Wastewater treatment in island locations

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Keywords

Technico-economic approach, wastewater treatment, treatment processes, sustainable management, small islands, reuse, water use, value-harnessing

Acronyms

CS Collective Sanitation
NCS Non-Collective Sanitation
CAPEX Capital expenditure
PE Population equivalent
EMFAF European Maritime, Fisheries and Aquaculture Fund
SS Suspended Solids
OPEX Operating expenses
SMILO Small Islands Organisation
UASB Upflow Anaerobic Sludge Blanket

Glossary

Blackwater (sewage water):
refers solely to wastewater flushed away down toilets. It comprises faecal matter (faeces) and urine, which means this water contains disease-causing contaminants (and possibly also traces of medication).

Buffer tank (or storm tank):
tank used for temporary storage of excess wastewater entering the treatment plant (in the event of very high flow volume), with a view to sending this water to the treatment facilities later, when the influx to the plant is lower and there is capacity to receive the excess wastewater.

Collective Sanitation – CS:
refers to any collection, treatment (pollution removal) and evacuation system installed to treat the wastewater produced by a hamlet, village or town/city. The wastewater is collected via a network and conveyed to a collective treatment plant to be treated.

Discharge:
treated wastewater that leaves a treatment plant and is discharged into nature or the ground (e.g. to a river, the sea, percolating through soil, etc.).

Disinfection:
additional treatment step to destroy infectious germs (e.g. viruses or bacteria) in the water or sludge, to avoid contaminating people and the environment. There are different disinfection technologies, which may be physical (such as filtration or UV light) or chemical (e.g. chlorination). The required level of disinfection depends on the sensitivity of the receiving environment and on local activities.

Effluent:
all types of water that should be conveyed via a sewerage network to a wastewater treatment plant. An effluent may be of domestic, industrial or agri-food origin, among others. As such, effluent in an urban context is a mixture of wastewater, rainwater, infiltration/inflow, industrial water authorised for release into the wastewater treatment network, etc. It is a liquid waste that undergoes treatment to remove pollutants before it can be released into a natural environment.

Extraneous water:
water that should not be present but constantly or temporarily passes through a wastewater treatment network. The source of this water may be natural (groundwater drainage, flooding of the networks, spring tapping) or artificial (e.g. a fountain, leakage of drinking water, a swimming pool being drained, etc.). This infiltration or inflow increases the hydraulic load volume entering the wastewater treatment plant, which increases the energy used for water treatment and disrupts the plant's operation. Infiltration and inflow volumes are estimated by comparing against the volumes of water passing through the network during rainy/dry periods and by day/night. Solutions must be explored in order to reduce the infiltration and inflow entering the wastewater treatment networks.

Gravity-fed network:
sewer network whose pipes allow wastewater to flow naturally and continuously downhill to the treatment plant, with no lift stations, thanks to a suitable topography (slope of the land). The advantage of gravity-fed networks is that they work without any energy input (as there are no lift stations).

Greywater (or household / domestic wastewater):
a household's slightly polluted used water (from baths, showers, sinks, washing machines and dishwashers). Greywater does not include water from toilets (blackwater) which contains disease-causing contaminants.

Hydraulic load:
quantity of inffluent entering the treatment plant, usually expressed in m^3/day.

Lift station (or backup station):
a structure, usually equipped with lift pumps, in a network or a wastewater treatment plant. This equipment lifts the wastewater so that it can then flow onward to its destination using gravity. For example, this kind of structure is necessary when due to the slope of the land, the wastewater network lines are located below the treatment plant.

Nitrification/denitrification:
removal of nitrogen pollution requires an initial nitrification process that transforms ammoniacal nitrogen (notably produced by urine) into nitrates, thanks to the action of "autotrophic" bacteria that use oxygen and carbonates in the wastewater. The nitrates produced are less toxic nitrogen compounds, but must still be removed because some natural spaces are vulnerable to their effects; nitrates are partly responsible for the eutrophication of aquatic environments. Therefore, the denitrification process will take place in a treatment facility where carbon is present but not oxygen, where "heterotrophic" bacteria work to decompose the nitrates into nitrogen gas.

Non-Collective Sanitation – NCS (also referred to an individual/independent sanitation):
refers to any wastewater collection, treatment (pollution removal) and evacuation system installed to treat the wastewater produced by an individual dwelling. Such systems are not connected to a public wastewater collection network.

Organic load:
quantity of pollution entering the treatment plant, usually expressed in kg/day for each pollutant analysed.

Population equivalent – PE:
The definition of PE in Europe is a regulatory concept used to characterise the size of a treatment facility or of an urban area. By definition, 1 PE produces a theoretical pollution load of 60g BOD_5/d. However, the pollution generated by one resident is lower: around 40g BOD_5/d per person in small towns with no associated industrial activity (i.e. in a small village, 1 resident = 0.7 PE). The PE for summer visitors "passing through" (i.e. day visits with few overnight stays) would be even lower (for example, 1 tourist passing through = 0.05 to 0.3 PE).

As an example in France, the Circular of 22 May 1997 indicates the relationship between the number of PE and the volumes of wastewater generated for each activity type (to be adjusted to actual local conditions!):

Activity	PE equivalent	Volumes produced (litres/day)
Permanent user	0.7* to 1	80* to 150
School (boarding), military barracks, nursing home	0.7* to 1	80* to 150
School (half-board) or similar	0.5	75
School (day pupils) or similar	0.3	50
Hospital, clinic, etc. (per bed) (including care and operations staff)	3	400 to 500
Factory personnel (per 8-hour shift)	0.5	75
Personnel in offices or shops	0.5	75
Hotel with restaurant, guest house (per room)	2	300
Hotel or guest house not offering meals (per room)	1	150
Campsite	0.65* to 2	100* to 300
Occasional user (public spaces)	0.05	5 to 10

** figures produced from recent feedback gathered in France, not mentioned by the French Circular of 22 May 1997*

Population variation:
a number referring to the increase (and decrease) in a population over the course of a year, usually due to a tourist attraction. This variation is calculated as follows: population at peak tourist season (max. number of people) / permanent population (min. number of people).

