



# Good Practices in Wastewater Treatment and Reuse



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# Good practices in wastewater treatment and reuse

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## Introduction

This document "Good practices in wastewater treatment and reuse" was developed within the framework of the GEF CReW+ project under the leadership of the German Development Cooperation – GIZ – and through the *Sanitation for Millions* program which is implemented on behalf of the Inter-American Development Bank (IDB).

The document systematizes lessons and good practices presented in the course "Reuse of Treated Domestic Effluents" developed by the GEF CReW+ Academy, which addressed the problem of water pollution, the importance of wastewater treatment, main wastewater treatment technologies, as well as fundamental aspects that must be considered when planning a wastewater treatment and reuse project, including issues related to governance, regulations, costs, nutrient recovery, and circular economy.

This course was held between August and October 2021, as a joint effort between GIZ and the United Nations Environment Programme (UNEP).

The GEF CReW+ project is a collaborative project financed by the Global Environment Facility (GEF) and is co-implemented by the IDB and UNEP in 18 countries in the Greater Caribbean Region: Barbados, Belize, Colombia, Costa Rica, Cuba, Grenada, Guatemala, Guyana, Honduras, Jamaica, Mexico, Panama, Dominican Republic, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago. The GEF CReW+ is being executed on behalf of the IDB by GIZ and the Organization of American States (OAS) and on behalf of UNEP by the Secretariat of the Cartagena Convention.

## Wastewater in the Global Context: Challenges and Opportunities

### Water in the world

Global water consumption has tripled since last century, increasing from 1.3 trillion m<sup>3</sup> a year in 1950 to about 4 trillion m<sup>3</sup> today (see Figure 1).<sup>1</sup>

The increase in water consumption is mainly due to the growth of the world population, which is already approaching 8 billion inhabitants, the growth of cities, large investments in improving the coverage of water and sanitation services and the increase in agricultural area under irrigation. Globally, 70% of all water withdrawals in the world are destined to irrigation, 19% for industrial uses and 11% for domestic use (see Figure 2).

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<sup>1</sup> Hannah Ritchie and Max Roser (2017) - "Water Use and Stress". *Published online at OurWorldInData.org*. Retrieved from: '<https://ourworldindata.org/water-use-stress>' [Online Resource]

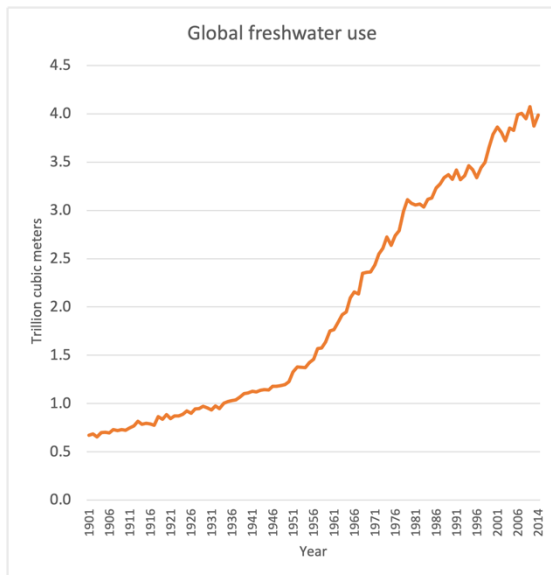


Figure 1: Water consumption in the world

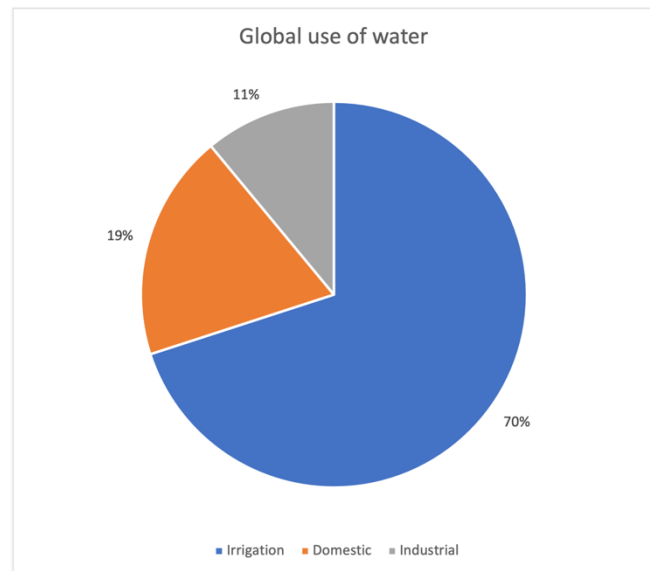


Figure 2: Global use of water

Any human activity that makes use of water generates a certain degree of pollution. For example, water used in sanitation systems becomes contaminated by organic matter, pathogens, and solids. Water used in industrial processes is susceptible to contamination with chemicals and heavy metals and water used for irrigation comes into contact with fertilizers and nutrients such as nitrogen, phosphorus and potassium.

An increase of phosphorus and nitrogen concentrations in water bodies causes excessive algae growth, and the depletion of oxygen available in the water can cause loss of biodiversity. This process is known as eutrophication. It is estimated that around 40% of aquatic ecosystems worldwide are affected by this process (Hupfer & Hilt, 2008).

Pathogen pollution from human and animal excreta affects nearly a third of river courses in Latin America, Africa and Asia, and endangers the life and health of millions of people. This type of pollution contributes to the spread of tropical diseases such as cholera, diarrhoea, and dengue.<sup>2</sup>

## The Sustainable Development Goals and national development agendas

According to UN-Water, only 8% of domestic and industrial wastewater is treated in low-income nations, a very small percentage compared to developed countries, where 70% of that water is treated.

The Sustainable Development Goals (SDGs), were adopted by all United Nations Member States in 2015 as a universal call to end poverty, protect the planet and ensure that all people enjoy peace and prosperity by 2030.

Specifically, the sixth goal (SDG 6) is related to water and sanitation issues. Among the goals agreed for 2030 in relation to this objective are: to achieve access to adequate and equitable sanitation and hygiene services for all people, to end open defecation and to improve water quality by reducing pollution, eliminating dumping and minimizing the emission of chemicals and hazardous

<sup>2</sup> <https://www.un.org/sustainabledevelopment/es/2017/03/las-aguas-residuales-tambien-pueden-ser-herramientas-para-el-desarrollo-sostenible/>

materials, halving the percentage of untreated wastewater and significantly increasing recycling and safe reuse globally<sup>3</sup>. It is expected that, until 2030, significant investments will be made in integrated water management. This can generate great opportunities and a favorable environment for the implementation of wastewater treatment projects.

