pond	50-80	120-200	60-90	> 15	> 20	> 4	10^6-10^7	< 1	75-85	65-80	70-80	< 50	< 60	< 35	1-2
Anaerobic pond + facultative pond	50-80	120-200	60-90	> 15	> 20	> 4	10^6-10^7	< 1	75-85	65-80	70-80	< 50	< 60	< 35	1-2
Facultative aerated lagoon	50-80	120-200	60-90	> 20	> 30	> 4	10^6-10^7	> 1	75-85	65-80	70-80	< 30	< 30	< 35	1-2
Anaerobic pond + facult. pond + maturation pond	40-70	100-180	50-80	10-15	15-20	< 4	10^2-10^4	< 1	80-85	70-83	73-83	50-65	50-65	> 50	3-5
Overland flow	30-70	100-150	20-60	10-20	> 15	> 4	10^4-10^6	< 1	80-90	75-85	80-93	35-65	< 65	< 35	2-3
Constructed wetlands	30-70	100-150	20-40	> 15	> 20	> 4	10^4-10^5	< 1	80-90	75-85	87-93	< 50	< 60	< 35	3-4
Septic tank + anaerobic filter	40-80	100-200	30-60	> 15	> 20	> 4	10^6-10^7	> 1	80-85	70-80	80-90	< 45	< 60	< 35	1-2
UASB reactor	70-100	180-270	60-100	> 15	> 20	> 4	10^6-10^7	> 1	60-75	55-70	65-80	< 50	< 60	< 35	1-2
UASB + activated sludge	20-50	60-150	20-40	5-15	> 20	> 4	10^6-10^7	> 1	83-93	75-88	87-93	50-85	< 60	< 35	1-2
UASB + submerged aerated biofilter	20-50	60-150	20-40	5-15	> 20	> 4	10^6-10^7	> 1	83-93	75-88	87-93	50-85	< 60	< 35	1-2
UASB + anaerobic filter	40-80	100-200	30-60	> 15	> 20	> 4	10^6-10^7	> 1	75-87	70-80	80-90	< 50	< 60	< 35	1-2
UASB + high rate trickling filter	20-60	70-180	20-40	> 15	> 20	> 4	10^6-10^7	> 1	80-93	73-88	87-93	< 50	< 60	< 35	1-2
UASB + dissolved-air flotation	20-50	60-100	10-30	> 20	> 30	1-2	10^6-10^7	> 1	83-93	83-90	90-97	< 30	< 30	75-88	1-2
UASB + maturation ponds	40-70	100-180	50-80	10-15	15-20	< 4	10^2-10^4	< 1	77-87	70-83	73-83	50-65	50-65	> 50	3-5
UASB + overland flow	30-70	90-180	20-60	10-20	> 15	> 4	10^4-10^6	< 1	77-90	70-85	80-93	35-65	< 65	< 35	2-3
Conventional activated sludge	15-40	45-120	20-40	< 5	> 20	> 4	10^6-10^7	> 1	85-93	80-90	87-93	> 80	< 60	< 35	1-2
Activated sludge – extended aeration	10-35	30-100	20-40	< 5	> 20	> 4	10^6-10^7	> 1	90-97	83-93	87-93	> 80	< 60	< 35	1-2
Convent. activated sludge - biological N removal	15-40	45-120	20-40	< 5	< 10	> 4	10^6-10^7	> 1	85-93	80-90	87-93	> 80	> 75	< 35	1-2
High rate trickling filter	30-60	80-180	20-40	> 15	> 20	> 4	10^6-10^7	> 1	80-90	70-87	87-93	< 50	< 60	< 35	1-2
Submerged aerated biofilter with nitrification	15-35	30-100	20-40	< 5	> 20	> 4	10^6-10^7	> 1	88-95	83-90	87-93	> 80	< 60	< 35	1-2

Source: adapted from von Sperling and Chernicharo (2005). For a full list of processes consult the reference
ThermoC: thermotolerant (fecal) coliforms
Chemical precipitation of phosphorus with any of the technologies above: P < 1 mg/l
Disinfection: e.g. chlorination, ozonization, UV radiation; Barrier: e.g. membranes (provided the disinfection/barrier process is compatible with the quality of the effluent from the preceding treatment): ThermoC < 10^3 MPN/100ml; helminth eggs: variable
Advanced primary treatment: the removal efficiencies vary depending on the coagulant dosage

Table 8. Typical characteristics of the main sewage treatment systems used in Brazil, under normal operating conditions, expressed as per capita values

System	Land requirements (m^2/inhab)	Power for aeration		Sludge volume	
		Installed power (W/inhab)	Consumed power (kWh/inhab.year)	Liquid sludge to be treated (l/ inhab.year)	Dewatered sludge to be disposed of (l/ inhab.year)
Primary treatment (septic tanks)	0.03 - 0.05	0	0	110 – 360	15 - 35
Conventional primary treatment	0.02 - 0.04	0	0	330 – 730	15 - 40
Facultative pond	2.0 - 4.0	0	0	35 – 90	15 - 30
Anaerobic pond + facultative pond	1.2 - 3.0	0	0	55 – 160	20 - 60
Facultative aerated lagoon	0.25 - 0.5	1.2 - 2.0	11 - 18	30 – 220	7 – 30
Anaerobic pond + facultative pond + maturation pond	3.0 - 5.0	0	0	55 – 160	20 - 60
Overland flow	2.0 - 3.5	0	0	-	-
Constructed wetlands	3.0 - 5.0	0	0	-	-
Septic tank + anaerobic filter	0.2 - 0.35	0	0	180 – 1000	25 - 50
UASB reactor	0.03 - 0.10	0	0	70 – 220	10 - 35
UASB + activated sludge	0.08 - 0.2	1.8 - 3.5	14 - 20	180 – 400	15 - 60
UASB + submerged aerated biofilter	0.05 - 0.15	1.8 - 3.5	14 - 20	180 – 400	15 - 55
UASB + anaerobic filter	0.05 - 0.15	0	0	150 – 300	10 - 50
UASB + high rate trickling filter	0.1 - 0.2	0	0	180 – 400	15 - 55
UASB + dissolved-air flotation	0.05 - 0.15	1.0 - 1.5	8 - 12	300 - 470	25 - 75
UASB + maturation ponds	1.5 - 2.5	0	0	150 – 250	10 - 35
UASB + facultative aerated pond	0.15 - 0.3	0.3 - 0.6	2 - 5	150 – 300	15 - 50
UASB + overland flow	1.5 - 3.0	0	0	70 - 220	10 - 35
Conventional activated sludge	0.12 - 0.25	2.5 - 4.5	18 - 26	1100 – 3000	35 - 90
Activated sludge – extended aeration	0.12 - 0.25	3.5 - 5.5	20 - 35	1200 – 2000	40 - 105
Conventional activated sludge with biological N removal	0.12 - 0.25	2.2 - 4.2	15 - 22	1100 – 3000	35 - 90
High rate trickling filter	0.12 - 0.25	0	0	500 – 1900	35 - 80
Submerged aerated biofilter with nitrification	0.1 - 0.15	2.5 - 4.5	18 - 26	1100 – 3000	35 - 90

Source: adapted from von Sperling and Chernicharo (2005). For a full list of processes consult the reference
In compact aerated systems (e.g.: activated sludge, submerged aerated biofilters) or after treatment with a UASB reactor, aeration control allows a certain economy (not all the installed power is consumed)

Table 9. Relative evaluation of the main domestic sewage treatment systems (liquid phase)

Treatment system	Removal efficiency			Economy					Resistance capacity to influent variations and shock loads			Reli-ability	Simpli-city in O&M.	Independence of other charact.for good perform.		Lower possibility of environmental problems			
				Requirements		Costs		Genera-tion											
	BOD	Nutrients	Coli-forms	Land	Energy	Constr.	O & M	Sludge	Flow	Quality	Toxic comp.			Climate	Soil	Bad odors	Noise	Aerosols	Insects and worms
Preliminary treatment	0	0	0	+++++	+++++	+++++	++++	+++++	+++++	+++++	+++++	+++++	+++	+++++	+++++	+	++++	+++++	+++
Primary treatment	+	+	+	+++++	++++	++++	+++	+++	++++	+++++	++++	++++	+++	++++	+++++	++	++++	+++++	+++
Facultative pond	+++	++	++/++++	+	+++++	+++	+++++	+++++	++++	++++	+++	++++	+++++	++	+++	+++	+++++	+++++	++
Anaerobic pond – facultat pond	+++	++	++/++++	++	+++++	++++	+++++	+++++	++++	++++	+++	++++	+++++	++	+++	+	+++++	+++++	++
Facultative aerated lagoon	+++	++	++/++++	++	+++	+++	++++	+++++	++++	++++	+++	++++	++++	+++	+++	++++	+	+	+++
Pond – maturation pond	+++	+++	+++++	+	+++++	+++	+++++	+++++	++++	++++	+++	++++	+++++	++	+++	+++	+++++	+++++	++
Overland flow	++++	+++	++/+++	+	+++++	+++	++++	+++++	++++	++++	+++	++++	+++++	+++	++	++	+++++	+/+++++	++
Constructed wetlands	++++	++	+++	+	+++++	+++	++++	+++++	++++	++++	+++	++++	+++++	++	++	++	+++++	+++++	++
Septic tank – anaerobic filter	+++	+	++	+++++	+++++	+++	+++	++++	+++	+++	++	+++	++++	++	+++++	++	++++	+++++	++++
UASB reactor	+++	+	++	+++++	+++++	++++	++++	++++	++	++	++	+++	++++	++	+++++	++	++++	+++++	++++
UASB reactor – post-treatment	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(b)	(b)	(b)	(a)	(a)	(a)	(a)	(b)	(a)	(a)	(a)
Conventional activated sludge	++++	++/++++	++	++++	++	+	++	+	+++	+++	++	++++	+	+++	+++++	++++	+	+/+++++	++++
Activated sludge (extend aer)	+++++	++/++++	++	++++	+	++	+	++	++++	++++	+++	++++	++	++++	+++++	+++++	+	+/+++++	++++
Trickling filter (high rate)	++++	++/+++	++	++++	+++	++	+++	+	++++	+++	+++	++++	+++	++	+++++	++++	++++	++++	+++
Submerged aerated biofilter	+++++	++/+++	++	+++++	++		+++	+	+++	+++	++	++++	++	++++	+++++	+++++	++	+++++	++++

Notes: the grading is only relative in each column and is not generalized for all the items. The grading can vary widely with the local conditions
+++++ : most favorable + : least favorable ++++, +++, ++: intermediate grades, in decreasing order 0 : zero effect
+ / +++++: variable with the type of process, equipment, variant or design

UASB reactor + post-treatment: (a) post-treatment characteristics prevail; (b) UASB reactor characteristics prevail

7. A SPECIAL LOOK ON UASB REACTORS IN BRAZIL

UASB (Upflow Anaerobic Sludge Blanket) reactors are very important in Brazil, as already shown in this report. Brazil has a leading role in the utilization of UASB reactors, with and without some form of post-treatment. The trend is that their utilization will continue to grow, since nowadays many of the initial constraints in their utilization have been addressed or partially solved. Because of this importance, this section is dedicated to brief specific comments on UASB reactors.

Literature on UASB reactors has increased substantially. Several international publications exist, and examples for the Brazilian reality are the book from von Sperling and Chernicharo (2005) and the Brazilian Standards ABNT NBR 7229/1993 (see Section 8).