Screening:
a structure that helps remove the largest pieces of debris in the wastewater, to protect the treatment equipments. The grating may be coarse (gaps measuring several centimetres) or fine (several millimetres).

Screenings:
wastes collected by the pre-treatment components (usually larger pieces retained by the grating). This debris is categorised as household waste and should be disposed of as such. Provisions must be made to double-bag this waste in strong bin bags.

Septic sludge:
sludge product removed when cleaning septic tanks (or all-water tanks) in non-collective sanitation (NCS) systems. It is a mixture of water, sludge and fatty substances, and its concentration varies widely between dwellings; the effluents are highly concentrated. The tank needs emptying from the moment the septic sludge volume is close to 50% of the tank's useful volume.

Septic tank (or all-water tank):
a closed tank sized to receive either blackwater only (septic tank) or a mixture of blackwater and greywater (all-water tank). This tank provides the pre-treatment stage in non-collective sanitation (NCS) systems, where solid matter and floating waste particles are retained, and where particulate matter is partially liquefied by anaerobic digestion. Subsequently, liquid is discharged from the tank as a continuous flow to the drainage field (e.g. via gravel pack filtration) while the sludge (septic sludge) is removed regularly for processing in a treatment plant.

Sub-products of wastewater treatment:
the waste generated by collecting and treating wastewater. It mainly consists of tank sludge and screenings (pretreatment). It may also refer to the sand, fatty or oily waste removed when specific systems are set up on the network or treatment plant.

Unconventional water resources:
rainwater, reused treated wastewater or desalinated seawater. This is as opposed to "conventional" water resources, i.e. from lakes, rivers or groundwater.

Wastewater (or residual water):
see **Effluent**.

Wastewater sludge:
the main sub-products generated by a collective treatment plant; they comprise septic sludge stored in a septic tank upstream of a treatment process. There are several different kinds of sludge: more or less dry; paste or liquid; solid; high in organic matter; or somewhat mineral or fermentable, etc. See also **Sub-products of wastewater treatment**.

Wastewater treatment:
all the systems involved in collecting and treating wastewater (pollution removal) and evacuating it into a natural environment.

Wastewater treatment system:
all the means of collecting, transporting (lift stations and networks) and treating (in treatment plant(s)) wastewater, before it is discharged.

01 Introduction

SMILO (Small Islands Organisation) is an association that supports small islands (with a surface area of less than 150 km²) in preserving their environment. It focuses its efforts on sustainable solutions in the fields of water and sanitation, waste, energy, biodiversity, landscapes and heritage. It drives activities for an international community of small islands, to boost their skills and facilitate the exchange of ideas for concrete, innovative solutions.

SMILO coordinates the "Lérins Islands Marine Habitat Improvement and Sustainable Island Strategy Development" project, financed by the European Maritime, Fisheries and Aquaculture Fund (EMFAF). In this capacity SMILO is supporting Saint-Honorat Island (France) to improve its wastewater treatment.

SMILO has created a group of experts in small island sanitation, to guide and direct the managers of small islands towards improved wastewater treatment. This technical guide has been produced through the work of the expert group.

Why treat wastewater on small islands?

Untreated wastewater is routinely discharged into the oceans from small islands that lack a suitable system for treating wastewater. This wastewater is often contaminated with pathogens, chemical pollutants, phytosanitary (= plant-protecting) products, fertilisers and other hydrocarbons or spent oils. This creates negative impacts, not only for the health of residents but also on the freshwater and marine environments. It would be advisable to reduce these impacts by setting up facilities to treat the wastewater, in order to remove the pollutants before either reusing the treated water or discharging it into nature.

Wastewater treatment in island locations faces many constraints: confined space; limited financial and technical resources; dependence on other territories for both incoming supplies and final disposal of sub-products (e.g. importing materials, exporting waste). These criteria are all the more significant for small islands not connected to the mainland.

Objectives of the guide

Ce guide s'intéresse principalement aux petites îles (< 150 km2) non raccordées au continent, qui font face à des enjeux énergétiques et de gestion de la ressource en eau.

This guide chiefly focuses on small islands (< 150 km²) that are not connected to the mainland and face challenges in energy provision and water resource management.
This guide is intended for managers of small islands who want to reduce the impact of wastewater on their environment by introducing suitable sanitation. It offers simple, practical recommendations to guide their choices in relation to sanitation systems. Although the recommendations are mainly aimed at construction of new treatment networks and plants, they are also relevant for upgrading old sites.

The guide aims to show that wastewater treatment has a major role to play in maintaining human activity and water use in a way that respects the often-sensitive environment of island locations. In addition, wastewater treatment produces some useful, even essential resources to harness for use on the island; the approaches of treated wastewater reuse (TWWR) and returning organic matter to the soil (sludge management) both align with circular economy principles.

Les critères décisionnels majeurs dépendent des contraintes propres à chaque territoire. Le coût des projets ne doit pas constituer le seul élément décisionnel, c'est pourquoi une approche technico-économique est proposée.