## Climate Change and Water

Climate Change is evidenced by slow onset effects such as salinization, land and forest degradation and desertification. In this way, variations in the water cycle are generated, which causes an increase in the intensity and frequency of meteorological phenomena that can cause further damage and loss of habitats. These variations also reduce the availability of water resources and our ability to forecast its availability in the future generating risks to biodiversity and the enjoyment of human rights to water worldwide. Furthermore, some Climate Change mitigation measures, such as the use of biofuels, can further exacerbate water scarcity.

Clearly, current water practices and business as usual are not sustainable in the long term and new opportunities must be considered. Sustainable water management, therefore, implies optimizing its use and promoting recycling and resource recovery practices.

## Wastewater and the circular economy

Wastewater, once treated, can be used for irrigation of parks, gardens, crops, or reforestation. Additionally, wastewater contains valuable resources that can be recovered and converted into useful products such as fertilizers, soil conditioners, biomass and energy. For example, the average person defecates 4.5 kg of nitrogen, 0.5 kg of phosphorus and 1.2 kg of potassium each year. These elements and other micronutrients found in excreta are essential for the fertilization and restoration of agricultural soils. The energy value of feces is on average 4.115 kcal/kg of dry solids. These solids are separated from wastewater during a treatment process and can be used as an energy source to be used in the same treatment plant and thus reducing energy costs<sup>4</sup>.

Under this perspective, the concept of the circular economy gains relevance because, unlike the linear vision of resource use-and-dispose, not only seeks to reduce the pollution of water bodies, but also to recover resources, in accordance with the *Bellagio Principles* in which the apparent waste becomes a new resource. In this line, the 3Rs - recycle, reduce and reuse – can be applied to the treatment of wastewater and by extension to on-site sanitation, in which methane gas and fecal sludge derived from the treatment can be used in a sustainable way, either for energy generation or as soil improvers for agricultural use.<sup>5</sup>

## Good practices for the planning and implementation of a wastewater treatment and reuse project

Traditionally, the sector has prioritized *infrastructure projects over service development*. This infrastructure-centric approach has resulted in many treatment plants being abandoned shortly after their construction or are currently being underutilized. For their operation, treatment facilities require management systems, personnel with specific technical skills and a series of inputs and resources. The same is valid for reuse systems. The next three guidelines are the basis for sound project planning and for ensuring sustainable services over time:

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<sup>3</sup> <https://www.un.org/sustainabledevelopment/es/water-and-sanitation/>

<sup>4</sup> Mcconville, Jennifer and Niwagaba, Charles and Nordin, Annika and Ahlström, Marcus and Namboozo, Vivian and Kiffe, Mark (2020). *Guide to Sanitation Resource-Recovery Products & Technologies: a supplement to the Compendium of Sanitation Systems and Technologies*. (NL, NJ) > [Dept. of Energy and Technology](#), Sveriges lantbruksuniversitet. Report / Department of Energy and Technology, SLU

<sup>5</sup> <https://www.caf.com/es/conocimiento/visiones/2017/03/el-tratamiento-de-aguas-residuales-bajo-un-enfoque-de-economia-circular/>

## Guideline 1: “Plan from the end” and select appropriate technologies

Wastewater contains several resources that can be potentially recovered if a treatment system is designed under a *reuse* approach. This approach entails the identification and consideration of water reuse or other resource-recovery opportunities from the outset. In other words, first identify water reuse and resource-recovery opportunities and then work the design of the system backwards. Thus, the term *plan from the end*.

### The type of reuse and/or final destination of wastewater determines the type and level of treatment required

Wastewater contains water, large and small solids (solid waste), sedimentable solids (sand), suspended solids, fats, organic matter, nutrients and pathogens and could contain chemicals, heavy metals and residues of medical compounds such as hormones and antibiotics. Large and small solids are normally separated at the beginning of treatment and are directed to the waste management system. Organic matter can be recovered and used to improve soil, as a source of energy (fuel) or other industrial purposes. By the term *nutrients* we usually refer to nitrogen (N), phosphorus (P) and potassium (K). They are called nutrients because they are essential elements for the growth of plants and crops.

Wastewater contains energy. For example, wastewater normally has a higher temperature than drinking water, this difference in temperature can be tapped using a heat exchanger. The kinetic energy of wastewater can also be harnessed to generate electricity through a turbine, although the technology still needs to be further developed. Finally, biogas can be obtained from the sludge separated as part of the wastewater treatment using a reactor and converted into electricity.

The level of treatment will depend on the final destination of the effluent, the type of reuse application. For example, nutrients must be removed from the effluent before discharging it in a lake to prevent eutrophication. Nutrient removal entails a higher (more sophisticated) level of treatment as compared to water for irrigation which can contain nutrients that will be up taken by crops. In the second case, the soil completes the water purification process and plants are benefit from the nutrients.

Wastewater contains viruses, bacteria, parasites, and worm eggs that can cause gastroenteritis, diarrhea, giardiasis, viral infections, and skin and eye infections. If treated water is to be used for irrigation of vegetables or vegetables that are consumed raw, a disinfection process should be considered to ensure that the food is not contaminated.

### Selection of appropriate technologies

Wastewater treatment is carried out through a series of unitary processes that are combined to achieve the desired degree of treatment. Basically, what a wastewater treatment system does is separate water from contaminants. The following table summarizes the main stages of a treatment process.

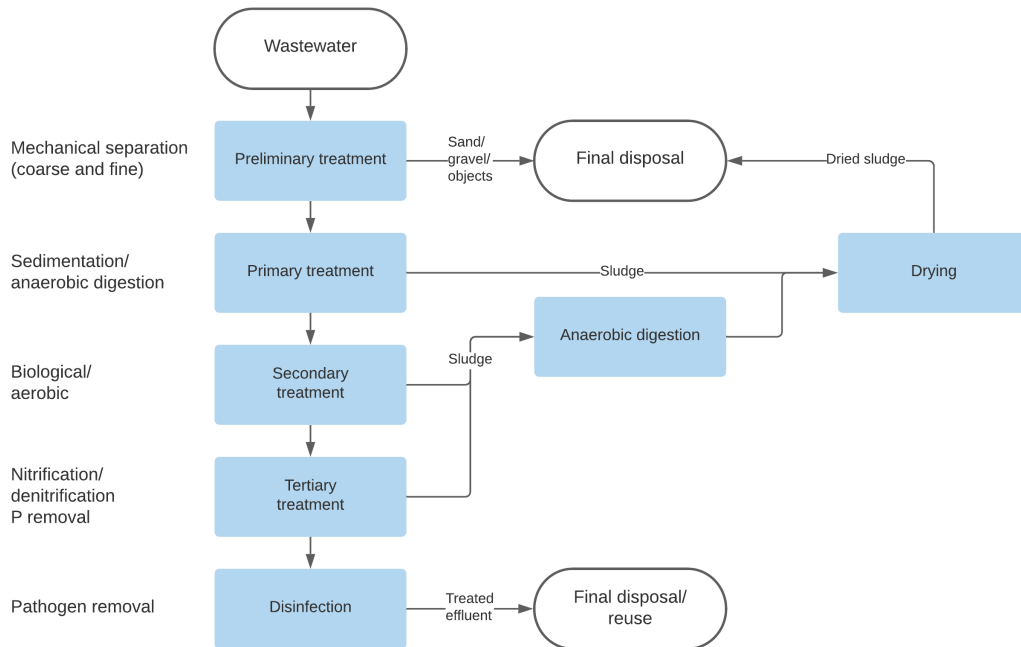


Figure 3: Description of a classic treatment train

The sequence of a treatment processes is called *treatment train*. There are different technological options for each stage of treatment (pre-treatment, primary, secondary, tertiary treatment and disinfection), but in general almost all treatment systems follow this sequence. Depending on the desired effluent quality, one or more stages may be skipped.