The present section is based on two critical reviews published in 2015 (Chernicharo et al, 2015a, 2015b), which present several important aspects on the utilization of anaerobic reactors, with a detailed view on Brazil. UASB reactors used for the treatment of domestic wastewater are now considered a consolidated technology in Latin America, where several large full-scale plants, treating a population equivalent up to one million inhabitants (Onça WWTP, Belo Horizonte, Brazil), have been in operation for more than 10 years. The reviews emphasize the large importance of UASB in the context of warm-climate countries and present several design and operational criteria, which are difficult to summarize here because of space limitations.

The cited reviews list the following constraints that have been partially addressed but still require further development for the utilization of UASB reactors:

General constraints:

- Preliminary treatment and pumping station
    - Odor emission
    - Flowrate variation
    - Passage of debris
- Reactor
    - Corrosion
    - Feeding system
- Biogas (from tri-phase separator) and waste gas (from settling tank)
    - Odor emission
    - Greenhouse gas emission
    - Energy recovery
- Liquid effluent
    - Residual carbon
    - Nutrient
    - Pathogen
    - Surfactant
- Sludge inside the reactor and excess sludge
    - Nutrient recovery
    - Energy recovery
    - Pathogen elimination
    - Presence of sand and debris

The following **operational constraints** are cited:

- Process operation with low skilled personnel
- Design and construction
- Sludge withdrawal
- Scum removal
- Atmospheric methane emissions

The **challenges** listed by the authors are:

- Energy recovery from biogas
- Energy recovery from sludge and scum
- Dissolved effluent methane recovery
- Agricultural use of treated effluents

Further details can be found in the cited references. The list of constraints and challenges, instead of passing the view that there are still several problems, should indicate the opportunities that lie ahead of this important treatment system in Brazil. All treatment processes have their own limitations and processes, and the list here was presented because of the relevance of UASB reactors in most new projects in Brazil.

8. DESIGN CRITERIA FOR THE MAIN TREATMENT PROCESSES USED IN BRAZIL

Brazilian literature on wastewater treatment has improved substantially in the past two decades, and design criteria for the major treatment systems are presented in a consolidated form. Van Haandel and Lettinga (1994), Jordão and Pessoa (2015) and von Sperling and Chernicharo (2005) are examples of books portraying the Brazilian experience on sewage treatment. A large contribution was given by the Brazilian Research Program on Basic Sanitation (PROSAB), which, for several years, enhanced the level of applied research within a network of universities and sanitation companies, generating important publications, including books freely downloadable[11]. In addition, in 2011 ABNT[12] (Brazilian Association on Technical Standards) issued a new version of its standards for wastewater treatment ("Hydraulic and sanitary engineering design for wastewater treatment plants"), under the code ABNT NBR 12209:2011.

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[11] Link for downloading books by PROSAB (books in Portuguese): http://www.finep.gov.br/apoio-e-financiamento-externa/historico-de-programa/prosab/produtos

[12] ABNT: Associação Brasileira de Normas Técnicas

Table 10 presents summary values of the main design criteria for the units of interest in the major sewage treatment processes used in Brazil. The values are based on **mean** influent flows. The reference von Sperling and Chernicharo (2005) is cited because it presents several of these values, but the original references cited by both authors should be consulted.

Table 10. Main design criteria for the major sewage treatment processes used in Brazil

Process	Unit	Value	Reference
Anaerobic pond	Pond	OLR_V: 0.25 – 0.35 kgBOD/m^3.d (depending on T) Height: 3.0 – 5.0 m	Von Sperling and Chernicharo (2005) (*)
Facultative pond	Pond	OLR_S: 150 – 300 kgBOD/ha.d (depending on T) Height: 1.5 – 2.0 m	Von Sperling and Chernicharo (2005) (*)
Facultative aerated pond	Pond	HRT: 5 – 10 d Height: 2.5 – 4.0 m	Von Sperling and Chernicharo (2005) (*)
Maturation pond	Pond	Series arrangement or baffled Total HRT: 10 – 20 (depend on the number of units) Height: 0.8 – 1.0 m	Von Sperling and Chernicharo (2005) (*)
Overland flow	Vegetated slope	HLR: 0.2 – 0.4 m^3/h per m width (for UASB post-treatment) Length: 30 – 45 m Slope: 2 – 8% Intermittent operation	Von Sperling and Chernicharo (2005) (*)
Wetlands	Filter bed	Various design criteria, based on influent quality, filter media, plant, operational mode etc.	-
Septic tank	Tank	HRT: 12 – 24 h (depending on the influent contributions and frequency of sludge removal) Height: 1.2 – 2.8 m (depending on the tank volume)	ABNT NBR 7229/1993

Anaerobic filter	Reactor	HRT: 12 – 24 h (depending on T) Volume $\geq$ 1000 L Height (bed): $\leq$ 1.2 m	ABNT NBR 13969/1997
UASB reactor	Reactor	HRT: 6 – 10 h (depending on T) Upflow velocity: $\leq$ 0.7 m/h Height: 4 – 6 m	ABNT NBR 12209/2011
	Internal settler	HRT: $\geq$ 1.5 h HLR: $\leq$ 1.2 $m^3/m^2.h$ (for $Q_{máx}$)	ABNT NBR 12209/2011
Trickling filter	Filter (high rate; stones)	OLR_V: $\leq$ 1.2 $kgBOD/m^3.d$ HLR: $\leq$ 50 $m^3/m^2.d$ (including recirculation) Height: $\leq$ 3.0 m	ABNT NBR 12209/2011
	Secondary settler	HLR: $\leq$ 24 $m^3/m^2.d$ Height (side wall): $\geq$ 3.5 m	ABNT NBR 12209/2011
Activated sludge	Reactor	Sludge age: 4 – 15 d (conventional); $\geq$ 18 d (extended aeration) F/M: 0.20 – 0.70 $kgBOD_5/kgMLVSS.d$ (conventional); $\leq$ 0.15 $kgBOD_5/kgMLVSS.d$ (extended aeration) MLSS: 1550 – 4500 mg/L Aerobic sludge age for nitrification: $\geq$ 3 – 8 d (depending on T); in the case of effluent from UASB reactors: $\geq$ 7 – 20 d (depending on T)	ABNT NBR 12209/2011
	Secondary settler	HLR: $\leq$ 28 $m^3/m^2.d$ (for sludge age < 18 d); $\leq$ 16 $m^3/m^2.d$ (for sludge age > 18 d) SLR: $\leq$ 144 $kgSS/m^2.d$ (for sludge age < 18 d); $\leq$ 120 $kgSS/m^2.d$ (for sludge age > 18 d) HRT: $\geq$ 1.5 h Height (side wall): $\geq$ 3.5 m	ABNT NBR 12209/2011
Aerated biofilters	Reactor	There are different criteria, depending on the variant: submerged aerated filter or submerged aerated biofilters	ABNT NBR 12209/2011

Only major elements are given. For other design criteria: consult the references.
(*) There are no Brazilian standards. This reference is cited, but there are many others in the Brazilian literature.
OLR_V: volumetric organic loading rate; OLR_S: surface organic loading rate; HRT: hydraulic retention time; HLR: hydraulic loading rate; SLR: solids loading rate; F/M: food-to-microorganism ratio; T: temperature
Height: net (useful) height, not taking into account freeboard

9. ACTUAL PERFORMANCE OF TREATMENT PLANTS IN BRAZIL

9.1. Introduction

Actual treatment performance of full-scale plants in Brazil has been investigated by Oliveira and von Sperling (2008a, 2008b, 2009, 2011), Oliveira et al (2006), von Sperling and Oliveira (2009). These publications are based on the same database, but cover different angles and, to our knowledge, is the most wide reaching survey undertaken in Brazil, comparing different processes. The survey evaluated the actual behavior of **166 full-scale wastewater treatment plants** in operation in Brazil, providing information on the performance of **six treatment processes** in terms of effluent quality and removal efficiency. Due to the climatic, social and economic diversity of the region investigated, the results obtained are likely to be representative for other similar regions. The text below is mainly based on a simplification of Oliveira and von Sperling (2011), which links treatment performance with loading conditions and other factors.

Some of the treatment technologies most widely used in Brazil are evaluated here. The observed results of effluent concentrations and removal efficiencies of the constituents BOD (biochemical oxygen demand), COD (chemical oxygen demand), TSS (total suspended solids), TN (total nitrogen), TP (total phosphorus) and FC (fecal or thermotolerant coliforms) are compared with the typical expected performance reported in the literature. The treatment technologies selected for the study are: (i) septic tank + anaerobic filter (ST+AF), (ii) facultative pond (FP), (iii) anaerobic pond followed by facultative pond (AP+FP), (iv) activated sludge (AS), (vi) UASB reactor without post-treatment (UASB) and (vi) UASB reactor followed by several post-treatments (UASB+POST).

In view of the large performance variability observed in the systems investigated, it is also analyzed whether good or poor performances are related to underloading or overloading conditions, respectively. Thus, operational conditions are evaluated in order to verify the existence of a relationship between design/operational parameters and the performance of the plants or, in other words, whether there is evidence of a better performance when the systems operate within loading rates recommended by the technical literature.

The treatment technologies described and evaluated in this work are located in Southeast Brazil (latitudes 20 to 22° South, tropical climate, average liquid temperatures between 20° and 25° C), in the states of São Paulo and Minas Gerais. The data used were obtained directly from the operational records of the Water and Sanitation companies responsible for the operation of the treatment plants. The data obtained span a period ranging from 1976 to 2003, with variations within this period for each specific plant.

The operational conditions were evaluated to verify the existence of a relationship between design and operational parameters and the performance of the treatment plants. Typical design and operational parameters recommended by the technical literature are listed in Table 11 and show broad ranges, in view of the diversity of characteristics of the influent and climatic conditions in the region under study. Some differences in the design criteria presented in Table 11 may exist, because the performance survey was done in two states in Brazil, and not in the overall country, where climatic conditions may very more widely. Based on these typical ranges, the plants were classified as underloaded (actual BOD load less than the minimum of the recommended range), normally or usually loaded (BOD load within the range) and overloaded (BOD load higher than the maximum of the range).

Table 11. Typical design and operational parameters used to evaluate WWTP performance

Technologies		Parameter		
		Type	Unit	Usual range
Facultative pond (FP)		Ls – surface BOD loading	kg BOD.ha^{-1}.d^{-1}	150 – 300
		HRT: hydraulic retention time	days	15 – 45
Anaerobic + facultative ponds (AP + FP)	AP	Lv: volumetric BOD loading	kg BOD.m^{-3}.d^{-1}	0,10 - 0,35
		HRT: hydraulic retention time	days	3 – 6
	FP	Ls – surface BOD loading	kg BOD.ha^{-1}.d^{-1}	150 – 300
		HRT: hydraulic retention time	days	15 – 45
Activated sludge (AS)	AT (c)	F/M ratio: food/ microorganism ratio	kg BOD.kgMLVSS^{-1}.d^{-1}	0,3 – 0,8 (CAS) (a) 0,08 – 0,15 (EAAS) (b)
		HRT: hydraulic retention time	hours	6 a 8 (CAS)
				16 - 24 (EAAS)
	SC (d)	HLR: hydraulic loading rate	m^3.m^{-2}.h^{-1}	0,67 – 1,33 (CAS)
				0,33 - 0,67 (EAAS)
		SLR: solids loading rate	kgMLSSm^{-2}.h^{-1}	4 – 6 (CAS) 1 – 5 (EAAS)
UASB reactor (UASB)		HRT: hydraulic retention time	hours	6 – 9
		v: upflow velocity	m.h^{-1}	0,5 - 0,7

Note: CAS – Conventional activated sludge; EAAS – Extended aeration activated sludge; AT – Aeration tank; SC – Secondary clarifier

Source: Oliveira and von Sperling (2011)

Additionally, in order to analyze whether there was a difference in the performance of smaller and larger plants, which is a topic of particular relevance for this IDB report, all systems were ranked by flow, and split into two groups: lower flows (0 to 50 percentile of mean flows) and higher flows (50 to 100 percentile of mean flows).