Methodology

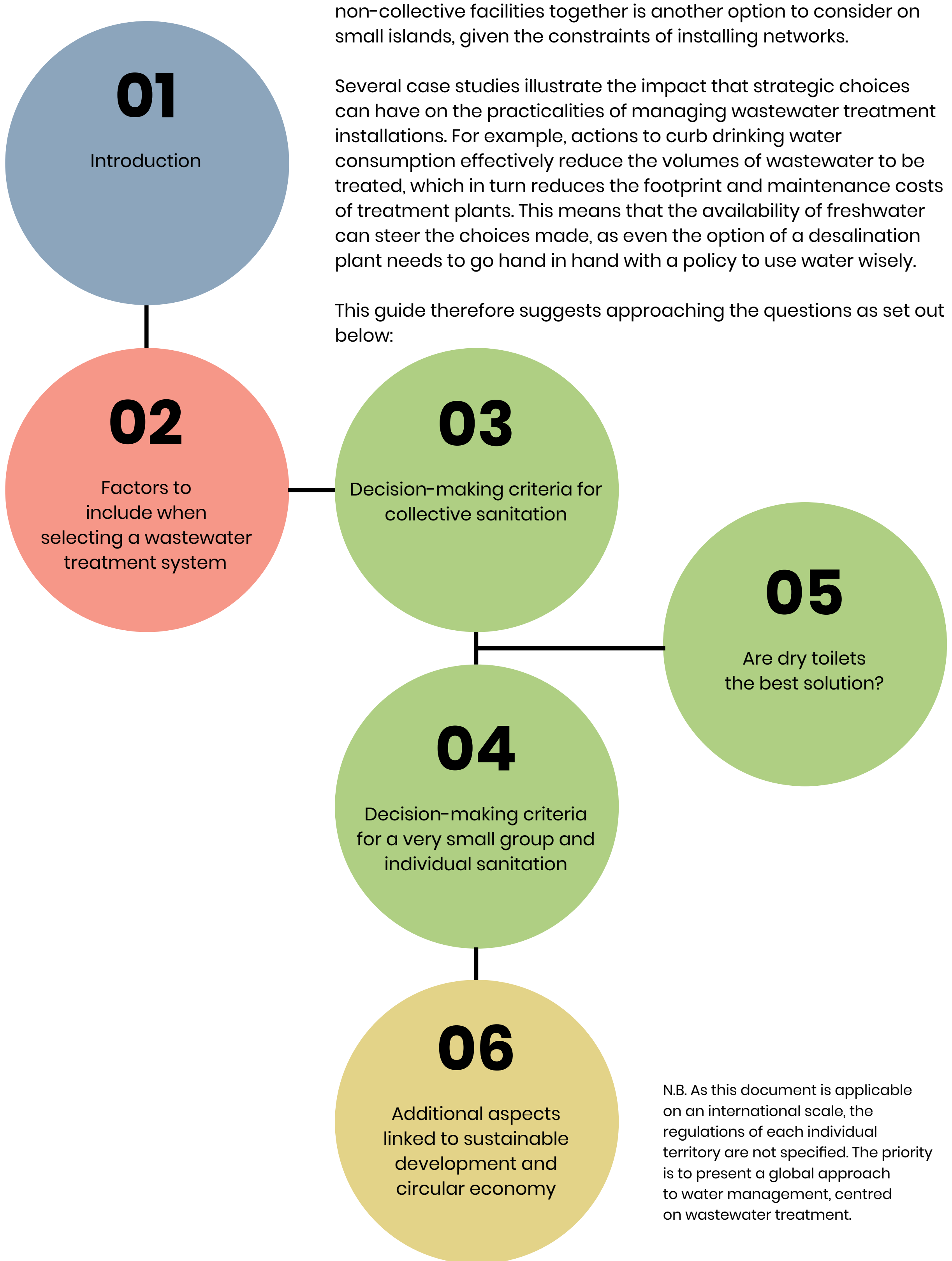
A significant challenge is posed by the multiplicity and diversity of constraints affecting each island: the size of the island and available space, the distance from the mainland, water and energy resources... so many criteria which can make it difficult to choose a suitable, sustainable process. This guide helps users to identify particular features of an island territory that can impact on this choice, and devise solutions that reconcile the needs with local activities.
This guide also provides support for making decisions about wastewater treatment for collective or non-collective sanitation.

The key criteria for decision-making depend on the specific constraints of each territory. The cost of projects should not be the only factor in decision-making, which is why a technico-economic approach is proposed.

At the heart of the debate is the issue of whether to have a number of separate treatment facilities or to centralise them. Grouping non-collective facilities together is another option to consider on small islands, given the constraints of installing networks.

Several case studies illustrate the impact that strategic choices can have on the practicalities of managing wastewater treatment installations. For example, actions to curb drinking water consumption effectively reduce the volumes of wastewater to be treated, which in turn reduces the footprint and maintenance costs of treatment plants. This means that the availability of freshwater can steer the choices made, as even the option of a desalination plant needs to go hand in hand with a policy to use water wisely.

This guide therefore suggests approaching the questions as set out below:



N.B. As this document is applicable on an international scale, the regulations of each individual territory are not specified. The priority is to present a global approach to water management, centred on wastewater treatment.

02 Factors to Include When Selecting a Wastewater Treatment Facility

2.1 First of all: know what's there already!

The first stage of any project relating to water and sanitation is to conduct a full review of existing infrastructure. The following will always need to be considered:

- Drinking water extraction and treatment sites;
- Existing networks: the condition of pipes, lengths, installed equipment, connection points, lift stations… and areas not connected to certain networks;
- The structures used for storing and/or treating wastewater: processes, capacities, performance;
- Points of discharge into the natural environment;
- The different types of space: unspoilt nature, urbanised, protected, etc.

Field surveys are essential, and they also yield information on whether certain households or neighbourhoods have already invested in wastewater treatment techniques.

Having **excellent knowledge of the land area** guarantees optimal input to the rationale for creating or reviewing wastewater treatment zones.

2.2 Island-specific features to consider before creating a project

To identify the way forward for an island-based sanitation project, the key aspects to examine are listed below, in the light of feedback from known cases. They provide the starting point for thinking about a project **at the outset, asking the essential questions**:

High importance

- What are the **risks for the local environment**? Be aware of the sensitivity of marine, scenic and other land-based areas. What would be the **impact of discharged water on local activities** (e.g. bathing, shellfish cultivation)?
- **Population variation**: be familiar with the seasonality, frequency and scale of the annual variation. Wastewater treatment installations will have to be able to process the entire volume of used water, all year round.
- **Sludge**:
  - what options does the island offer for storing, utilising or evacuating sludge?
  - is it necessary to consider a specific method of tackling odours? Study the prevailing winds.
- **Tourism appeal** of the site: is it of interest from a tourism or leisure perspective? Consider **integration into the landscape**: appearance of the structures, ease of access, a site enclosure made from or covered with greenery, etc. Landscape protection: are there restrictions relating to visible built structures?
- **Careful use of energy**: electrical power available?
- **Equipment transport** and logistics: are the extra import-related costs acceptable?
- Is there much **land** available?
- **Proximity to dwellings**: research the project's acceptability among local residents (regarding appearance in the landscape, management of odours and noise), and particularly for seasonal rental properties. Is there a land use map providing information on the distribution of dwellings?
- **Population habits**: water volumes used, type of access to wastewater treatment, financially willing/able to pay a usage fee?
- **Wastewater treatment service**: already present, or must it be created?