The technologies used at each stage of treatment should be appropriate to the local context and conditions and should consider both available resources and constraints. When choosing technologies, it is recommended to consider the following aspects: investment costs, operation and maintenance costs, technical skills necessary for their operation and maintenance, available physical space, local technical service/assistance, availability of supplies and spare parts, energy consumption and lifespan of components.

The following diagram proposes a sequence of steps and decisions for the planning phase under the concept of *planning from the end*:

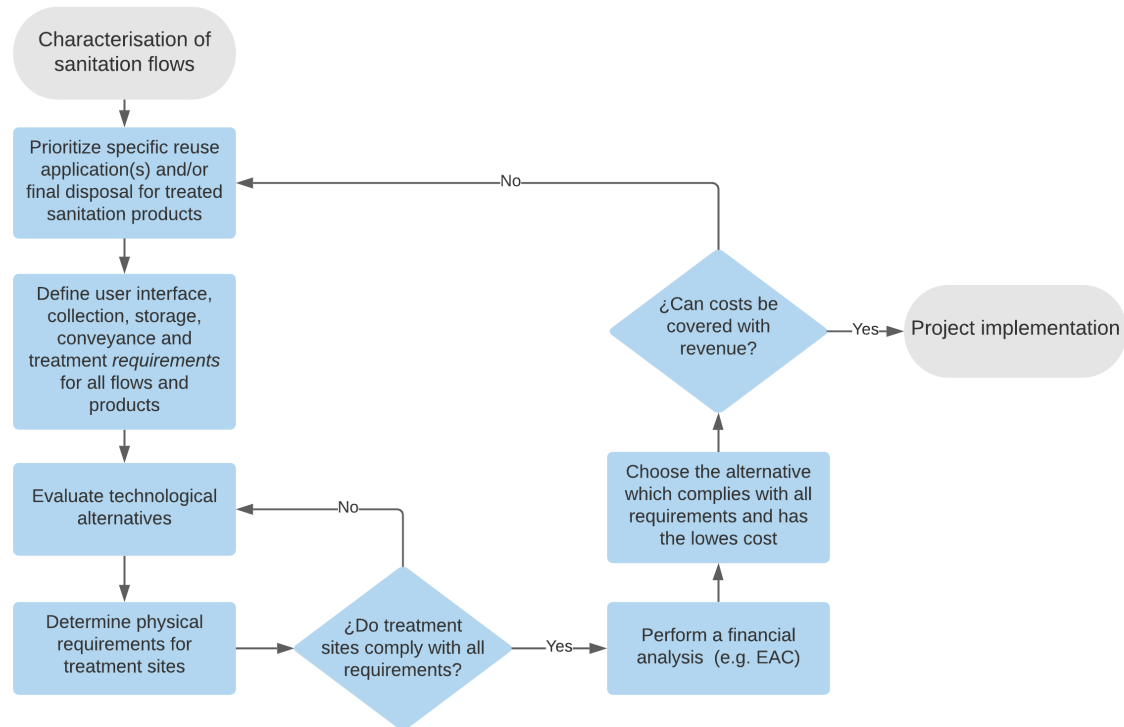


Figure 4: Planning from the end

There are sources of information and extensive literature on sanitation and wastewater treatment technologies. Here are two resources that can be very useful:

- EAWAG, Compendium of Sanitation Systems and Technologies 2nd Edition (Spanish Version) <https://www.eawag.ch/en/department/sandec/publications/compendium/>
- SEI, Sanitation, Wastewater Management and Sustainability, 2nd Edition (Spanish Version) <https://cdn.sei.org/wp-content/uploads/2021/06/saneamiento-gestion-de-aguas-residuales-y-sostenibilidad-2021.pdf>

## Guideline 2: Treat wastewater properly and adopt a multi-barrier approach

### Guidelines for treatment and reuse

Wastewater must be treated at a level commensurate with the final destination of the wastewater, either for final disposal to the environment or for the desired reuse applications. Each country has specific regulations for wastewater treatment and, in recent years, regulations for reuse have been developed. In addition to local regulations, there are several international guidelines that can be very useful in time to evaluate treatment alternatives. In Table 1 we cite the most important:

Table 1: International guidelines for wastewater reuse

International organization that generates the guide	Guide name	Notes on the content	Web Link
World Health Organization (WHO)	Guidelines for the safe use of wastewater, excreta and greywater (2013).	This latest edition of the guidelines was published addressing the following topics: (Vol. 1) Normative aspects and summary of the guidelines; (Vol. 2) Use of wastewater in agriculture; (Vol. 3) Use of wastewater and excreta in aquaculture; (Vol. 4) Use of excreta and greywater in agriculture. In this edition, the guidelines have been updated considering new evidence on pathogens and chemicals, and other factors, such as: changes in population characteristics and sanitation practices; improved methods for risk assessment; and socio-cultural practices.	<a href="https://www.who.int/publications/i/item/9241546824">https://www.who.int/publications/i/item/9241546824</a> (Vol. 1) <a href="https://www.who.int/publications/i/item/9241546832">https://www.who.int/publications/i/item/9241546832</a> (Vol. 2) <a href="https://www.who.int/publications/i/item/9241546840">https://www.who.int/publications/i/item/9241546840</a> (Vol. 3) <a href="https://www.who.int/publications/i/item/9241546859">https://www.who.int/publications/i/item/9241546859</a> (Vol. 4)
International Organization for Standardization (ISO)	ISO 5667 Water quality	ISO 5667 is a multi-part document that, among other contents, provides guidance on sludge sampling from wastewater treatment plants, water treatment plants and industrial processes. This standard is applicable to all types of sludge derived from the treatment and also to sludge of similar characteristics, such as septic tanks. It also provides guidance on the design of sampling programs and techniques for sample collection.  Part 10: Guide to Wastewater Sampling (2020) Part 13: Guide to Sludge Sampling (2011) Part 15: Guide to the Preservation and Handling of Sludge and Sediment Samples (2009)	<a href="https://www.iso.org/standard/42892.html">https://www.iso.org/standard/42892.html</a>
	ISO 16075 Guidelines for the use of treated wastewater for irrigation projects (2020-2021)	This standard aims to maximize the benefits related to the treatment and reuse of wastewater in agricultural irrigation projects and minimize the associated risks. The guidelines for the development of the project also include design, materials, construction, and performance for the following activities: restricted and unrestricted irrigation of agricultural crops; irrigation of public and private gardens and landscaped areas (sports fields, parks, cemeteries, etc.); and irrigation of individual private gardens.  Part 1 - Basis for a reuse project for irrigation Part 2 - Project development Part 3 - Components of a reuse project for irrigation Part 4 - Monitoring Part 5 - Disinfection of treated wastewater and equivalent treatments	<a href="https://www.iso.org/standard/73482.html">https://www.iso.org/standard/73482.html</a> (Part 1) <a href="https://www.iso.org/standard/73483.html">https://www.iso.org/standard/73483.html</a> (Part 2) <a href="https://www.iso.org/standard/73484.html">https://www.iso.org/standard/73484.html</a> (Part 3) <a href="https://www.iso.org/standard/73485.html">https://www.iso.org/standard/73485.html</a> (Part 4) <a href="https://www.iso.org/standard/72929.html">https://www.iso.org/standard/72929.html</a> (Part 5)
	ISO 20469 Guidelines for water quality grade classification for water reuse (2018)	ISO 20469 published in 2018 provides guidelines for water quality grade classification to help users determine the suitability and quality of recovered water for safe non-potable reuse applications, based on exposure level. The objective is to allow the	<a href="https://www.iso.org/standard/68138.html">https://www.iso.org/standard/68138.html</a>