Also a monitoring index (MI - average number of samples collected per year in each plant) was investigated as a possible indicator of the operational level in the plant (higher MI values could be associated with more operator's involvement and, therefore, possibly a better operation). Also in this case, the plants were separated into two groups (50% lower and 50% higher MI percentiles), as shown in Table 12.

Table 12. Operational parameters used to evaluate the WWTP performance

Technologies	Influent flow range	Monitoring Index MI
	($m^3 day^{-1}$)	(samples/year)
FP	Group 1: ≤ 217 m^3/d; Group 2: > 217 m^3/d	Group 1: ≤ 2.3; Group 2: > 2.3
AP+ FP	Group 1: ≤ 549 m^3/d; Group 2: > 549 m^3/d	Group 1: ≤ 3.0; Group 2: > 3.0
AS	Group 1: ≤ 3099 m^3/d; Group 2: > 3099 m^3/d	Group 1: ≤ 25; Group 2: > 25
UASB	Group 1: ≤ 780 m^3/d; Group 2: > 780 m^3/d	Group 1: ≤ 25; Group 2: > 25

Source: Oliveira and von Sperling (2011)

9.2. Performance evaluation

Table 13 presents the monitoring frequency and the number and percentage of treatment plants within each category. In total, almost 42,000 data from the 166 WWTPs were analyzed and the results showed a great variability in terms of sampling frequency, monitoring period and measured parameters. However, the majority of treatment plants had no clearly identifiable monitoring frequency (undefined) and the number of parameters monitored in each WWTP also varied substantially - from 4 constituents in some treatment plants, up to more than 30 parameters in others.

Table 13. Typical monitoring frequency in the 166 WWTP investigated

Monitoring frequency	Number of WWTPs	% of WWTPs
Daily	0	0,0
Twice per week	2	1,2
Weekly	10	6,0
Twice per month	10	6,0
Monthly	13	7,8
Quarterly	15	9,0
Once per four months	0	0,0
Undefined	116	69,9
Total	166	100,0

Source: Oliveira and von Sperling (2011)

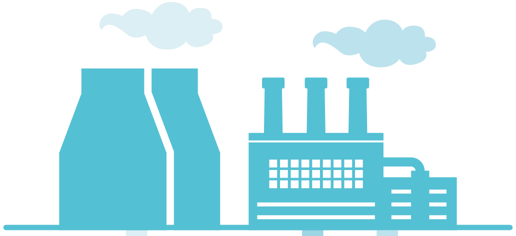
The number of evaluated systems, the average influent flow, the mean concentrations of raw and treated wastewater, and the mean removal efficiencies associated with the six treatment technologies are presented in Table 14.

Table 14. Mean concentrations and mean removal efficiencies, according to the six treatment configurations

Parameter	Technologies		ST+AF	FP	AP+FP	AS (1)	UASB	UASB+POST (2)
	Number of WWTP evaluated		19	73	43	13	10	8
	Average flow (m^{3}d^{-1})		205	400	1628	64484	3038	253
BOD	Influent (raw)	(mgL^{-1})	665	553	510	315	371	362
	Effluent (treated)	(mgL^{-1})	292	136	89	35	98	42
	Removal efficiency	(%)	59	75	82	85	72	88
COD	Influent	(mgL^{-1})	1398	1187	1095	575	715	713
	Effluent	(mgL^{-1})	730	525	309	92	251	141
	Removal efficiency	(%)	51	55	71	81	59	77
TSS	Influent	(mgL^{-1})	479	430	411	252	289	334
	Effluent	(mgL^{-1})	165	216	153	57	85	51
	Removal efficiency	(%)	66	48	62	76	67	82
TN (3)	Influent	(mgL^{-1})	78	69	78	47	43	-
	Effluent	(mgL^{-1})	61	38	45	22	48	-
	Removal efficiency	(%)	24	44	39	50	-13	-
TP	Influent	(mgL^{-1})	9	9	11	3	7	7
	Effluent	(mgL^{-1})	7	4	7	1	6	5
	Removal efficiency	(%)	30	46	36	46	-1	23
FC (4)	Influent	(MPN100mL^{-1})	2.6×10^7	5.3×10^7	2.0×10^8	3.7×10^7	1.2×10^8	1.8×10^8
	Effluent	(MPN100mL^{-1})	5.5×10^6	1.2×10^6	4.3×10^5	1.3×10^5	3.4×10^7	9.7×10^6
	Removal efficiency	(log units)	0.9	1.6	2.2	2.0	0.6	2.8

(1) Activated sludge process includes: conventional and extended aeration
(2) UASB+POST includes as post-treatment: aerated filter; anaerobic filter; trickling filter; flotation unit; facultative pond or maturation pond
(3) TKN and TN were used
(4) Fecal (thermotolerant) coliforms. Geometric mean used.

Source: Oliveira and von Sperling (2011)



It was observed that the **influent wastewater** presented a mean concentration higher than that usually reported in the literature for prevailingly domestic wastewater. The simpler treatment systems, that is, ST+AF, FP and AP+FP, showed systematically much higher influent concentrations for all constituents, except fecal (thermotolerant) coliforms. Possible explanations that could justify the high concentrations of raw wastewater treated by these processes could be: unreported industrial contributions, type of sampling practiced (prevalence of grab samples, collected at peak hours), low per capita water consumption, low infiltration rates, and low wastewater/water return coefficients.

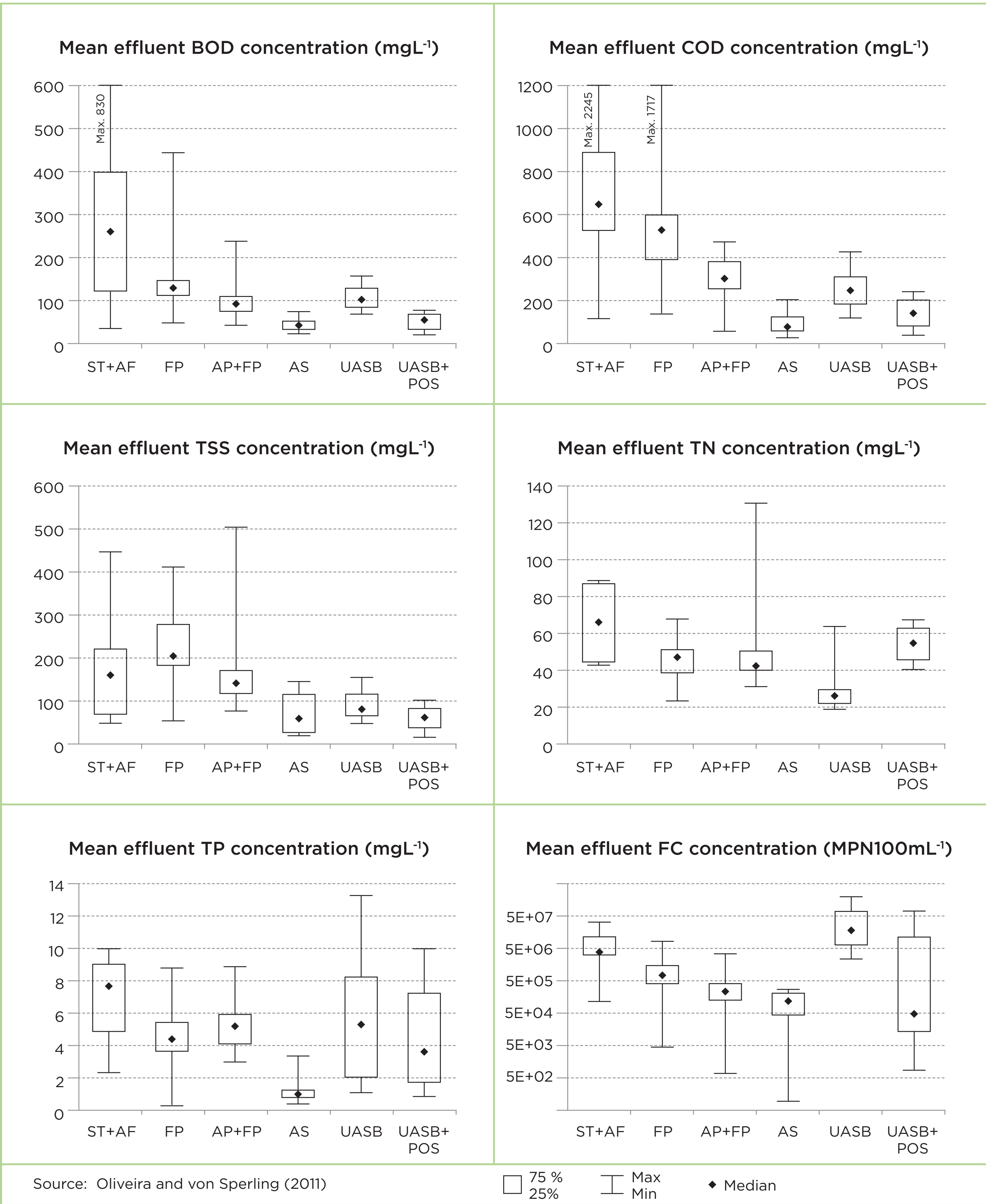
Besides the data presented in Table 14 (mean values), the central tendency and variability of effluent concentrations and removal efficiencies can also be seen in the box-plot graphs in Figures 28 and 29.

The ST+AF (septic tank + anaerobic filter) systems had a high percentage of WWTPs with a lower performance than expected (see Table 7 for expected performance values), considering both mean effluent concentrations and removal efficiencies. This low performance was observed for all constituents, except for FC, which presented a high percentage of WWTPs with performance above or within the expected range.