Lower importance

- **Availability** of concrete and other **materials for construction and earthworks**: could there be a short circuit for supply on the island, or will goods have to be imported?
- **Island topography and thin ground**: this brings severe geotechnical constraints with regard to buried equipments (sewer networks, lift stations, wastewater treatment plants).
- Seawater intrusion into the network: what will be the **salinity level of effluent** to be treated? Impact of this on potential treatment processes?
- Be aware of the **timescales** to bring a project to fruition on the island, including acceptance by the population.
- Depending on the treatment processes, it may be necessary to bring in a **drinking water** supply. Might there be aquifers for pumping drinking water?
- What kind of on-site workforce is available to manage and maintain the wastewater treatment system?

GOOD PRACTICE

No drinking water resource: what are the solutions?

Chausey Island (north-western France, 0.7 km²) opted to continue having a tanker supply its water, to stimulate actions to use drinking water wisely. This choice has been advantageous in three ways:

- It limits the quantity of wastewater to be treated, which in turn reduces the footprint and maintenance costs of the treatment plant;
- It ensures security of the drinking-water supply;
- It promotes the use of unconventional water resources (rainwater, treated wastewater reuse).

This supply approach has a very low environmental impact, because the boat bringing the water tanker performs double duty by transporting passengers.

Today, Chausey's public officials are seeking solutions to enable the island to be fully autonomous in terms of its drinking water supply.

Photo: Roger Estève, Nosy Hara, Madagascar

GOOD PRACTICE

Self-sufficient sites: what are the alternative and circular solutions?

On the island of Tinos (a Greek island in the Cyclades archipelago, pop. approx. 8,500), some isolated sites are not connected to any network: water, wastewater treatment or electricity. The Tinos Eco-lodge is one such property; it comprises several cottages, can sleep 13 and has two permanent residents. The only energy used comes from the sun.

The site's freshwater requirements are met partly by rainwater collection (for domestic use and irrigation) – in tanks that blend well against the landscape and can collect around 175 m3 of rain in a year (collection surface area around 500 m²; tanks with capacity 175 m³) – and partly by reusing treated greywater to irrigate certain crops grown on the site (about 50 m³/year).

The wastewater (greywater) is cleaned by a constructed wetland of vertical-flow reed beds covering 27 m²; UV disinfection is also applied. The system provides enough water to irrigate a 2,600 m² garden, producing 900 kg of vegetables a year; these are eaten by guests and staff, and sold locally. One of the cottages has dry toilets, while the others have toilets fitted with a urine/faeces separator. Solid waste is used to produce compost, in a mixture with garden waste.

Dry toilets

Constructed wetland and rainwater tanks under construction

Constructed wetland operational

2.3 Finding a balance between centralised/decentralised collective sanitation and individual/group non-collective sanitation

cs

A "collective" sanitation system (CS) usually corresponds to the "centralised" model: a network collects the wastewater produced by a group of dwellings in a single township with at least 20 residents (the threshold and definition vary in different countries), and conveys it to a single treatment plant. The system generally forms part of public services. Collective sanitation can also be "decentralised", as soon as there are several treatment plants serving one urban area.

ncs

By contrast, "non-collective" sanitation (NCS) is included in the "decentralised" model, and implies the presence of multiple treatment facilities handling wastewater from individual or grouped dwellings. This generally involves stand-alone wastewater treatment systems that are part of the private domain.

For any wastewater treatment project in an island context, it is necessary to decide whether to send effluents to a single wastewater treatment plant (centralised model) or build multiple structures (decentralised model).

Creating the pipelines that form a network is actually a very high-cost operation requiring specific equipment. On islands with thin ground and outcrops of bedrock, severe geotechnical constraints may be encountered when digging the ground to lay networks. The longer the pipes, the greater the risk of seawater intrusion or the formation of hydrogen sulphide (H_2S; see **Appendix 1**) on islands with a hot climate and high seasonal variation in the population. Furthermore, seismic activity on certain islands can cause problems and damage the network. Lastly, with multiple treatment facilities the quality of maintenance and of the resulting water may vary, with consequences for the natural environment.

Figure 1 summarises the advantages and drawbacks of centralised ("1 network + 1 treatment plant") versus decentralised ("several networks + treatment plants", including NCS) configurations. These basic details are essential for comparing the two options, bearing in mind the particular features of your island.

Figure 1.

Advantages and drawbacks of centralisation versus decentralisation of a wastewater treatment systemd

	Advantages	Drawbacks
Centralised sanitation	+ Only one treatment facility operating + Centralised management of the sludge produced + The cost-benefit analysis of treated wastewater reuse (TWWR) may be favourable for activities requiring large volumes and located near the treatment plant	× Need to create and operate long network lines, sometimes requiring water lift stations (which consume energy) × Pollution is concentrated in a single location on the island × Risk of producing H_2S (and problem odours) with long networks, and in the summer (see **Appendix 1**) × It might be tricky to find a suitable discharge point (due to activities that would be affected, and/or large water volumes) × Fees would need to be collected from the various users
Decentralised sanitation	**Small collective or group NCS** + Shorter lines in the network to be operated + Lower risk of infiltration and inflow + Small flow rates + Generally easier to find a local discharge point	× More structures to operate; these need to be managed by an authorised public body and a qualified operator × A particular footprint would need to be available for each potential treatment plant site × Care must be taken to ensure the system can be adjusted for intermittency (seasonal residences) × Many opportunities for TWWR
	NCS + No network to operate + Small flow rates, which accommodate infiltration if the ground and subsurface characteristics allow (presence of a water table) + The dwelling owner pays the installation and maintenance costs	× Septic sludge produced has to be removed and dealt with × Deployment constraints: an individual system must be underground (in compatible soil), except for constructed wetlands that utilise plants. × Care must be taken to ensure the system can be adjusted for intermittency (seasonal residences)

There is also a need to study a “hybrid” operating approach, between centralisation and decentralisation. For example, creating individual septic tanks (NCS), with septic sludge pumped out and transferred regularly to a dedicated treatment plant, would not require long network lines and would reduce the need for lift pumps if the topography does not enable gravity-driven flow to the plant. For this scenario, the option of septic tank servicing trucks should be explored in the early stages of the project.