International organization that generates the guide	Guide name	Notes on the content	Web Link
		identification of the degree of water quality at the point of use.	
U.S. Environmental Protection Agency (EPA)	EPA/600/R-12/618 (2012) Guidelines for Water Reuse	In 1980, the EPA published the first edition of the "Guidelines for Water Reuse," which was updated in 1992, 2004, and most recently in 2012. This latest edition offered new information and more detail about a wide range of reuse applications and introduces new concepts. and treatment technologies that support water reuse operations.	<a href="https://www.epa.gov/sites/default/files/2019-08/documents/2012-guidelines-water-reuse.pdf">https://www.epa.gov/sites/default/files/2019-08/documents/2012-guidelines-water-reuse.pdf</a>

Local health authorities are responsible for setting water quality threshold values based on authorised uses and are also responsible to define protection measures for health and the environment based local specificities.

From the agronomic perspective, the main limitation in the use of treated wastewater for irrigation arises from its quality. Treated wastewater, unlike water supplied for domestic and industrial use, contains higher concentrations of suspended and dissolved inorganic materials (total soluble salts, sodium, chloride, boron and, potentially, heavy metals), which can damage soil and irrigated crops. Dissolved salts are not removed by conventional wastewater treatment technologies, and it is intended that good management, agronomic and irrigation practices are used to avoid or minimize possible negative impacts.<sup>6</sup>

## Multi-barrier approach

In relation to biological risks, a series of actions or activities (barriers) can be implemented to prevent, eliminate, or reduce risks to an acceptable level. Each barrier reduces the number of pathogens along a route considerably. A multi-barrier approach is recommended, i.e., the use of more than one control measure against hazards.<sup>7</sup>

Treatment systems and agricultural practices provide several controls throughout the process to reduce risks to human health. In systems where the waste product is used, e.g. in agriculture or aquaculture, it is useful to understand the routes of exposure and transmission to get an idea of the effectiveness of control measures. For example, if a control measure is impractical, very costly, or socially unacceptable, it will influence its effectiveness even if it were technically effective.

The following table presents some examples of barriers:

Table2: Multi-barrier approach

Barrier type	Examples
Wastewater treatment	<ul style="list-style-type: none"> <li>Physical sedimentation (e.g., sedimentation tank)</li> <li>Biological treatment process (e.g., activated sludge)</li> <li>Adsorption (e.g., in in constructed wetlands)</li> <li>Biological inactivation (e.g., composting)</li> <li>Chemical inactivation (e.g., use of chlorine)</li> <li>Ultraviolet radiation</li> </ul>

<sup>6</sup> ISO 16075. Guidelines for treated wastewater use for irrigation projects (2020-2021).

<sup>7</sup> Sanitation Safety Planning: Manual for the Safe Use and Disposal of Wastewater, Grey Water and Excreta, World Health Organization, 2016.

Agricultural practices and application of treated water	<ul style="list-style-type: none"> <li>• Crop selection</li> <li>• Type of irrigation</li> <li>• Retention times</li> <li>• Control of hosts and intermediate vectors</li> </ul>
Other protective measures	<ul style="list-style-type: none"> <li>• Use of personal protective equipment</li> <li>• Restricted access to treatment or use sites</li> <li>• Disinfection, washing and cooking of products</li> </ul>

Behavioral controls are often applied in combination with treatment and untreated barriers. Behavioral practices depend on individual values and preferences (e.g., fears, phobias, habits), limitations (e.g., cost, time, interest), sense of responsibility, and sociocultural perceptions and practices and can be reinforced by promoting health and hygiene.

### Guideline 3: Determine the costs and benefits of treatment-reuse and ensure financial sustainability of service provision

#### Cost-benefit analysis

Any treatment and reuse system generates costs, but at the same time it can generate a series of benefits. To ensure the financial sustainability of any system, it is very important to perform a cost-benefit analysis using financial modeling tools.

A cost-benefit analysis is usually performed from the perspective of the economy as a whole and not only compares costs of the various potential solutions, but also recognizes and assigns value to the benefits generated by each alternative.

Conceptually, a cost-benefit analysis would produce a single indicator of the net value of each alternative investment for the economy and recognizes that the benefits are not only those perceived by the households and companies that benefit from wastewater treatment or reuse, but also those that can affect productive activity in other sectors, the well-being of neighboring communities and the economic and natural environment. To produce a single indicator to compare the net worth of each solution, a cost-benefit analysis not only requires the identification and measurement of the expected sanitation, productive, urban and environmental costs and benefits; it also requires that each of them be valued. These requirements present significant challenges while performing a complete cost-benefit analysis and, therefore, this type of economic analysis will normally be carried out in projects at the city, municipality or regional level. However, for any size of project it is important to perform at least one financial analysis that considers all cash flows. To achieve this purpose, two methodologies are used: The Net Present Value (NPV) and the Equivalent Annual Cost (CAE).