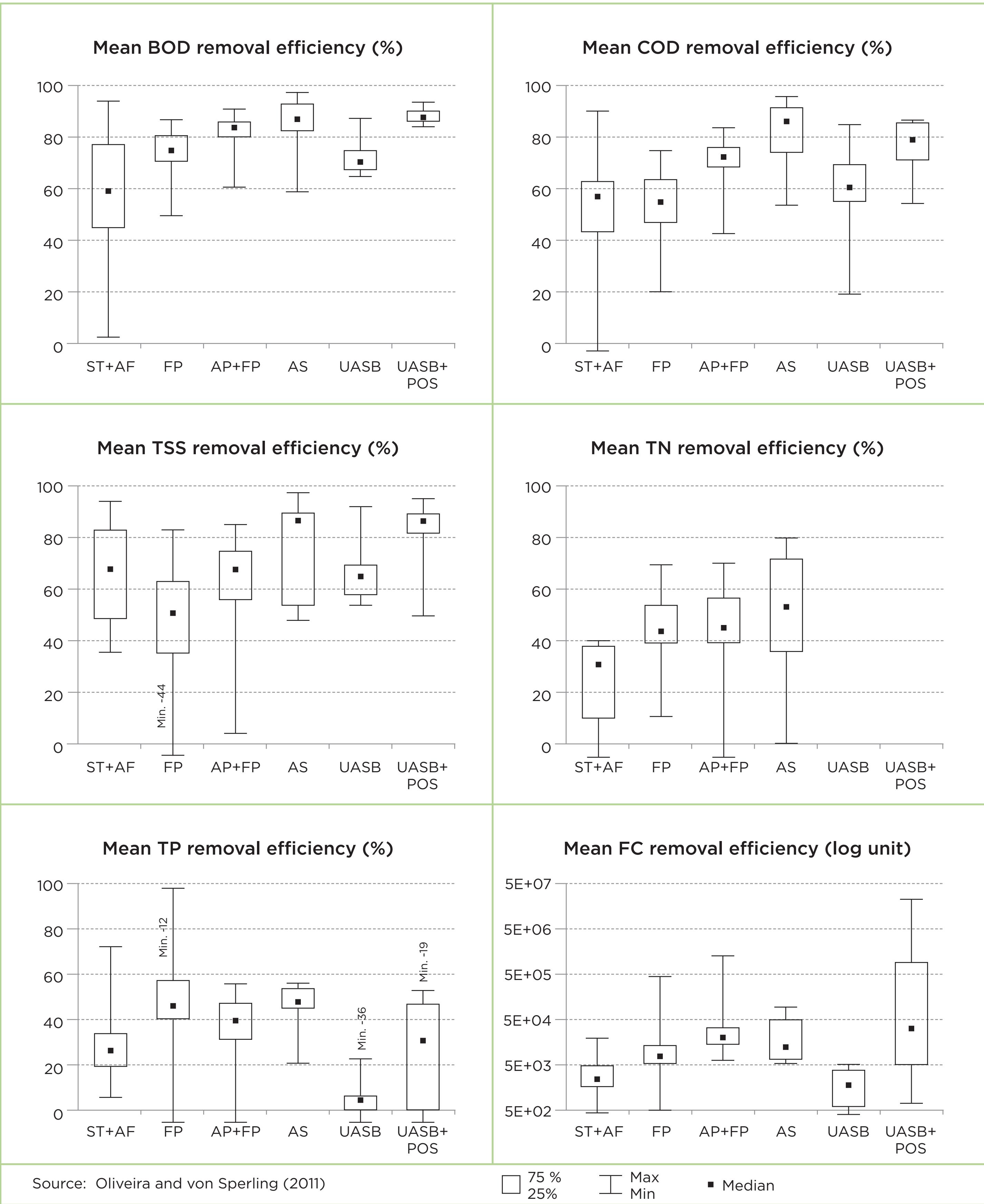
Concerning facultative ponds (FP), a very high percentage of WWTPs showed a low performance in terms of COD, TSS and TN, but a good performance in terms of TP and FC.

The anaerobic ponds followed by facultative ponds (AP+FP) showed good BOD, COD, TP and FC removal efficiencies, presenting a substantial percentage of WWTPs with efficiencies above the upper limit of the expected literature ranges. However, the actual effluent concentrations were significantly above the upper expected value (poor performance), for practically all constituents. In this case, the only exception was also the mean effluent thermotolerant coliform concentrations, which were lower than the expected values.

Fig. 28. Mean effluent concentration for the six treatment configurations



Source: Oliveira and von Sperling (2011)



Source: Oliveira and von Sperling (2011)

Fig. 29. Mean removal efficiencies for the six constituents, considering the six treatment configurations

The activated sludge (AS) process presented BOD and COD effluent concentration values closer to the expected values. However, considering BOD and TSS removal efficiencies, the performance was below the expected for activated sludge plants. This can be partially explained by the low influent concentrations, which makes the achievement of high removal efficiencies more difficult. Effluent concentrations systematically below the limit value were observed for TP and FC, showing a better performance than that reported in the literature.

The UASB reactors showed good BOD and COD removal efficiencies and a poorer performance compared with the reference ranges reported in the literature, considering TSS, FC and nutrients.

The performance achieved by the UASB reactors followed by some form of post-treatment (UASB + POST) was the one with the closest similarity with the literature. However, the literature ranges are larger due to the diversity of possible post-treatment systems. By comparing the results between UASB reactors and UASB+POST, it becomes evident that the post-treatment is highly important for an improved final effluent quality.

It is worth mentioning that the observed low removal efficiencies in terms of nutrients was expected, since none of the analyzed technologies has been designed for either nitrogen or phosphorus removal. However, the good performance presented by the AS process, considering TP is somewhat unexpected, with 100% of the wastewater treatment plants presenting effluent concentrations lower than the expected.

9.3. Influence of the operational conditions on treatment performance

All data obtained from four treatment processes (132 plants) were evaluated in order to verify the existence of a relationship between design/operational parameters and the performance of the plants. It was not possible to analyze all 166 WWTP, which comprise the six technologies, because some of them (septic tank + anaerobic filter - ST+AF and UASB reactor followed by some post-treatments - UASB+POST) did not have the required data to calculate the operational parameters.

The recommended intervals referred to in Tables 11 and 12 were used as references for the determination of the loading conditions of the treatment processes. For example, if a FP operated at a loading rate above the upper limit of the recommended range for this region (300 $kgBODha^{-1}day^{-1}$), it was considered to be in an overloading condition, whereas if it operated at a rate below the lower limit (150 $kg BODha^{-1}day^{-1}$), it was considered to be in an underloading condition. Regarding HRT, values higher than the upper limit of the reported range indicated underloading.

This criterion was used for all the loading rates and treatment technologies. After the calculation of the parameters, a graphic comparison between observed and recommended loading rates was undertaken. It is recognized that, ideally, mathematical models for each process and plant should be used, but the shortage of input data and the complexity of the analysis for such a large number of treatment plants made this approach unfeasible.

Scatter plots relating effluent concentrations and removal efficiencies with the loading conditions have been made, but they should be consulted in the original reference Oliveira and von Sperling (2011). However, interpretation of the relationships is provided here.

A statistical analysis (Kruskal-Wallis followed by multiple comparison of mean ranks for all groups), at the 95% confidence level, was undertaken for the effluent concentrations of the six constituents, but this is not reported here, for the sake of simplicity. Oliveira and von Sperling (2011) should be consulted about the details of these tests, but conclusions based on their output are presented here.

The loading conditions and separation into groups were those used for BOD (Table 11 – under, usual and overloaded groups in terms of specific parameters; Table 12 – groups 1 and 2 in terms of both flowrate and MI). All results are discussed below, separated by technology type. The ponds are discussed separately, considering the primary facultative, secondary facultative and anaerobic type, and they have already been analyzed, in detail, in a previous study published by von Sperling and Oliveira (2006).

Primary facultative ponds

Effluent BOD concentration and BOD removal efficiency from primary facultative ponds were investigated in terms of the relationship with the following variables: surface organic loading rate (Ls), hydraulic retention time (HRT), influent flow and monitoring index (MI). The loading conditions (under, usual or overload) for each pond, operating as a primary facultative, were also analyzed.

As expected, when the ponds operated under overloading conditions (high Ls or low HRT), there was a tendency to an increased effluent BOD concentration, with results confirmed by the statistical tests. However, in some cases very high loading rate values did not seem to have caused a significant deterioration in the effluent quality. The concentration values were, in general, above the expected ranges reported in the literature. BOD removal efficiencies were not significantly influenced by the loading conditions.

The mean and median effluent concentrations of BOD, COD, TN and FC from those ponds operating at organic overloading were significantly higher than those operating at usual or underloading conditions. This is a coherent result, not only in terms of BOD and COD, but also in terms of nitrogen and coliforms: organic loading influences dissolved oxygen concentrations and pH levels in the ponds, which are directly linked to the main N and FC removal mechanisms. The statistical tests indicated that the flow (indicator of plant relative size) and monitoring index (possible surrogate for operational involvement) had little influence on the effluent concentrations, but more influence on removal efficiencies.

Secondary facultative pond

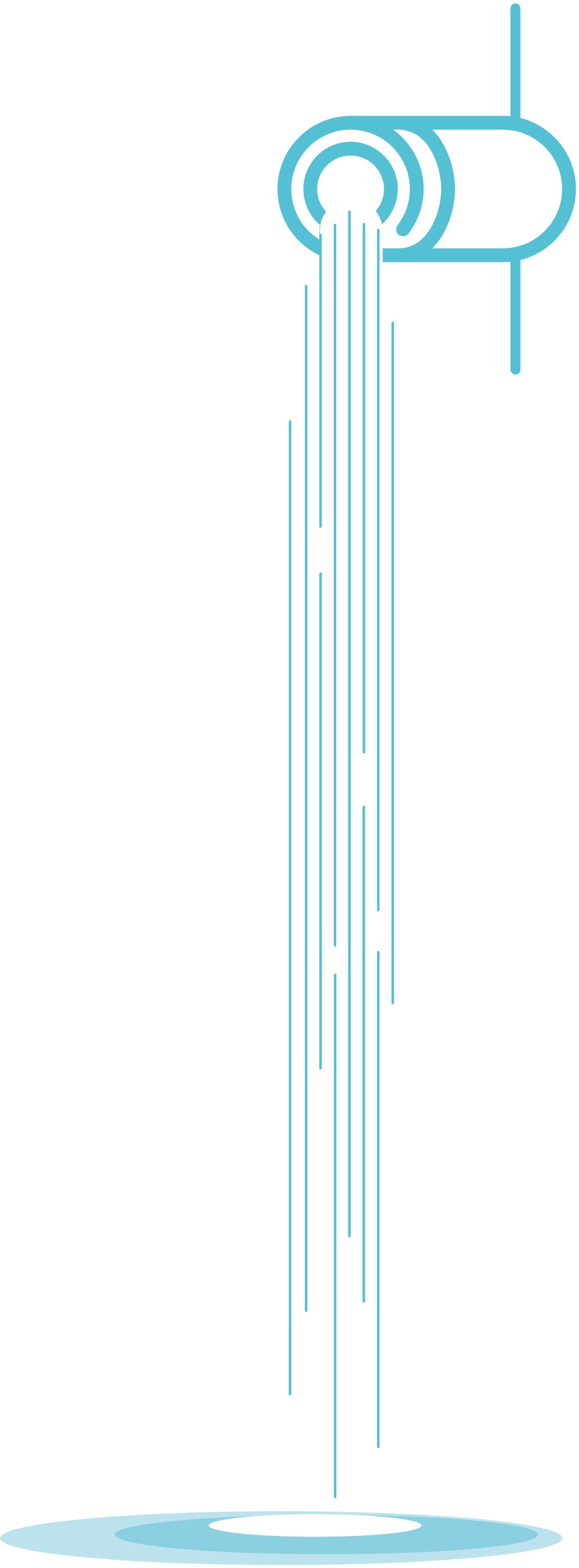
Performance of secondary facultative ponds was analyzed in terms of the relationship with Ls, HRT, influent flow and MI. The results indicate that the applied surface organic rate and resulting HRT did not influence substantially the performance of the secondary FPs. Differently from what could be expected, there were cases of very poor effluent quality with underloading conditions and also good effluent quality with overloading conditions. Although the poor performance of some overloaded ponds seemed to have been influenced by this condition, there were cases of ponds operating within the usual intervals, but without a good corresponding effluent quality. Similarly to the primary ponds, the statistical tests confirmed the influence of the organic loading on the effluent coliform concentration. Flow and monitoring index were more influential in the effluent quality than in the primary ponds.

Anaerobic ponds

Foa the anaerobic ponds, the relationship between effluent BOD concentration and BOD removal efficiency was analyzed in terms of the following variables: L_v, HRT, influent flow and MI parameters. Organic underloading conditions were observed on most anaerobic ponds investigated, and no pond exceeded the maximum organic load recommended. The statistical tests confirmed that there were no statistically significant differences in terms of Lv, considering all constituents analyzed. Most of the ponds operated under hydraulic underload, that is, with hydraulic retention times longer than the usual, and HRT was found to be influential in terms of effluent BOD, SS and FC concentrations. The effluent quality from the pond system was influenced by the influent flow (plant size) and monitoring index.