2.4 Key criteria for decision-making

To help guide choices, here are the criteria to consider:

National and local regulations

Exchanges with government services are of great importance, at all stages of projects. They relate to construction permits, coastal protection laws, national and local regulations on environmental protection, requirements linked to human activity, local activities, etc.

Number of inhabitants (capacity)

The applicable law usually depends on the capacity of the treatment plant.

Environmental management of by-products

Any water purification procedure creates sub-products, particularly sludge, which must be treated and utilised locally as far as possible, or otherwise disposed of. Having a plan for managing sludges is an essential prerequisite in developing an island’s wastewater treatment!

Integration into the landscape

Structures must blend in as much as possible to preserve the character of the island landscape. Preference should be given to treatment processes that are underground and/or involve using vegetation.

Operation and maintenance

There are many advantages to using ease-of-use and low-maintenance options: low operating costs, less training of personnel, easy maintenance if repairs are needed, and so on.

Energy consumption

Low-energy processes are to be promoted, and will ensure simple operation and low associated costs.

Carbon footprint of processes

Transportation of construction equipment and materials, mostly from the mainland, has high associated financial and environmental costs.

Value-harnessing opportunities

A circular economy loop, to harness the value of the sludge (e.g. for composting, anaerobic digestion) and/or treated wastewater (reuse), should be examined in the context of local requirements.

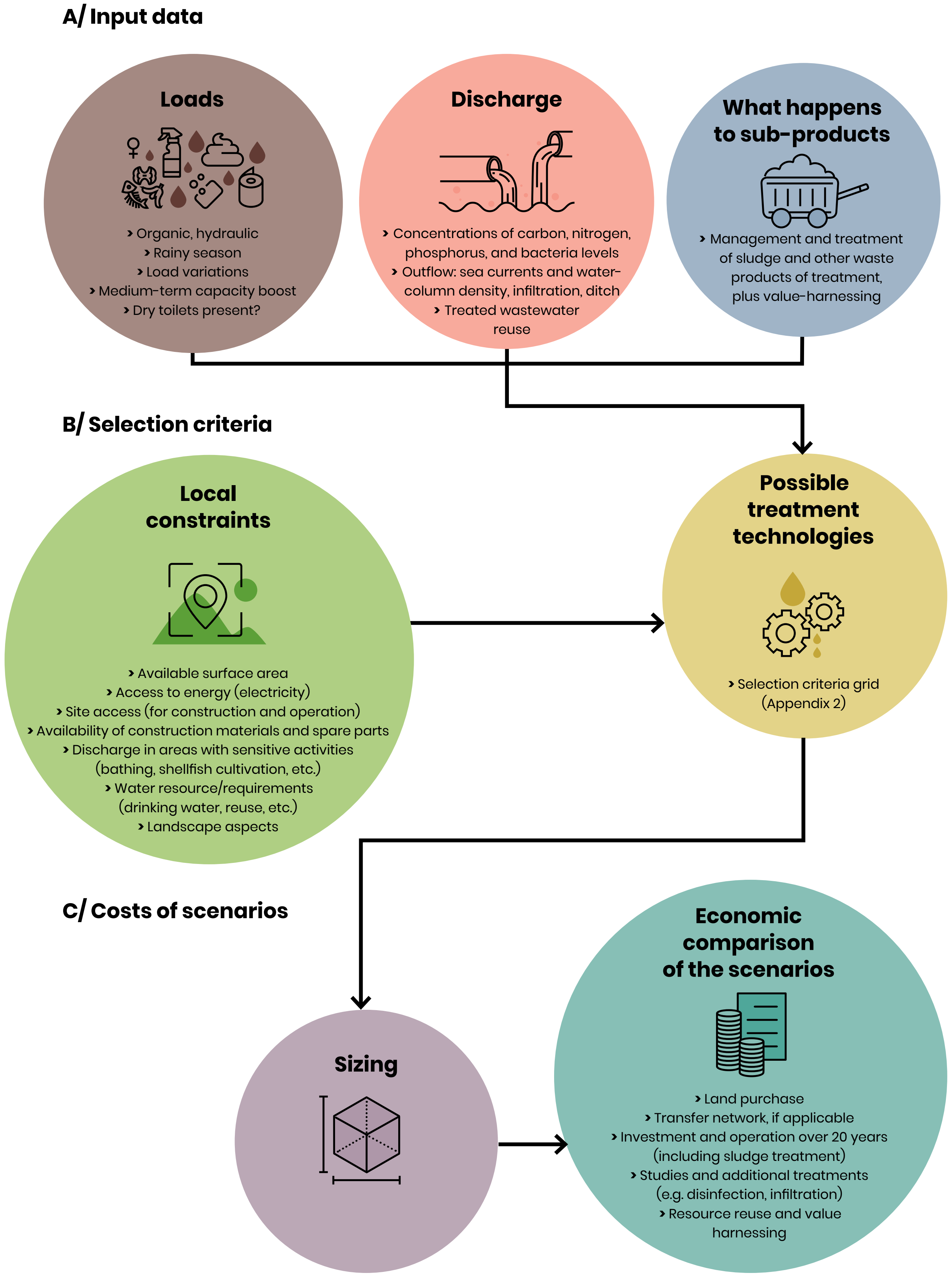
03 Decision-making criteria for collective sanitation

3.1 General methodology for process selection

To guide decision-makers towards the treatment processes best suited to a given territory, Figure 2 presents a decision-making assistance chart. Section 3.2 provides more detail on each criterion.