The calculation of the NPV allows to compare the present value of a series of future flows (income and expenses) of one or more projects or alternatives. When the NPV is positive ( $NPV > 0$ ), it is understood that the project is profitable and that the revenues (benefits) outweigh the costs. The NPV is widely used in the sector for project evaluation and is very useful from the investor's perspective; however, there is another methodology that is more practical from the perspective of the project owner or the service provider because it expresses all the costs and financial benefits of the system in terms of *annual* money flows. The methodology is called Annual Equivalent Cost (AEC).<sup>8</sup>

AEC calculation includes all construction costs (infrastructure and equipment components). These costs are called CAPEX (*capital expenditures*). Additionally, all operating, and maintenance costs are considered both in the short and long term (labor, spare parts, energy, supplies, rents, etc.). These costs are called OPEX (*operational expenditures*).

<sup>8</sup> Heredia et. Al. Evaluation of the equivalent annual cost of the wastewater treatment plants of the municipalities of Cliza and Tolata, 2020. <https://www.researchgate.net/profile/Gustavo-Heredia-3>

AEC analysis considers the investment cost of each component of the infrastructure, its useful life in years and an annual discount rate equal to the cost of capital including inflation in such a way that an annualized cost is determined per component and for the entire system. In parallel, the annual costs of all operation and maintenance activities are determined.

Similarly, the costs of reuse-related components such as piping systems, treated water storage, drip systems, etc. can be analyzed.

Once the annual cost (EAC) has been determined, mechanisms must be planned to ensure that all costs can be covered. Normally, the following are considered sources of income to cover costs: Fees, transfers/subsidies, taxes and income from the sale of products and services as can be seen in the following illustration.

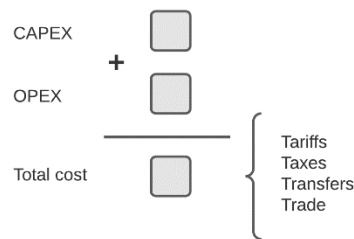


Figure 5: Annualized treatment-reuse costs and possible income sources to cover them

When providing sanitation services (both public and private utilities) typically charge a fee to their users. This is a regular cash flow that can fully or partially cover costs. In case the costs are not covered by this source, there can be other sources of income such as taxes or transfers from other government levels (especially for public or state-owned operations). Private systems (e.g., hotels, resorts, condominiums) will typically cover costs with revenue of their own. Finally, when resources recovered from treatment (e.g., irrigation water, sludge, nutrients, or energy) are sold or traded, additional revenue can be generated. This revenue can generate profits or in other cases partially cover costs, resulting in cost savings for the system owner.

Annex 2 presents a concrete example illustrating how the AEC of a wastewater treatment facility can be calculated.

## Case study: Wastewater treatment and reuse benefits (Comparative analysis of a linear approach to water management vs. a circular approach)

Below is a specific case of wastewater treatment with reuse approach implemented in Cochabamba – Bolivia between 2015 and 2021.

### Context

The "Valle Alto" region of the department of Cochabamba in Bolivia is a region with a tradition of agricultural productive activity, especially corn, fodder, and peach production. The area is relatively dry, receiving an annual rainfall of only 490 mm/year. The rainy season is concentrated in a few months of the year (November – February), and with almost no rainfall during the rest of the year. To avoid depending on rainfall exclusively, many farmers in the area have drilled deep wells (50-120 meters) and extract water for irrigation using pumps. These boreholes are also the source of the region's main drinking water systems.

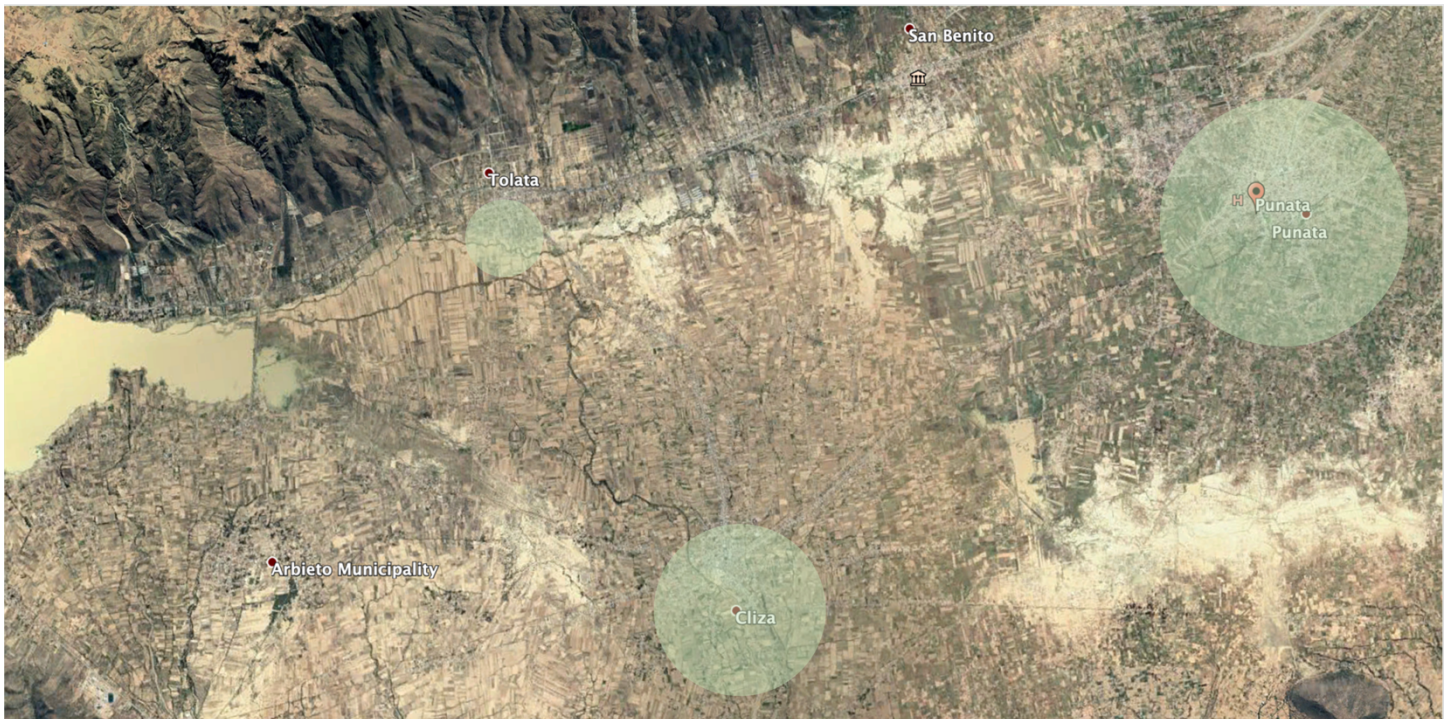


Figure 6: Geographical location of the municipalities of Cliza, Tolata and Punata in Cochabamba - Bolivia

The project called "Sustainable Water and Sanitation Systems" funded by the Embassy of Sweden in Bolivia and the Aguatuya Foundation, initially focused on three municipalities in this region: Punata, Cliza and Tolata. These three municipalities have municipal water and sanitation systems (piped water distribution systems as well as piped sewer networks). However, in none of the three cases was wastewater being treated appropriately). The following table summarizes the initial situation of the project:

Table 3: Project sizing information

Name of the municipality	Population to be served in urban center [inhabitants]	Generated wastewater flow [ $\text{m}^3/\text{year}$ ]	Treatment plant area [ $\text{m}^2$ ]	Investment in treatment infrastructure [USD]
Cliza	10.000	207.300	8.000	533.963
Punata	26.600	924.700	48.804	1.191.809
Tolata	5.000	118.900	2.930	257.694
<b>Total</b>	<b>35.000</b>	<b>1.250.900</b>	<b>60.930</b>	<b>1.983.466</b>

## Wastewater treatment systems with reuse approach

Wastewater treatment plants have been implemented in all three municipalities. In the case of Cliza and Tolata, new plants were implemented because there was no existing plant. In the case of Punata, an existing plant (based on stabilization ponds) that was not operational has been recovered, expanded, and improved.