Activated sludge

For activated sludge, the relationship between effluent BOD concentration and removal efficiency was investigated in terms of the following variables: food/microorganism ratio (F/M ratio) in the aeration tank, hydraulic retention time (HRT), hydraulic loading rate (HLR) in the final clarifiers, solids loading rate (SLR) in the final clarifiers, influent flow and monitoring index (MI). The different food/microorganism ratios and HRT values did not influence significantly the performance of the aeration tanks, what was confirmed by the statistical tests. The same behavior was observed in the secondary clarifier, considering the HLR and SLR



applied. The statistical tests showed that the great difference between the influent flows did not influence significantly the plants' performance, considering the effluent quality. The mean and median effluent concentrations of BOD, COD, TSS, TN, TP and FC from the treatment plants operating at overloading conditions were not significantly higher than those operating at usual or underloading conditions.

UASB reactor

For UASB reactors, the relationship between effluent BOD concentration and BOD removal efficiency was analysed in terms of the following variables: upflow velocity (v), hydraulic retention time (HRT), influent flow and monitoring index (MI). Similarly to the activated sludge process, the statistical tests did not show any influence of the organic and hydraulic loading, as well as flow and monitoring index, on the effluent quality.

9.4. Concluding remarks on the performance evaluation of the treatment plants investigated in Brazil

Performance evaluation

- A great variability was noticed in the effluent concentrations and in the removal efficiencies, considering all analyzed constituents and all treatment technologies.
- The septic tank + anaerobic filter (ST+AF) process presented a performance much below that reported in the literature.
- The performance of the facultative ponds (FP) was lower than expected, considering COD, TSS and TN removal efficiencies. However, good TP and FC removal efficiencies were achieved.
- The anaerobic ponds + facultative ponds (AP+FP) showed a good performance in terms of BOD, COD, TP and FC removal, with a significant percentage of WWTPs with efficiencies within and even above the values reported by the literature.

- The performance presented by the activated sludge (AS) plants, considering organic matter removal, was the highest among the evaluated systems, although it was below the expected range.
- The UASB reactors showed good BOD and COD removal efficiencies and a poor performance regarding TSS, FC and nutrients, in terms of the reference ranges reported in the literature. The performance achieved by the UASB reactors followed by post treatment (UASB + POST) was good and the closest one with the expected values from the literature.

Influence of the operational conditions

- In general, the influence of the loading conditions was very small and scattered in all the treatment processes.
- A single variable or a group of variables could not be used to explain the differentiated performances among all the WWTPs. The contribution and influence of each variable seemed to differ from one WWTP to another and, as expected, this is likely to be a combination of multiple design and operational aspects.

Final remarks

The purpose of this section was to present a diagnosis of the wastewater treatment reality in Brazil, reflecting actual operating conditions. If this portrays the existing reality, care should be taken in not considering that the expected performance of the treatment technologies will always be within the range obtained. From the literature and from results from some of the plants investigated, the expected performance may be higher than the overall performance achieved. This shows that improvements in the current situation are possible, thus serving as an incentive to designers and plant operators.

In view of the results, it is evident that each WWTP should be evaluated individually to justify either good or poor performances, since these result from several factors. The designer and operator are required to have a broad and integrated knowledge of each system, involving not only the implications of the applied hydraulic and organic loads, but also factors not always directly measurable. Specific characteristics of each influent, microbiological aspects in the reactors, hydraulic details in the inlet, outlet and transfer structures, dead zones, hydraulic short circuits, operating conditions of the electromechanical equipment, in addition to design, construction and maintenance aspects, should be jointly analyzed in order to lead to an overall evaluation of each treatment plant.

10. COSTS ASSOCIATED WITH WASTEWATER TREATMENT

10.1. Construction costs

Construction costs for the implementation of WWTPs are based on the study undertaken by von Sperling and Salazar (2013). In their publication, costs were obtained from published data, consulting companies and water and sanitation companies, and have all been converted to the base date of April 2010. For the current study, all values in Brazilian currency (R$ = reais) were converted to the base date of **October 2015** using the National Construction Cost Index[13] from Getúlio Vargas Foundation (all values in Brazilian reais were multiplied by 1.49, which was the correction of INCC indices from April 2010 to October 2015). The costs in US dollars were converted from the costs in Brazilian reais using the exchange rate of US$ 1.00 = R$3.80 (15/Nov/2015, Central Bank of Brazil). The cost figures presented in this paper cover all construction costs involved in the implementation of the systems, including material, equipment, personnel, incidental values etc.

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[13] INCC: Índice Nacional de Custos da Construção da Fundação Getúlio Vargas (http://www.portalbrasil.net/incc.htm)

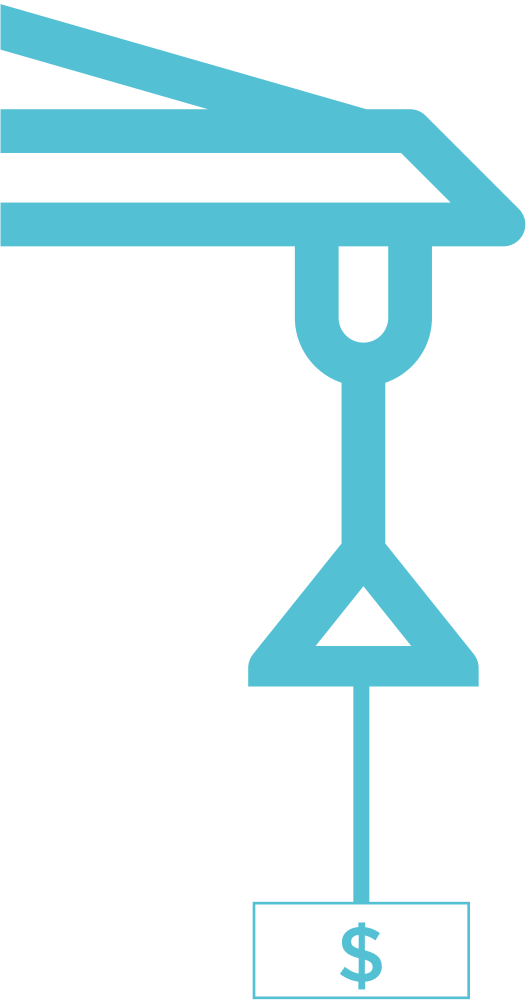
The treatment plants were separated into eight categories, representing commonly applied systems in Brazil: (i) facultative ponds and anaerobic+facultative ponds; (ii) facultative and anaerobic+facultative ponds followed by maturation ponds; (iii) UASB (upflow anaerobic sludge blanket) reactors; (iv) UASB reactors + one or two maturation ponds in series; (v) UASB reactors + three or more maturation ponds in series; (vi) UASB reactors + anaerobic filters; (vii) UASB reactors + trickling filters; (viii) activated sludge. Data from 84 treatment plants were used.

The resulting construction costs are summarized in Table 15. These cost ranges are structured in such a way as to comprise the 25 and 75 percentiles of cost values. In other words, 50% (=75-25) of the towns are likely to have construction costs that fall within this percentile range, which could be considered as the typical costs. Of course, lower and higher values are encountered, reflecting the diversity in the implementation conditions for the units comprising the treatment system. Per capita values as a function of the population range were tried, but there was no clear association, and this is the reason why per capita cost values are presented as fixed ranges.

Table 15. Capital cost information for wastewater treatment plants in Brazil (base date October 2015)

Type	Number of data	Population (inhab) (min-max)	Costs per inhabitant (R$/inhab) 25-75 %iles	Costs per inhabitant (US$/inhab) 25-75 %iles
Facultative and anaerobic+facultative ponds	15	2,089 – 61,000	**135 – 230**	35 – 60
Facultative and anaerobic-facultative ponds + maturation ponds	10	1,000 – 14,485	**300 – 545**	80 - 145
UASB reactors	5	4,320 – 15,146	**60 – 180**	15 - 50
UASB + one or two maturation ponds in series	10	5,135 – 138,000	**285 – 435**	75 - 115
UASB + three or more maturation ponds in series	4	7,292 – 41,330	**390 – 650**	105 - 170
UASB + anaerobic filters	9	1,381 – 199,041	**215 – 320**	55 - 85
UASB + trickling filters	22	4,584 – 300,000	**215 – 365**	55 - 95
Activated sludge	9	40,000 – 1,500,000	**360 - 440**	95 - 115

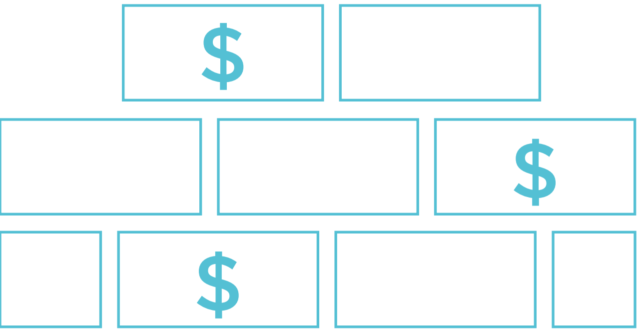
Exchange rate: US$ 1.00 = R$3.80 (15/Nov/2015, Central Bank of Brazil)
The exchange rate fluctuated considerably in the last years, so that cost values should be reported as US dollars and Brazilian reais, and the exchange rate needs to be clearly shown



Because of the high exchange rate (R$3.80 per US$1.00) at the moment of writing this report, the costs in USD are lower than those in the von Sperling and Salazar (2011) publication, in which the exchange rate was much lower. Therefore, costs should be analyzed in terms of both Brazilian reais and US dollars to allow a solid comparison and future corrections.

Natural treatment by ponds (facultative or anaerobic+-facultative) has unit costs between R$135 and R$230/inhabitant (round figures), and the inclusion of a pathogen removal stage by maturation ponds increase the total costs by a factor around 2.3 (associated with the larger number of ponds and total area required). Treatment by UASB reactors alone represents the cheapest variant, with round unit costs between R$60 and R$180/inhabitant. Several post-treatment options for the UASB effluent are presented here, from natural to compact systems. Post-treatment by ponds raise the total costs to around between R$285 and R$435/inhabitant, in the case of one or two ponds, and between R$390 to R$650/inhabitant, in the case of three or more maturation ponds. Post-treatment by compact systems such as anaerobic filters and trickling filters have somewhat similar total costs, in the range of R$215 to R$365/inhabitant. Treatment by activated sludge has the highest costs among the compact systems.