Figure 2.

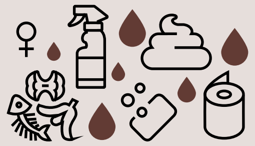
Methodology for specifying a collective sanitation project in a remote island location



3.2 Description of the choice criteria

The items in the above chart (Figure 2) will now be explained in detail:

A/ Input data



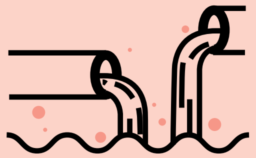
Pollutant loads to be treated

Since small islands usually offer a key tourist attraction, their populations tend to vary significantly over the course of a year. Population changes may occur on a year-long scale (summer *vs.* winter) or within a single week (weekdays *vs.* weekend). **Before planning any wastewater treatment project, it is essential to know the accurate numbers of permanent residents and peak-season visitors (scale of the load variation)**. In fact, not all wastewater treatment processes can cope with varying pollutant loads, whether organic (quantity of pollution to be treated) or hydraulic (volume of influent).

Changes in permanent and maximum populations over the medium term (next 5-10 years) and long term (next 30 years) are too-often overestimated, resulting in substantially oversized facilities. Consequently there are extra costs, especially in energy use, as well as odours and malfunctions in the under-loaded facilities. **Estimates of future population growth must be reasonable.**

Influent or sludge arriving from external systems for treatment (e.g. septic sludge from NCS facilities) must also be taken into account. By contrast, load volumes that stay out of the network (thanks to the presence of dry toilets) must be estimated.

It is also important to factor in rainwater management when calculating the hydraulic load volumes to be treated; see section 3.3 for details.

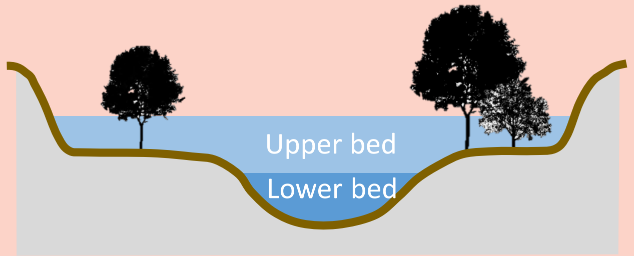


Discharge

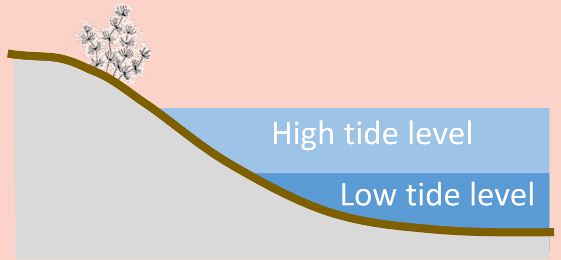
Required discharge limits in treated effluents (concentrations), and minimum treatment performance (output) will be determined in the project's initial phase, in agreement with the water regulation compliance services. In particular, the discharge limits will depend on the quality and sensitivity of the receiving environment, and the dilution level of the effluents discharged there. In sensitive areas, enhanced treatment of nitrogen – including nitrification (removal of ammonium, NH_4^+) and denitrification (removal of nitrates, NO_3^-, for overall nitrogen rejection, NGL) – and even phosphorus treatment (Pt) may be required. For discharge near bathing areas, plans should include additional

treatment of pathogenic germs. Discharge limits for releases into the sea depend on local activities (bathing, shellfish cultivation, etc.). It may be necessary to study the sea currents and water-column density to evaluate the impact of the discharge (particularly bacteria levels) on these activities.

As a first preference, discharge should be onto the land surface (and diluted):



low-flow channel of a water body



below the low-water line of the sea (= low tide level) via an outfall pipe at a location compatible with the sea currents

Where this is not possible, the treated effluents may infiltrate underground, if studies of the ground and subsurface allow (consider infiltration speeds, an aquifer's sensitivity with regard to drinking-water, etc.).

Also, in certain local contexts treated wastewater reuse may be welcome, following an analysis of the requirements and regulatory compliance; it could help with water shortages, green space maintenance, farming activities, firefighting and more.

Discharge to the natural environment may also be temporary (defined and timetabled beforehand) and suspended in particular cases, e.g. treated wastewater reuse on salt marsh for part of the year, or discharge prohibited in bathing areas.

What happens to by-products

Any wastewater purification process produces sludge. These sub-products are stabilised to a greater or lesser extent (sludge in liquid, paste or solid form) depending on the treatment methods used, and they are removed from the treatment system either frequently (e.g. weekly/monthly) or infrequently (after 10-15 years).

Value can be extracted from sludge, subject to strict regulatory constraints. Sludge is generally composted or spread locally (harnessing its value as a soil improver for farming). The issue of how to treat and utilise sludge is a major constraint that must be considered from the pre-project phase onwards.

If there are regulatory constraints regarding phosphorus, the physicochemical phosphate removal process increases sludge production by a further 20-30%. In all scenarios, significant volumes are produced.

Other waste (sub-products) is also generated by a treatment plant:
- screenings (disposed of with household waste),
- fats and sand (to be managed via a suitable treatment process),
- plant matter, for vegetation-based processes such as constructed wetlands, even if this waste can be composted where it is used.

B/ Choice criteria based on local constraints

Available surface area

Natural spaces of ecological interest (including nature reserves, protected areas, wildlife reserves and Natura 2000 sites) tend to play a very important role in island environments. Furthermore, on certain small islands a great many (or even most) of these areas may be on private estates. Consequently, there are limited options for developing property on public land, and there may be severe constraints (available space and cost per m²) when it comes to setting up or expanding a wastewater treatment plant. Point of note: while some compact processes can be attractive, most projects involve significant operating constraints.

Aside from treating the wastewater, the surface area needed for sludge treatment on the island must also be studied.