The following is the treatment train used at the Tolata plant as an example:

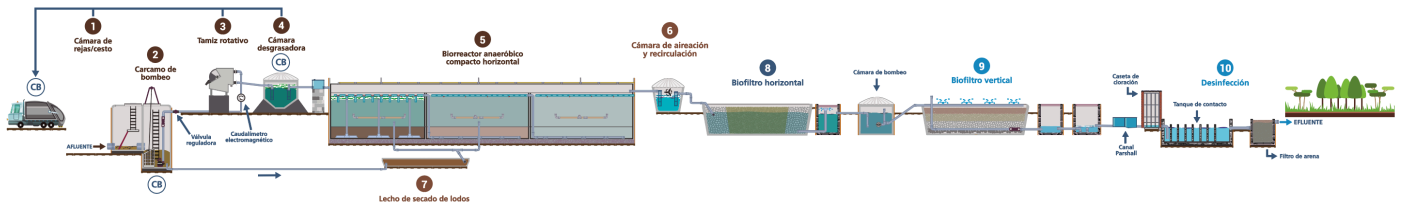


Figure 7: Tolata Wastewater Treatment Plant Treatment Train

In any treatment train, it is important to ensure effective preliminary treatment (pre-treatment). In this case, an automated rotary sieve (item 3 of the diagram) has been used to separate any solid greater than 3mm in diameter. This ensures that only wastewater enters the treatment plant and prevents the entry of solid waste or garbage that could reach the plant along with sewer water.

To reduce energy consumption to a minimum, anaerobic reactors have been implemented in all plants. This type of reactors do not require energy for their operation because they do not need aeration. Compartmentalized anaerobic reactors (item 5 of the diagram) have BOD and COD removal efficiencies of between 50% and 70%. This treatment is complemented in the Cliza and Tolata plants by gravel filters, both horizontal and vertical (items 8 and 9 of the diagram). In the case of the Punata plant, the primary treatment has been followed by a pond system waterproofed with polyethylene geomembrane. Considering both primary and secondary treatment, the total performance of the plants meets local regulations for discharge of treated effluents. The overall COD efficiency is 92%, SS is 98%, NH<sub>3</sub>-N is 49%, and P is 31%. It is evident that, with appropriate technologies like these, high removal efficiencies for organic load and suspended solids can be achieved. The removal efficiencies for nitrogen and phosphorus (nutrients) are significantly lower. Since the destination of treated water is agricultural irrigation, the presence of these nutrients in effluent is desirable because they become fertilizer for crops. At the same time, the sludge that is periodically extracted from the anaerobic reactors is dried in the sun, and becomes a soil improver for agricultural land. Finally, in the case of the Tolata plant, a chlorination system has been implemented that can be used for reuse in the irrigation of vegetables that are consumed raw (unrestricted irrigation). The plants of Cliza and Punata do not have a disinfection system, so reuse for irrigation is limited to high-stemmed crops or fodder, such as corn and alfalfa (restricted irrigation).

In case the final disposal of the treated water is in a body of water sensitive to eutrophication, such as a lake, the treatment should be done to a higher level, since the concentrations of N and P of the effluent should be further reduced before discharge. This involves more sophisticated and expensive processes such as aeration, nitrification and denitrification. Therefore, the benefit of carrying out the treatment of water at the reuse level (discharge to the soil for irrigation) presents a double benefit: On one hand, it allows the recovery of water and nutrients for crop irrigation and, on the other hand, it reduces the total costs of treatment systems. In fact, it is the soil and plants that finish the work of water purification.

## Benefits of the reuse approach (circular model)

The following illustration compares two different approaches to wastewater management. At the top of the diagram, you can see the problem of untreated wastewater that ends up polluting water bodies. This is the initial scenario for the three municipalities in this case study. This scenario, corresponds to a linear "use and discard" approach that entails the following consequences:

1. For the irrigation of their crops, farmers depend on rain (which is scarce and with variable and unpredictable times) or water from deep wells at a high cost due to the cost of pumping.
2. To fertilize their crops, farmers must import synthetic fertilizers.
3. The urban center pumps water from deep wells for distribution as drinking water, contaminates while using it for domestic purposes and, finally and discharges wastewater into a river without any treatment.