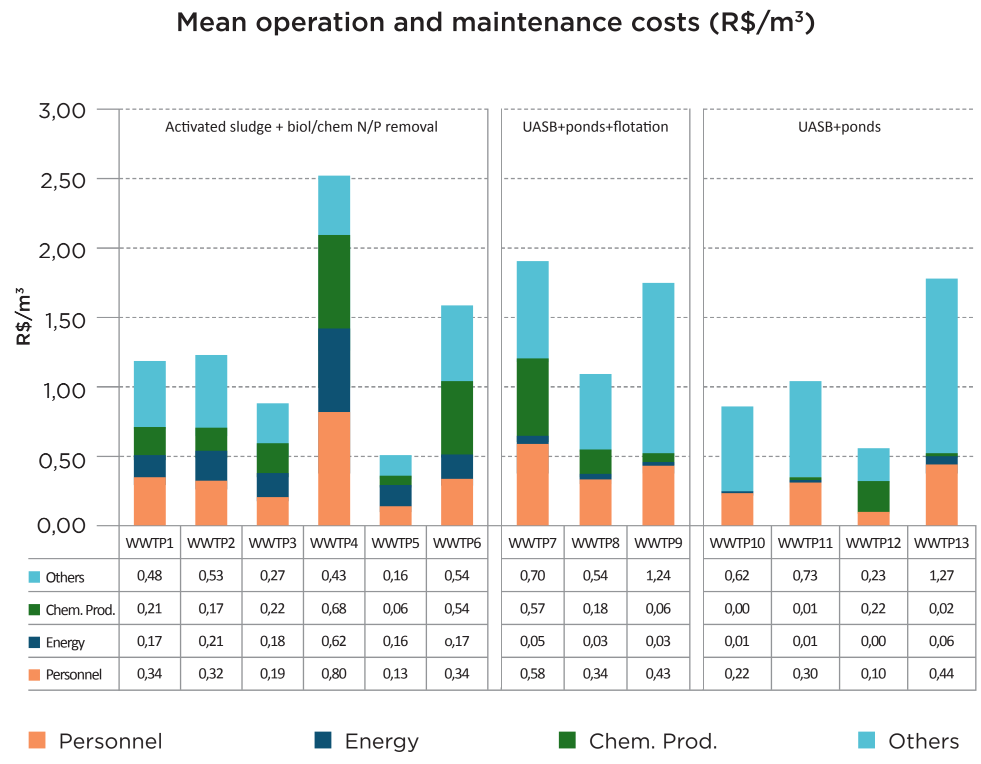
The comparison of processes based purely on per capita costs hides the fact that the processes investigated here have different treatment objectives. Most of them aim mainly at the removal of organic matter and suspended solids. The two variants incorporating maturation ponds (after anaerobic/facultative ponds and UASB reactors) are those with the higher construction costs among the processes investigated. However, it should be understood that these systems are able to remove the four categories of pathogenic bacteria (practically 100% of protozoan cysts and helminth eggs, and more than 99.99% pathogenic bacteria and virus), as well as achieving substantial removal of ammonia. In a similar way, the activated sludge process is the most expensive of the compact systems, but the process is also able to remove ammonia by nitrification.



10.2. Operation and maintenance costs

It is not easy to obtain operation and maintenance (O&M) cost from the sanitation service providers, because these data are generally not disclosed to the public. Data from one particular water and sanitation company were obtained. Costs have been converted to the base date of October 2015 using the INPC[14] (National Index for Prices to Consumer) from IBGE.

The data obtained comprise 13 WWTPs and are separated according to personnel, energy, chemical products and others. Values are expressed as Brazilian reais (R$) per m³ of wastewater treated. The treatment plants are separated into three major groups: (a) activated sludge with biological and chemical N and P removal; (b) UASB + ponds + flotation; (c) UASB + ponds. Unfortunately these treatment groups do not match exactly with those analyzed in more detail in this report (with the exception of UASB + ponds), but at least they contribute to having a rough idea of operating costs. It is difficult to estimate how well can these data be extrapolated to other regions in Brazil, considering the specificities of the treatment processes and of this particular water and sanitation company. From Figure 30 it can be seen that total O&M costs varied between around **R$0.50/m³ to R$1.50/m³** for most treatment plants. In this particular utility, costs associated with personnel played an important role.



	WWTP1	WWTP2	WWTP3	WWTP4	WWTP5	WWTP6	WWTP7	WWTP8	WWTP9	WWTP10	WWTP11	WWTP12	WWTP13
Others	0,48	0,53	0,27	0,43	0,16	0,54	0,70	0,54	1,24	0,62	0,73	0,23	1,27
Chem. Prod.	0,21	0,17	0,22	0,68	0,06	0,54	0,57	0,18	0,06	0,00	0,01	0,22	0,02
Energy	0,17	0,21	0,18	0,62	0,16	o,17	0,05	0,03	0,03	0,01	0,01	0,00	0,06
Personnel	0,34	0,32	0,19	0,80	0,13	0,34	0,58	0,34	0,43	0,22	0,30	0,10	0,44

Fig. 30. Operation and maintenance costs expressed as R$/m³ for different treatment plants, treatment processes and cost components. Base date: October 2015

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[14] INPC: Índice Nacional de Preços ao Consumidor

11. OPERATIONAL AND MAINTENANCE ASPECTS

The success of a wastewater treatment plant relies on a well undertaken study of conception, a judicious process design (process calculation of the reactors and tanks), a good detailed design (including hydraulics, electricity, mechanical, structural, architecture, landscaping etc), a responsible construction and, last but not the least, good operation and maintenance. In many developing countries, this has been a decisive issue, and many cases of failure could be attributed to lack of proper operation and maintenance.

Maintenance is usually associated with simple but important tasks, such as cleaning of pipes, connections and treatment units, removal of screenings and grit at the preliminary treatment, cutting of grass and vegetation at embankments, painting against corrosion, cleaning of diffusers in aerated tanks and similar activities. Electro-mechanical maintenance is also essential, especially in highly mechanized processes, and involves verification of the functioning of pumps, aerators and blowers in aeration tanks, scrapers in clarifiers and thickeners, mixers in digesters, dewatering equipment etc, if they are present. A good electro-mechanical structure is necessary, with the storage of spare parts or the possibility of having fast acquisition of equipment in cases of breakage.

The more sophisticated the treatment process (such as activated sludge and aerated biofilters), the more equipment it is likely to have, and complete plant failure can take place if essential pieces of equipment do not perform accordingly. Natural treatment processes (such as ponds, wetlands and overland flow) are less dependent on equipment, and because of this they tend to be more robust. On the other hand, they have less flexibility in terms of operational control.

Operation usually involves the control of the treatment process, so that it performs according to desired targets. The main purposes of the implementation of operational control in a wastewater treatment plant can be (von Sperling and Chernicharo, 2005):

- produce a final effluent with a quality that complies with the discharge standards or specified targets
- reduce the variability of the effluent quality
- avoid large process failures
- reduce operational costs
- increase the treatment capacity without physical expansion of the system
- reduce labor requirements
- allow a faster start-up

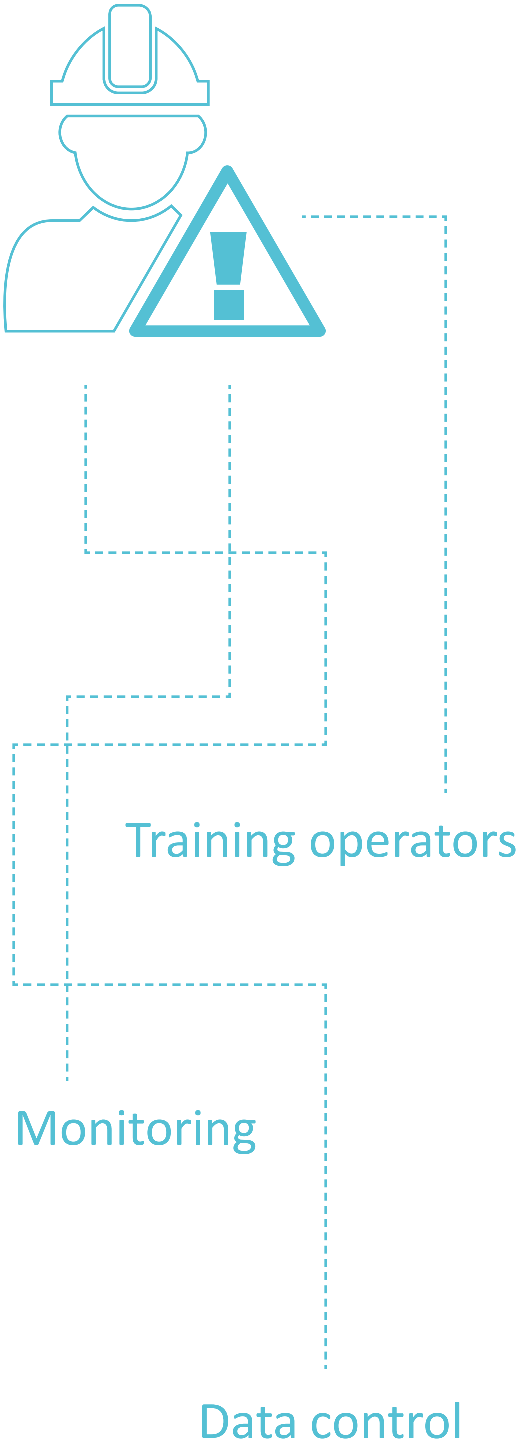
Being highly variable, the influent loads to a sewage treatment plant represent an incentive for the adoption of operational control but, at the same time, they introduce a great difficulty in its implementation. The control of a sewage treatment plant differs from the control of an industrial process, mainly regarding the great variability in the characteristics of the influent. In industrial processes, where control techniques have been traditionally used, the characteristics of the influent are deterministic, or have minor variations around the reference value, being usually directly controllable.

In terms of automated operational control, difficulties that have reduced its application in a broader way have been:

- the characteristics of the influent are of a dynamic, stochastic nature, with unknown disturbances and measurement noises superposed to variations in the process
- the effect of the control actions varies for the different process variables, in terms of both time lag and magnitude of the response
- there is a lack of reliable on-line sensors for some process variables
- not all the process variables can be directly measured
- the control actions are usually limited by the physical restrictions of the system
- in several plants, the possibility of control is limited due to a design with little flexibility
- there are difficulties in incorporating complex process models in the control algorithms and, conversely, there are limitations in the control strategies based on very simple process models

However, several of these problems have been recently reduced by the development of more robust sensors, cheaper and more accessible information technology, more reliable mathematical models, new control algorithms, and designs that are more flexible and adaptable to automated strategies.

When aiming at applying sophisticated equipment and treatment processes, the decision makers must ensure that a good maintenance and operational structure will be in place. It has been observed that this is not always the case and, as stated above, processes failures happen, especially in regions where institutional or financial limitations exist within the service provider. Therefore, **simplicity** is an important element, especially in small to medium size treatment plants.



This limitation should not be always the case: if one looks at a treatment plant as an industry that processes an input (raw sewage) in order to deliver an output (treated wastewater) of good quality, a different view on wastewater treatment plants could arise. Even in financially deprived areas, it is not uncommon to see well-functioning industries with well-trained workers. A similar view could be applied to sewage treatment plants, and investments in operation and maintenance could be essential steps towards a successful operation.

Training of operators to adequately perform their duties is a must, but very frequently this does not happen, and operators have little incentive to progress and understand the reason of certain operational procedures.

Another important element is adequate **monitoring**. Monitoring can be implemented with two main functions: assessment of **compliance with the legislation** and obtaining **data for control** purposes. In Brazil, some state environmental agencies require monthly monitoring of the influent (raw sewage) and effluent (treated sewage) and, in some cases, also of the receiving water body (upstream and downstream of the discharge). Although this assists in evaluating plant performance and the compliance with legal standards, it is in many cases insufficient for control purposes. For a good operational control, sampling at intermediate points in-between units for assessing the performance of each stage and also inside units (e.g. biological reactors) to understand its behavior is necessary. Other water quality constituents need to be analyzed and not only those required by the environmental agency. Of course that more sophisticated treatment processes require a higher level of monitoring (more sampling places, higher frequency, more constituents).

It is recognized that monitoring is not cheap, especially for small treatment plants. In addition, the logistics for remote plants may limit collection of samples and transportation to laboratories. However, this should not be a reason for the absence of monitoring: each case needs to be analyzed individually, but under the perspective that monitoring is an important element in the operational structure.

Automatic sensors of key variables (such as flow, on-off of equipment and some selected water constituents) and transmission by **telemetry** to centralized operational units may be a way forward in many places.

12. CASE STUDIES ON TREATMENT PLANTS IN BRAZIL

It is not simple to select representative case studies on wastewater treatment in Brazil, considering the great diversities in such a large country. The following examples have been selected to illustrate specific points mentioned on this report.