Access to energy (electricity)

Small islands not connected to a mainland electricity network must produce their own energy (from solar or wind sources), or may even rely on fuel-oil tanks. Due to the challenges of electricity availability, wastewater treatment processes have to be very economical in terms of energy use. Some processes work without using energy, if the topography permits.

GOOD PRACTICE

Importing materials by "beaching" (unloading onto the beach)

On Chausey Island (north-western France, 0.7 km²) there was a ban on collecting local sand to construct the plant (capacity: 175 PE). This meant that all the necessary items for building the plant had to be imported from the mainland. In total, 1,500 tonnes of equipment and materials were transported by barge. Since the goods could not be unloaded onto the stone slipway, the only solution was to place them on a beach. For this island, which has a very large tidal range (14 m), the hours in which delivery could take place depended largely on the high tides, so there was no option but to schedule deliveries for the middle of the night!

GOOD PRACTICE

Vegetation-based processes at centre stage... but reeds are not endemic everywhere

Processes involving filtering reed beds, also called constructed wetlands, are very widespread thanks to their ease of use, their capacity to accept varying load volumes, and the high-quality treatment they deliver (see Appendix 2). The plants used are normally common reeds (Phragmites australis), chosen for their mechanical action. However, the reed is considered an invasive plant species in certain regions (particularly in North and South Americas, and across most of the inter-tropical zone). In this case, the plants to use would be local substitutes, whose development characteristics meet the required criteria (e.g. Heliconia, Cana or Cyperus).

A treatment stage of constructed wetlands in Martinique (photo credit: INRAE)

Site access (for construction and operation)

The operator may encounter difficulties in accessing the plant: less frequent boat connections in winter, (lack of) vehicle availability on the island, and/or a hard-to-access plant, among others. **Therefore, treatment processes involving simple operation should be chosen in preference: low-tech and requiring infrequent visits to the site.**

It is also wise to anticipate options for having reactants delivered, and access by tank-cleaning vessels (barges), for example.

Availability of construction materials and spare parts

For plants larger than individual or small collective scale (< 50 residents), cut-and-fill is often a preferable approach to earthworks, if the ground characteristics permit. This method reduces the need to bring in construction materials, especially concrete. However, if tanks are to be used this approach does require more space than a rigid concrete structure, since it involves creating sloping banks.

It is strongly advisable to **choose locally available materials** (gravel, sand), and also equipment known to the local construction traders for its proven reliability and supply channels for spare parts or consumables.

Some treatment processes require higher-level maintenance that involves replacing components: pumps, pipes, membranes, probes, aeration devices, etc. The manufacturers of these parts must indicate how often they need to be changed. At times it can be difficult to get certain parts transported quickly; their procurement should therefore be planned ahead as far as possible. **Low-maintenance processes should be chosen in preference.**

Discharge in areas with sensitive activities (bathing, shellfish cultivation, etc.)

Depending on the discharge location (sensitivity of the environment), constraints associated with the discharge point (bathing areas in particular) and/or the potential for reusing the treated wastewater, additional disinfection treatments may be imposed. There are a number of existing technologies:

- physical, using membranes (these need a lot of power to function, i.e. high energy use; they also involve chemicals, backwashing which consumes large quantities of water and energy, and restrictions on operation),
- UV lamps (energy-intensive, and not very reliable if something fails to function),
- ozone (very energy-intensive),
- other solutions include natural lagooning, electrooxidation and peracetic acid.

Processes that use chemicals are not recommended. For example, bleach can cause a reaction if discharged to the sea: the chloride ions in chlorine-containing substances react with organic matter to produce halogenated organic compounds, and chloramines form in the presence of ammonium. These sub-products are highly toxic.

Water resource and requirements (drinking water, reuse, etc.)

Some islands have very little drinking water available, particularly if their water is imported by boat from the mainland. In these cases, processes that do not require washing with clear water, or that enable recycling of the treated water leaving the plant, present real benefits.

Landscape aspects

To preserve the tourist appeal and character of the island landscape, it is important to ensure that the buildings comprising the treatment plants blend in optimally with the surroundings. Some processes can be buried, while others utilise vegetation.
Vegetation-based processes may be constrained by the range of local plant species available.

GOOD PRACTICE

Regarding disinfection by UV

This system of disinfection using ultraviolet radiation is widely used, due to it being so simple to install and operate. It uses no chemicals. It is highly effective, as long as the following rules are strictly adhered to:

- the discharge must contain no algae or suspended solids (< 15 mg SS/L)
- the lamp must be cleaned frequently (monthly, if not every week),
- certain parts must be replaced regularly (bulb: every year; quartz protective sheath: every 5 years; power regulator: every 10 years).

Furthermore, the system must be rigorously designed and installed so that the lamps do not heat up (a problem encountered in sequentially fed processes such as constructed wetlands); it needs an integrated purge system, protection against direct solar radiation and heat, etc.

Possible technologies

Appendix 2 contains an overview table detailing the criteria for the **size** (surface area needed) and **performance** (guaranteed levels in discharge, average outputs, reduction of bacteria content) of collective plants. It also presents the criteria for **operation**: adaptation to variations in load volume, energy consumption, an estimate of the personnel hours needed for plant operation, potential for upgrading to align with future requirements and the regulatory framework (for example, treating phosphorus if this becomes necessary), and capacity to store the sludge produced and add value to it on the island.

With regard to **sludge treatment** technologies, non-intensive vegetation-based processes (sludge drying beds with plants) should be the first choice where possible. Their operation is relatively simple, they treat the waste effectively and they blend well with the landscape. Intensive sludge-treatment processes can present significant odour risks.

When it comes to selecting collection and treatment techniques, **consultation with the local population is essential**, to win their support for the project.

Photo: Stéphane Ledoux, Ibo, Mozambique

C/ Costs of Scenarios

Sizing

The first step involved in sizing a plant is defining its treatment capacity. The volumes to be treated are established based on:

Hydraulic load.

The quantity of water to be treated varies substantially between sites. For example, sizing of plants in rural areas in Europe assumes a water use volume of 80-100 litres/day per resident, in the absence of businesses or industries discharging effluent into the network. In urban areas, volumes arising from professional activities are added to household discharge volumes. Additional volumes may come from infiltration and inflow: rising groundwater entering the network, faulty connections of rainwater flow channels, etc.