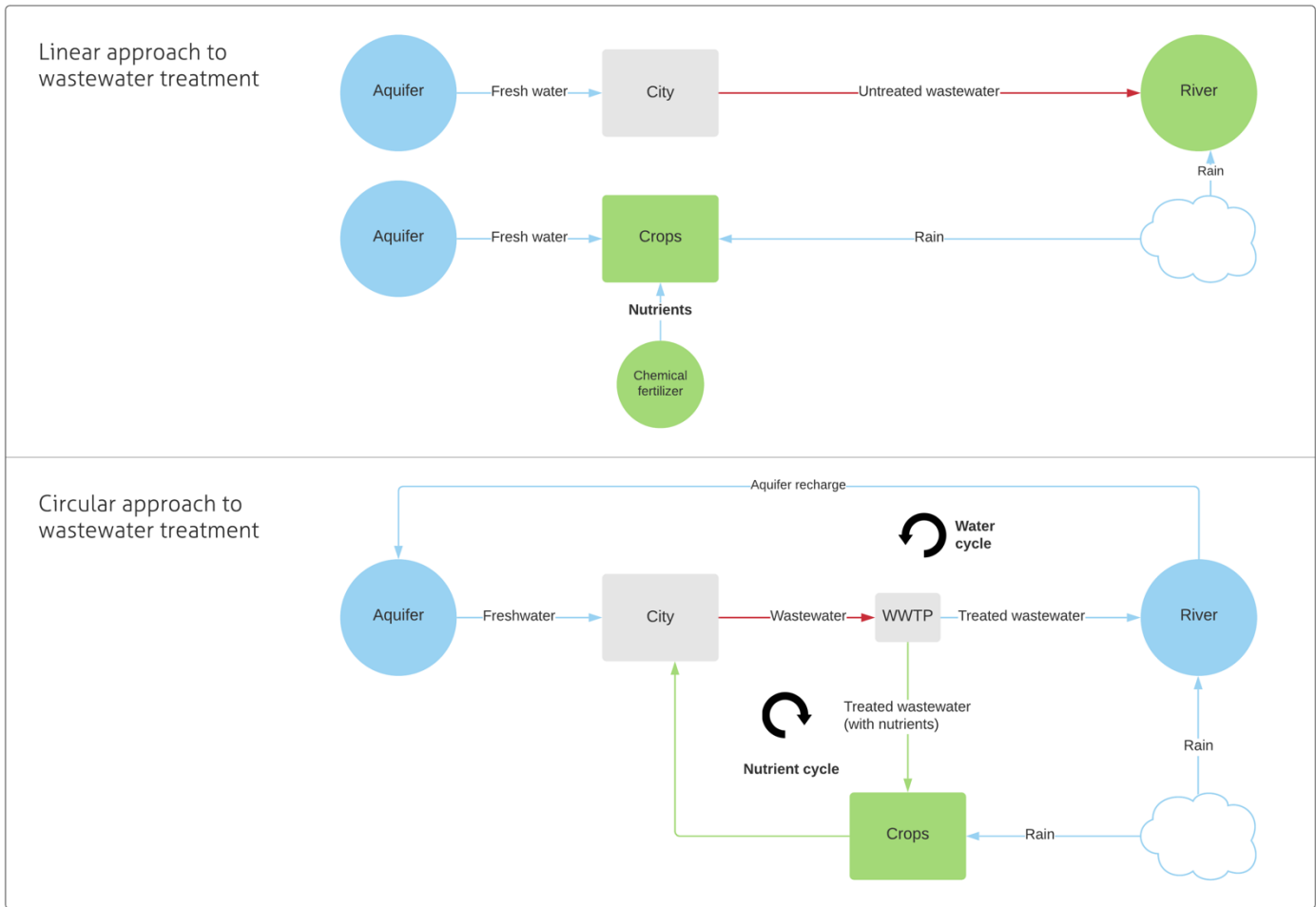


Figure 8: Comparison between a linear (use – dispose) approach in which wastewater is a problem and a circular approach in which waste becomes resources

When wastewater treatment systems are implemented **with a reuse approach**, we have a circular model (resource recovery). Under this second scenario, the current situation of the three municipalities studied, the following positive impacts can be observed:

1. Thanks to the implementation of treatment plants, the rivers are no longer polluted.
2. By having treated wastewater for crop irrigation, farmers obtain a double benefit:
  - a. They have a constant supply of water (all year round). In the case of the municipalities studied, farmers were able to obtain two harvests a year instead of one, practically doubling their production.
  - b. Partial or total savings in fertilizer costs since irrigation water has a certain concentration of nutrients.
3. Both the water cycle and the nutrient cycle are closed in an appropriate and sustainable way since the water returns to the environment after treatment and the nutrients return to the soil where they are used by the plants.

In the following table, some benefits generated by the implementation of a wastewater treatment system with a re-use approach are presented:

Table 4: Benefits generated by reuse approach

Parameter/indicator	Linear approach	Circular approach	Difference	Δ%
Organic load discharged to the river [Kg BOD/year]	241. 000	6. 000	-235. 000	-97%
Suspended solids from wastewater ending up in the river [Kg SS/year]	167. 000	6. 000	-161. 000	-97%
Nutrients N discharged into the river [Kg BOD/year]	37,000	14. 000	-23. 000	-62%
Nutrients P discharged into the river [Kg BOD/year]	5. 000	2. 000	-3. 000	-57%
Groundwater exploitation for irrigation [m <sup>3</sup> /year]	296. 000	0	-296. 000	
Imports of fertilizers (N and P) [Kg/year]	12. 000	0	-12. 000	

In this case, the last two benefits (reduction of groundwater exploitation and reduction in fertilizer imports respectively) can be easily quantified as shown in Table 5:

Table5: Quantification of benefits

Benefit	Amount avoided	Unit cost	Total savings USD/year
Groundwater exploitation for irrigation [m <sup>3</sup> /year]	296.000	0,15	44. 400.00
Import of fertilisers (N and P) [Kg/year]	12.000	0,62	7,440.00
<b>Total savings in irrigation water and fertilizers</b>			<b>51.840,00</b>

As can be seen, by valuing both irrigation water and fertilizers at market value, two of the direct benefits generated by the implementation of a circular treatment-reuse model can be quantified. In this case, the benefit for farmers using the treated water for agricultural irrigation would be 51,840.00 USD/year.

## Conclusions

In this guide of good practices for the treatment and reuse of wastewater, three basic guidelines have been presented:

1. Plan from the end and use appropriate technologies
2. Properly treat wastewater and use *multi-barrier approach*
3. Implement sustainable management models, ensuring that all costs are covered

Planning a wastewater treatment system "from the end" allows us to consider opportunities for water reuse and recovery of several resources present in wastewater. This involves moving from a linear approach based on *use-and-dispose* to a more sustainable circular approach in which waste becomes resources. This circular approach can generate environmental economic benefits, such as improving both the water cycle and nutrient cycles and can also generate financial as well economic benefits when the products of treatment are valued and marketed e.g., irrigation water, fertilizers, soil improvers or energy.

The technologies used for wastewater treatment must be appropriate to the local context to work effectively and sustainably in the long term. When selecting a technology, financial aspects (costs), space availability and compatibility with available resources and environmental conditions must be considered: Access to technology and technical service, as well as the skills and capabilities necessary to operate and maintain the systems in operation.

The level of wastewater treatment must be in accordance with reuse needs and comply with local wastewater regulations. Wastewater treatment is carried out to protect the environment (water sources) and to protect people's health (reduce the risk of exposure of people to different pathogens). To achieve this goal, in the context of reuse, water can be treated at an advanced level that includes a disinfection process thus eliminating pathogens or, alternatively, a series of agricultural measures and practices can be adopted to reduce or eliminate health risks. These practices include the use of personal protection equipment by farmers and restricted irrigation systems such as reforestation, fodder irrigation, long-stem plants or crops that are cooked or processed before being consumed by the public. This is known as multi-barrier approach. Wastewater discharges may be often regulated by local governments, but sometimes, reuse activities are not. In this case, there are international guidelines on the subject (ISO, WHO and EPA) that can be very useful for designing a reuse system.