Stabilization ponds in the state of São Paulo

Ponds have been built there for decades. Facultative and anaerobic ponds are frequently adopted. In the state of São Paulo (Southeast region), there are hundreds of ponds, and most of them are operated by SABESP, the largest water and sanitation company in Brazil. Some recent ponds are very well built (e.g. Jales, west state of São Paulo, 60 L/s) and provide a pleasant environment. Some old ponds, after many years of operation, require desludging. In ponds without preliminary treatment, substantial accumulation of sand occurred near the inlet. Even though the absence of preliminary treatment could lead to less routine maintenance (no frequent sand removal), in the end this resulted in operational problems at the vicinity of the inlet pipes.

Stabilization ponds in the state of Ceará

The state of Ceará is in the Northeast Brazil, with exceptional climatic conditions for the implementation of ponds (abundant sunshine, high temperature). Ponds play an important role there, and many of them are situated in a semiarid region, and the effluent from maturation ponds could be used for agricultural reuse. The lack of a regulatory framework for reuse in Brazil hinders this effluent use in a formal way, and informal abstraction of wastewater is done by some nearby inhabitants. This informal situation points out to the need of establishing a suitable legislation for water reuse in Brazil, such that informal practices may be regulated, bringing the incentive to adequate solutions and avoiding the occurrence of uncontrolled practices, which could pose public health or environmental hazards. The largest pond system in Brazil (Maracanaú, operated by CAGECE) is located there, occupying a total area around 100 ha, and comprising one anaerobic pond, one facultative pond and three maturation ponds, each with around 1000 m length and 300 m width. Given these dimensions, the maintenance requirements in terms of keeping the embankments without vegetation are not small.

Stabilization ponds with algae removal

Algae are an integral element in well-functioning facultative and maturation ponds. The discharge of effluents with high concentrations of algae (suspended solids) may or may not cause direct problems in the receiving water body. If algae survive, they will contribute positively to the dissolved oxygen balance, but if they die, they will impose an additional oxygen demand in the water body. Some treatment plants implemented a final stage for algae removal, most frequently using coarse filters. The water and sanitation company in the Federal District (capital Brasília and neighboring areas; Central-West region), CAESB, implemented in some pond systems algae removal by dissolved air flotation. The addition of chemicals also assist in the precipitation of phosphorus, which is a nutrient of concern in the area, due to the eutrophication of important water reservoirs. One such example is Samambaia WWTP (180,000 inhabitants), in which dissolved air flotation was introduced some years ago and brought a large improvement in the effluent quality. The increase in the operational complexity of the system could be accommodated by the company, because of the large size of the treatment plant, which already required dedicated operation. This proved to be a successful practice for the removal of particulate organic matter, suspended solids and phosphorus from the pond effluent, but its implementation in other regions of Brazil must be preceded by a careful analysis of the benefits versus the increase in operational costs and complexity. This Samambaia system is also known because of the fact that the UASB reactors are immersed in the inlet zone of the facultative pond, what was an innovative idea at the time when they were implemented.

Ponds for the post-treatment of UASB reactor effluents

Ponds have been implemented in several places for the post-treatment of UASB reactors. In Brazil, these ponds have received the generic denomination of “polishing ponds”, but they can play the role of sedimentation ponds, facultative ponds or maturation ponds. In the state of Paraná (South region), the water and sanitation company (SANEPAR) was the Brazilian pioneer in large-scale implementation of UASB reactors, with hundreds of units built (there the anaerobic unit is called fluidized bed anaerobic reactor). Polishing ponds have been implemented with short retention times, mainly with a function of allowing complementary settling of suspended solids. In other states, such as in Minas Gerais (Southeast region), the water and sanitation company (COPASA) implemented facultative ponds as post-treatment. Later on it was shown that maturation ponds can be adopted instead, and the first pond may remain aerobic (thus not releasing malodorous gases), even if it has a smaller area than a facultative pond. The advantage of having maturation ponds is that the additional objective of pathogen removal is incorporated. Research has shown that shallow ponds in series may be efficient for the removal of ammonia and very efficient for the removal of coliforms.

Constructed wetlands for condominiums

It was shown that the number of constructed wetlands for urban wastewater treatment, according to the survey undertaken by ANA, is not large. However, there are many applications of this system, especially for individual or small clusters of houses, or even condominiums for more than one thousand inhabitants. Examples can be found in the state of Santa Catarina (South region). The units are inside the condominiums and are not operated by the state water and sanitation company. A private company (e.g. Rotaria do Brasil) designs, implements and operates some of these systems. Other private suppliers exist, and this can be a market for these specific applications. Sludge from septic tanks are also treated by this process. Considering the potential of expansion of the utilization of wetlands, it is important that the full-scale systems be monitored in order to enhance the knowledge about their applicability in Brazil and for developing suitable design criteria for our wastewater and climatic conditions.

Overland flow for the post-treatment of UASB reactor effluents

Land disposal by overland flow is a simple process. There are not many units with this process in Brazil, as shown in ANA´s survey. In the state of Minas Gerais (Southeast region), the water and sanitation company (COPASA) implemented this systems in small communities, but also in towns with populations as high as 20,000 inhabitants. These units serve as post-treatment of the effluent from UASB reactors. Satisfactory BOD removal efficiencies are obtained and, in some cases, there is no final effluent to be discharged. This has been reputed to the dry climate of the region and the high evapotranspiration rates. In the Federal District (Central-West region), CAESB operates a large system for around 80,000 inhabitants, incorporating UASB reactors, overland flow and maturation ponds – the area for the overland flow alone is 19 ha. In this latter application, because the area is so large, it is difficult to remove the plants from the plots after cutting, and the cut vegetation is left on the same place, undergoing decomposition.

Trickling filters for the post-treatment of UASB reactor effluents

UASB reactors followed by trickling filters can be considered one of the most important trends in many places, not only in Brazil, but also in other countries in Latin America. They have been adopted whenever compact systems are required. The combination of anaerobic and aerobic treatment is advantageous, and this system is simpler than those involving activated sludge, and leads to much lower energy consumption. This system is applied in Brazil for populations ranging from few thousands up to one million inhabitants. An important example is the Onça WWTP, situated in Belo Horizonte, Minas Gerais (Southeast region) and operated by COPASA, being the largest in the world for urban wastewater treatment using UASB reactors. One subject of current investigation in Brazil regarding this system is the destination of the excess aerobic sludge, removed from the secondary sedimentation tanks situated downstream the trickling filters. Many conceptions advocated sending this aerobic excess sludge to the UASB reactors, where they would undergo digestion and thickening, together with the anaerobic sludge. The only sludge to require further processing would then be the mixed sludge from the UASB reactors, and treatment would comprise only dewatering, since the mixed sludge would be already digested and thickened in the UASB reactor. Some experiences have reported that the aerobic sludge causes partial solids flotation in the UASB reactor, and a different destination for the aerobic sludge has been implemented. On-going studies in Brazil are investigating this aspect. Even with this point requiring further investigation, the overall system has proven to be simple and with a satisfactory efficiency in organic matter removal. Designing trickling filters for nitrification, especially if they use stones or gravel, implies much higher tank volumes and areas, and a careful analysis needs to be done on the cost implications of incorporating this treatment objective with trickling filters.

Submerged aerated biofilters for the post-treatment of UASB reactor effluents

In the state of Espírito Santo (Southeast region), the system comprised by UASB reactors followed by submerged aerated biofilters is popular, and has been implemented in several communities operated by the water and sanitation company (CESAN). The system follows the same logic of anaerobic-aerobic treatment. Energy consumption is similar to the activated sludge process, and the aerobic stage is capable of allowing nitrification. A compact solution is achieved.

Activated sludge for the post-treatment of UASB reactor effluents

Activated sludge has been used for the post-treatment of anaerobic effluents in several localities, for populations ranging from tens of thousands to hundreds of thousands of inhabitants. The state of São Paulo (Southeast region) pioneered this application for domestic sewage treatment in Brazil. In the state of Minas Gerais (Southeast region), the Betim WWTP (370,000 inhabitants), operated by COPASA, delivers one of the best effluent qualities from all treatment plants operated by this company. A by-pass of the UASB reactor allows sending part of the raw sewage to the aeration tanks, in order to provide more organic carbon for the heterotrophic bacteria, if necessary. Nitrification can be achieved in the aeration tanks treating the anaerobic effluent, but it is recommended to employ higher sludge ages compared with the treatment of raw sewage (this recommendation is explicit in the Brazilian standards for designing WWTPs – see Section 8). In Betim WWTP, the biogas generated in the UASB reactors is used for sludge disinfection by thermal treatment.

Activated sludge with utilization of biogas from anaerobic digesters

Conventional activated sludge plants usually stabilize the primary and secondary sludge by anaerobic digestion. Although practiced in several countries, with a special mention to Germany, biogas utilization for energy generation has not yet found due recognition in Brazil. However, some years ago the water and sanitation company COPASA implemented gas recovery from anaerobic sludge digesters in its largest treatment plant (3.7 m^3/s, Arrudas Plant, Belo Horizonte, Minas Gerais, Southeast region). Biogas, after cleaning and storage, is used in microturbines for energy generation, covering part of the expenditures with the aeration in the biological reactor (aeration is the largest energy consumption element in an activated sludge plant). The objective is to obtain full recovery of the energy use for aeration when all microturbines are implemented. The warm off-gases released in the process are used for sludge heating in the digesters.

Advanced treatment

Advanced treatment is not common in Brazil. The vast majority of treatment plants aim only at the removal of suspended solids and organic matter. The water and sanitation company in the Federal District (CAESB, Central-West region) was a pioneer in the implementation of activated sludge with biological nitrogen and phosphorus removal followed by chemical phosphorus removal. The objective was eutrophication control in the receiving water body (Lake Paranoá, Brasília)). With the on-going operation of the nutrient removal stage in the treatment plants discharging to Lake Paranoá, its water quality improved, and several of the water uses that had been precluded for years could take place once more. Although not frequent, nutrient removal was also implemented in other states in Brazil. Another level of advanced treatment is for water reuse. The largest project of this kind in Brazil is the Aquapolo Project, in São Paulo metropolitan area (SABESP/Odebrecht), which has the capacity to produce 1,0 m^3/s for use by the petrochemical sector. The effluent from a treatment plant (ABC WWTP) undergoes further treatment comprising membranes and other stages, generating a high quality effluent suitable for industrial reuse.

Wastewater treatment research at demonstration scale

The Center for Research and Training in Sanitation UFMG/COPASA is located at the Arrudas WWTP, Belo Horizonte, Minas Gerais (Southeast region). Raw sewage is abstracted from the inlet and feeds several full-scale treatment units for small communities (typical population equivalents between 100 and 500 inhabitants). This facility allows research from the Federal University of Minas Gerais on the treatment systems most widely used in Brazil. There are several UASB reactors, trickling filters, polishing ponds, coarse filter, horizontal subsurface flow wetland and vertical flow wetland. Verification of operational conditions, testing of different loading rates, derivation of design criteria, enhancement in the understanding of the behavior and mechanisms inside the biological reactors and formation of researchers have been successfully achieved during the 13 years of experiments at this center.

13. OVERALL CHALLENGES IN WASTEWATER TREATMENT IN BRAZIL

There are many challenges in the implementation of a suitable wastewater treatment infrastructure. Many years ago, the major challenge was simply to implement new treatment plants, because only few places treated their wastewater. Nowadays, there are many plants, and new challenges are in place. The following list divides the challenges into two groups: (a) challenges associated with the absence of wastewater treatment and (b) challenges associated with the existence of wastewater treatment.

Challenges associated with the absence of wastewater treatment

- Implement new treatment plants
    - o Undertake good conception reports (centralized vs decentralized systems; final effluent destination; treatment objectives; treatment process selection)
    - o Undertake good designs (process design; detailed design)
    - o Obtain financing for the implementation
    - o Undertake a good construction of the treatment plant

Challenges associated with the existence of wastewater treatment

- Receive sewage in the WWTPs
    - o Expand coverage of the collection system
    - o Implement interceptors in the bottom valleys
    - o Remove illegal connections with the stormwater system
    - o Avoid overflows due to stormwater intrusion or energy failures in pumping stations
- Guarantee proper functioning of installations and equipment
- Guarantee a suitable operational level (training)
- Guarantee safety and health of treatment plant personnel
- Monitor treatment units and effectively use monitoring data
- Guarantee compliance with discharge standards
- Guarantee compliance with receiving water body standards
- Guarantee a stable and reliable performance
- Incorporate pathogen removal
- Incorporate nutrient removal when necessary
- Incorporate removal of organic and inorganic micropollutants
- Manage suitably the sludge produced
- Manage suitably the biogas produced
- Reduce operational costs
- Expand treatment plants if necessary
- Guarantee safety and good relationship with neighborhood
- Look for a productive use of the treated effluent (agricultural, urban, industrial reuse)
- Look for a productive use of the treated sludge (biosolids)
- Look for a productive use of the generated biogas
- Look for resource recovery (phosphorus, sulfur, metals etc)
- Promote institutional development (service provider, environmental agency, regulatory agency)

It is clear that this agenda is very vast and may seem intimidating. Improvements must be achieved in a stepwise manner, always analyzing local conditions. The time frame required is also variable, but it is important to have targets in the agenda, even if some of the tasks will be accomplished only on medium or long term.

14. CONCLUSIONS

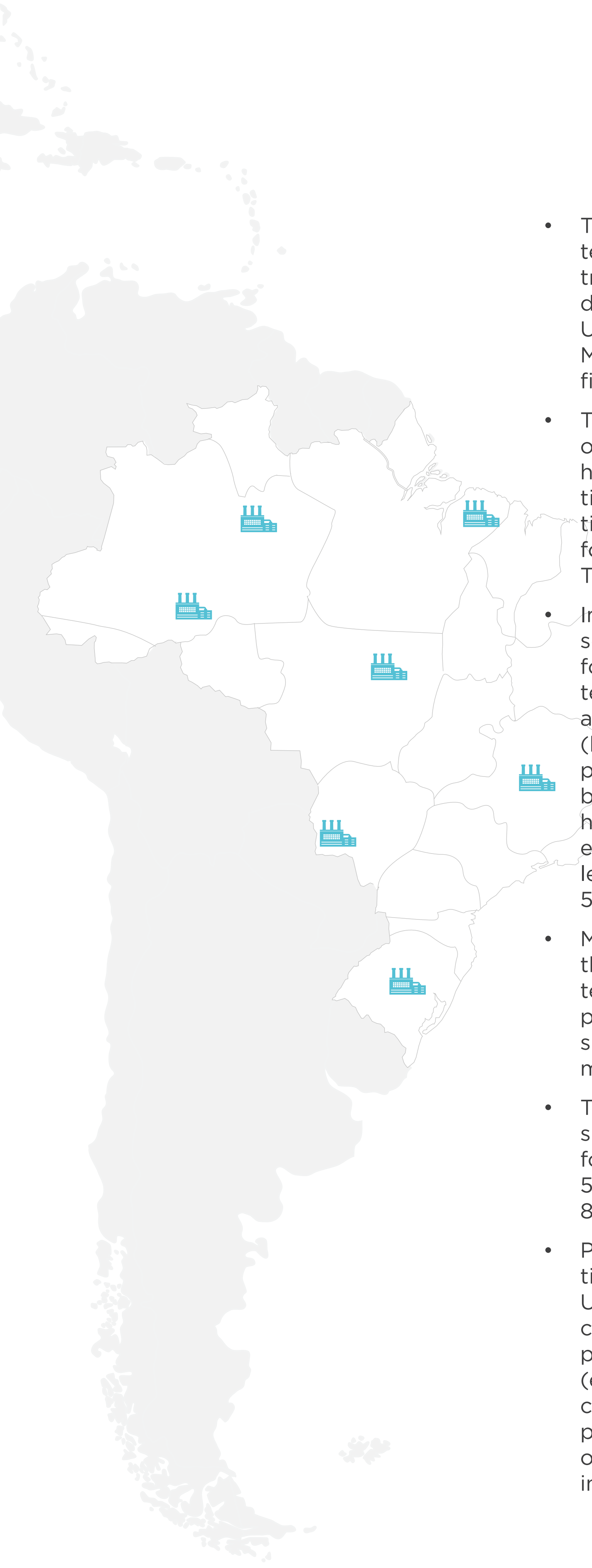
Due to its vast territorial dimensions, Brazil presents considerable regional diversities in economic and climatic conditions, what can influence the selection and adoption of wastewater treatment processes. Most of the population is located in towns and cities that are situated within less than 1,000 km from the Atlantic coast. Within this area, the Northeast region has exceptional climatic conditions for the adoption of natural treatment systems, and temperature and sunlight decrease towards the South of Brazil, but still keeping favorable conditions for biological treatment processes. The inverse occurs in terms of economic conditions, with the South and Southeast regions showing better indicators, what is reflected in terms of the coverage of the sanitation infrastructure.

Regarding the distribution of the population according to size, from the 5,570 Brazilian municipalities, around 25% of them have populations lower than 5,000 inhabitants, about 70% have populations with less than 20,000 inhabitants and approximately 95% of the municipalities have populations lower than 100,000 inhabitants. Therefore, the vast majority of municipalities in Brazil are small to medium-sized, and the selection of wastewater treatment process needs to take this into account.

In terms of coverage of sanitation services in Brazil, approximately half of the population is connected to a sewage network collection system and approximately 70% of the sewage collected in networks is treated. In terms of flow, only around 40% of the sewage produced is treated.

It is estimated that, from the total of 5,570 municipalities in Brazil, around 1,900 (34%) have WWTPs (wastewater treatment plants). The total number of WWTPs in Brazil is estimated to be around 2,800 plants.

A survey being conducted in Brazil by ANA (National Water Agency), with data obtained from 2,187 WWTPs, indicates the following major points (the results are still preliminary):



- The treatment configurations most widely adopted in terms of number of treatment plants (more than 200 treatment plants in each configuration) are, in this order: Anaerobic pond followed by Facultative Pond; UASB reactor; Activated sludge; Ponds followed by Maturation ponds; Septic tank followed by Anaerobic filter.
- The treatment configurations that dominate in terms of population equivalent (greater than 3 million inhabitants in each configuration) are, in this order: Activated sludge; Anaerobic pond followed by Facultative pond; UASB followed by Polishing pond; UASB followed by Activated sludge; UASB followed by Trickling filter; Aerated pond; UASB reactor.
- In terms of groupings of treatment systems, it is observed that: (a) ponds and UASB reactors alone or followed by any form of post-treatment dominate in terms of number of treatment plants, representing almost 80% of the 2,187 treatment plants analyzed; (b) UASB reactors alone or followed by any form of post-treatment, activated sludge and different combinations of ponds treat the largest number of inhabitants, representing 95% of the total population equivalent surveyed; (c) the total population equivalent treated by the 2187 WWTPs analyzed in Brazil is 51,878,930 inhabitants.
- Most of the existing treatment plants have a flowsheet that is compatible with the removal of organic matter. Pathogen removal (by disinfection or maturation ponds) is implemented in 22% of the treatment plants surveyed, and nutrient (nitrogen and phosphorus) removal is incorporated in a small number of WWTPs.
- The largest number of treatment plants in Brazil are for small towns: from the 2,187 plants surveyed, 25% are for populations lower than 2,000 inhabitants, almost 50% are for populations up to 5,000 inhabitants, and 80% are for populations less than 20,000 inhabitants.
- Ponds are used approximately evenly for population sizes up to 20,000 inhabitants. The number of UASB reactors alone (without post-treatment) decrease with the increase in population size. A similar pattern occurs for UASB followed by post-treatment (even though different post-treatment processes are covered). Activated sludge is evenly distributed in all population ranges, and septic tank followed by anaerobic filter is used mainly for populations up to 5,000 inhabitants.

An assessment of the performance of 166 WWTPs located in the states of São Paulo and Minas Gerais (Southeast region), comprising six different treatment configurations and six water quality constituents (BOD - biochemical oxygen demand, COD - chemical oxygen demand, TSS - total suspended solids, TN - total nitrogen, TP - total phosphorus and FC - fecal or thermotolerant coliforms), led to the following main conclusions:

- A great variability was noticed in the effluent concentrations and in the removal efficiencies, considering all analyzed constituents and all treatment technologies.
- The septic tank followed by anaerobic filter process presented a performance much below the expected one, based on the literature.
- The performance of facultative ponds was lower than expected from the literature, considering COD, TSS and TN removal efficiencies. However, good TP and FC removal efficiencies were achieved.
- Anaerobic ponds followed by facultative ponds showed a good performance in terms of BOD, COD, TP and FC removal, with a significant percentage of WWTPs with efficiencies within and even above the values reported by the literature.
- UASB reactors without post-treatment showed BOD and COD removal efficiencies compatible with those reported in the literature and a poorer performance regarding TSS, FC and nutrients.
- The performance achieved by the UASB reactors followed by post treatment was good and the closest one with the expected values from the literature.
- The performance presented by the activated sludge plants, considering organic matter removal, was the highest among the evaluated systems, although it was below the reported literature range.
- In general, the direct influence of the loading conditions to which the treatment plants were subjected was small and scattered in all the treatment processes.
- A single operational variable or a group of variables could not be used to explain the differentiated performances among all the WWTPs. The contribution and influence of each operational variable seemed to differ from one WWTP to another and, as expected, this is likely to be a combination of multiple design and operational aspects.

Based on another survey of construction costs (CAPEX) of WWTP built in the Southeast region of Brazil, converted to the base date of October 2015 (US$ 1.00 = R$3.80), the following ranges of typical values (round figures) have been obtained:

- Natural treatment by ponds (facultative or anaerobic followed by facultative) has unit costs between R$135 and R$230/inhabitant, and the inclusion of a pathogen removal stage by maturation ponds increase the total costs by a factor around 2.3 (associated with the larger number of ponds and total area required).
- Treatment by UASB reactors alone represents the cheapest variant, with round unit costs between R$60 and R$180/inhabitant. Several post-treatment options for the UASB effluent are available, from natural to compact systems. Post-treatment by ponds raise the total costs to around between R$285 and R$435/inhabitant, in the case of one or two ponds, and between R$390 and R$650/inhabitant, in the case of three or more maturation ponds. Post-treatment by compact systems such as anaerobic filters and trickling filters have somewhat similar total costs, in the range of R$215 to R$365/inhabitant.
- Treatment by activated sludge has the highest costs among the compact systems (R$360 to R$440/inhabitant).
- Operation and maintenance costs (OPEX) are more difficult to obtain. Data from only one service provider have been obtained, and it is difficult to extrapolate them to other regions in Brazil because the treatment systems employed were predominantly different from those covered in this report.

As a final conclusion, it is observed that several different treatment configurations are being used in Brazil. The most traditional system involves stabilization ponds, which are present in large numbers for populations up to around 20,000 inhabitants. Variants of the activated sludge process have been used for many population ranges, covering small, medium and large cities in Brazil. UASB reactors represent the main trend for all population ranges, especially when they are followed by a post-treatment stage. Several post-treatment options for the UASB effluent are available, with a special mention to trickling filters, which are being implemented in many locations, especially when land availability is not large, and also polishing ponds.

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