Finally, financial and environmental sustainability of the services should be of utmost concern. For this reason, it is vital to implement management models in which all actors have clear roles and responsibilities. Ownership of the infrastructure should be clearly defined. The owner of the infrastructure must ensure there is a human team capable of operating and maintaining all the components and have access to a technical service for solving technical problems, planning for improvements and expansions over time and which reports periodically on the status and efficiency of the plant. Financial sustainability occurs when the owner of the infrastructure is able to cover all costs (both capital costs – CAPEX – and operation and maintenance costs – OPEX)." These costs must be determined at the planning stage, along with the development of a *business plan* that ensures a revenue stream equal to or greater than the costs. Sources of income are normally limited to: (i) fees, (ii) transfers and subsidies, (iii) taxes and/or (iv) income from the sale of products and services. From a financial perspective, a reuse approach can generate revenue or cost reduction (savings) in time to recover and value resources such as treated water, nutrients, or energy.

## Additional resources

- CReW+ Academy: Course on wastewater treatment and reuse (Block 2)  
<https://www.academy.gefcrew.org/recurso>
- Eutrophication of water bodies and dead zones:  
<https://www.gaceta.unam.mx/zonas-muertas-en-los-oceanos-que-son-y-por-que-aumentan/>
- Paradigm shift - From waste disposal to nutrient recovery:  
<https://cdn.sei.org/wp-content/uploads/2021/06/saneamiento-gestion-de-aguas-residuales-y-sostenibilidad-2021.pdf>
- Methodology for costing a treatment/reuse system: Equivalent Annual Cost:  
<https://www.cuidatudinero.com/13074191/como-calcular-el-capital-y-los-intereses-de-un-pago-de-prestamo>
- Online tool for sanitation costing and planning at the city level:  
<http://cwiscostingtool.com>
- EAWAG/SANDEC Compendium (Spanish)  
<https://www.eawag.ch/en/departament/sandec/publications/compendium/>
- Compendium of Sanitation Technologies in Emergencies  
[https://www.eawag.ch/fileadmin/Domain1/Abteilungen/sandec/schwerpunkte/sesp/Emergencies/compendium\\_emergencies.pdf](https://www.eawag.ch/fileadmin/Domain1/Abteilungen/sandec/schwerpunkte/sesp/Emergencies/compendium_emergencies.pdf)
- Guide to Sanitation Resource-Recovery Products & Technologies: a supplement to the Compendium of Sanitation Systems and Technologies  
<https://pub.epsilon.slu.se/21284/>

## Annex 2:

### Example of calculating the Annual Equivalent Cost (CAE) of a treatment system

In the following example, we performed the CAE calculation for a wastewater treatment plant for 7,500 inhabitants, with a treatment capacity of 250,000 m<sup>3</sup>/year and considering a discount rate of 5% per year.

First, we need the investment costs of the main components of the plant and the expected useful life of each of them. As can be seen in table 3 below, the total investment of the plant is USD 488,721.00. Then, based on the investment cost of each component, the discount rate, and the service life of each component, we calculate the annualized value of each component using the following formula:

$$A = \frac{Po * i * (1 + i)^n}{(1 + i)^n - 1}$$

Where

**A** = Annualized investment rate of each component in USD

**Po** = Initial cost of each USD component

**i** = Discount tasa = 5% = 0.05

**N** = Service life of each component in years

#### Calculation of annualized CAPEX

Item	Description	Initial cost [USD] <b>(Po)</b>	Shelf life [years] <b>(n)</b>	Annualized cost [USD/year] <b>(A)</b>
1	Pumping chamber	25.287,00	20	2.029,09
2	Self-cleaning sieve, anaerobic reactor and artificial wetland	321.839,00	30	20.936,09
3	Disinfection system	21.552,00	20	1.729,39
4	Storage tank (readaptation)	4.310,00	30	280,37
5	Filling	7.184,00	30	467,33
6	Sludge drying area	5.819,00	30	378,53
7	Control booth	2.155,00	30	140,19
8	Roads and accesses	2.155,00	30	140,19
9	Perimeter fence	21.408,00	20	1.718,83
10	Electrical installations	8.621,00	20	691,77
11	Environmental mitigation measures	7.184,00	30	467,33
12	Sewerage network improvement	25.287,00	20	2.029,09
13	Sewer emissary (500m)	35.920,00	30	2.336,65
	<b>Total</b>	<b>488.721,00</b>		<b>33.343,85</b>

Table 3: Calculation of annualized CAPEX

#### Calculation of the annualized OPEX

For the calculation of the annualized OPEX, we simply have to add the annual operating costs of the main items of recurring expenses necessary to operate and maintain the plant. In case of having data on monthly, quarterly or semi-annual costs of some items, we must multiply these values by the number of periods per year to have the annual costs of each item and thus be able to total them. Table 4 below presents an example of calculating annual OPEX:

Item	Description	Cost [USD/period]	No. periods per year	Cost [USD/year]
1	Electrical energy	1.277,84	12	15334,08
2	Serene/security	574,71	12	6896,52
3	Operator	143,68	12	1724,16
4	Specialist Technician	50,29	12	603,48
5	Water quality monitoring	159,48	2	318,96
6	Maintenance of electrical equipment	359,20	3	1077,60
7	Reporting	25,14	4	100,56
8	Minor tools	215,52	2	431,04
9	Personal protective equipment and cleaning	143,68	3	431,04
10	Petrol	71,84	12	862,08
11	Drinking water service water	7,18	12	86,16
	<b>Total</b>			<b>27,865.68</b>

Through this analysis, the following results and conclusions are obtained:

R	Result	Value	Units	Interpretation/conclusions
R1	Initial investment	488.721,00	USD	This is the amount that is initially required to build the treatment plant.
R2	Annual equivalent cost of infrastructure (annualized CAPEX)	33.343,85	USD/year	It is required to have this amount every year to timely replace all the components at the end of the useful life of each of them.
R3	Annual Cost of Operation and Maintenance (Annual OPEX)	27,865.68	USD/year	This amount is required each year to cover all operation and maintenance costs.
R4	Annual Equivalent Cost (CAE) of the plant	61,209.53	USD/year	It is the sum of the annualized CAPEX (R2) plus the annual OPEX (R3)
R5	Unit cost per inhabitant/year	8,16	USD/inhabitant*year	Esto is what it costs us in total the water treatment per person per year taking into account all the costs of the plant. It is calculated by dividing the CAE of the plant (R4) by the number of inhabitants that the plant serves.
R6	Unit cost per m <sup>3</sup> of treated water	0,24	USD/m <sup>3</sup>	This is what it costs us in total to treat each m <sup>3</sup> of wastewater in the plant. It is calculated by dividing the CAE of the plant (R4) by the number of m <sup>3</sup> of wastewater that the plant processes each year.

The results (R1 to R6) of the table above are very useful in determining the costs that result from having, operating and maintaining a treatment plant. Based on these costs, financial strategies can be designed to cover them and, in this way, ensure

the financial sustainability of the service. The results R5 and R6 (cost per capita and cost per m3 respectively), are especially useful in time to design a tariff system for the service.

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