Organic load.

The definition of population equivalent (PE) in Europe is a regulatory concept used to characterise the size of a treatment facility or of an urban area. Therefore, by definition, 1 PE produces a theoretical pollution load of 60g BOD_5/d. However, the pollution generated by one resident is lower: around 40g BOD_5/d per person in small towns with no associated industrial activity. The PE for summer visitors “passing through” (i.e. day visits with few overnight stays) would be at least 30% lower still.

Accepting septic sludge.

Some collective treatment plants receive septic sludge from areas that operate NCS systems (septic tanks). Although this additional volume tends to be distributed through the year, it represents a very large incoming organic load. This septic sludge should ideally be sent to dedicated treatment facilities (such as reed-planted drying beds), or spread over the ground if regulations allow.

When the load volumes are highly variable (by a factor > 2), the treatment plant may be comprised of multiple processing lines; only one is used in the low season, whereas all are brought into operation during peak season. This kind of configuration generally requires advanced “preparation” that must be integrated in the system’s operation.

Photo: Ismael Mounibou & Nicolas Martin, Mer d’Emeraude

Economic comparison of the scenarios

Land purchase

Often, building plots are rare on small islands. This can be a severe constraint for some sites: prohibitive purchase costs and very little available land.

Transfer network, if applicable

The soil depth is usually small on islands where the bedrock outcrops at many points. Consequently, there are severe geotechnical constraints to creating wastewater collection networks, for example with regard to hollowing rock using dynamite, moving materials, etc. In such cases, suitable solutions could be investigated (a pressurised network, for instance).

In addition, the relief (elevation differences) of the island will be of key importance, since it will influence how many lift stations are needed to carry the wastewater to the plant, and whether the treatment process can be gravity-fed.

GOOD PRACTICE

A close look at example tariffs

Different tariffs in summer and winter:

With this system, it costs more to use water in summer, during the tourist season. This means that people staying in holiday homes contribute more effectively to the investment costs necessary to meet peak-season demand for drinking-water supply and wastewater treatment. Certain communities are reluctant to introduce this system, chiefly due to the cost of implementing water meter readings.

Water bill to make sure people pay for wastewater treatment:

In Tunisia, among other countries, the bill for water treatment (the “cleaning” aspect) is included in the water bill, on the basis of 80% of the quantity of drinking water used.

Investment and operation over 20 years

The investment costs associated with a wastewater treatment system (network + plant) are generally well known, and easy to plan over a 20-year period, the minimum theoretical service life of these kinds of structure. However, the site's operation over the same period must be worked out and integrated right from the initial project preparation, particularly including the costs of: personnel, reactants, consumables, energy use and sludge management (treatment, storage, value harnessing).

Studies and additional treatments (e.g. disinfection, tackling odours)

The natural environment on small islands tends to be vulnerable to any kind of pollution. A study examining the impact of discharge to the sea may be required.

Depending on the local economic and tourist activities (such as shellfish cultivation, bathing or fishing), the treated wastewater must undergo further treatment to control bacteria levels. It may be necessary to study the sea currents and water-column density to check the impact of the discharge on activities in the area. In some cases, it may be necessary to disinfect the output effluents. The equipments involved in this step can be energy-intensive, and the personnel operating them must be specifically trained in their use, as well as highly vigilant.

To ensure the safety of the local drinking water resource, there may be restrictions regarding the location of the discharge point.

If the wastewater treatment process and/or the sludge produce odours that could bother residents and tourists, it may be necessary to either treat the odours specifically or cover the plant structures. Good communication facilitates understanding by the island's residents and visitors.

GOOD PRACTICE

Centralised wastewater treatment: a sound solution for very small islands?

The little island of Brownsea (3 km², 30 permanent residents and 130,000 visitors/year) in the south-west of the UK previously relied on very old wastewater treatment infrastructure, mostly comprised of individual systems: septic tanks, Imhoff tank and sludge drying beds. Overflows from the storage tanks polluted the water and the ground, and created strong odours that caused much discomfort when welcoming visitors. Furthermore, it was very expensive (around €900,000/year) to transport the septic sludge to be treated on the mainland.

An audit of the existing facilities, together with a technico-economic study, showed that it would be advisable to increase the treatment capacity and centralise the wastewater management in a single treatment plant (using rotating biological contactors, RBC). This operation called for complex logistics, creation of wastewater treatment networks, and civil engineering including import of structures and electro-mechanical systems from the mainland. As such, the operation is now centralised, with sludge management facilitated by in-situ composting.

Reed-based constructed wetland solutions were ruled out, due to the undesirable discharges that would have flowed into the lagoons around the only area that offered sufficient space for a wetland system.

Resource reuse and value-harnessing

Encouraging the island's residents to equip their homes with **rainwater collection tanks** helps to reduce drinking water consumption. Storing and recycling rainwater lends itself to many uses, with no risk to health: a few examples are flushing toilets, washing clothes and watering the garden.

Unconventional water: rain, reuse

Treated wastewater reuse should be examined with a view to meeting local water requirements, e.g. for farming or watering green spaces. A feasibility study is necessary; this identifies the constraints applicable to each desired use of the treated water (storage, disinfection, etc.) as per the regulations in force on the island. Reuse is frequently used in "industrial" activities on treatment plants: the water leaving the plant can simply be filtered, then used on the site to clean certain structures.

From the moment any additional disinfection treatment is applied, e.g. for an area used for bathing/shellfish cultivation, the treated wastewater reuse option must be examined. In fact, it is usually easy to implement because the pathogens have been dealt with.

Sludge: biomethane

Producing biomethane and extracting value from it requires large volumes of sludge, to make the digester self-sufficient in energy and to produce a surplus of gas. The gas can be harnessed as methane or in co-generation of electricity. Facilities that utilise an Upflow Anaerobic Sludge Blanket (UASB) require special technical knowledge, plus enhanced safety measures if there is a gas production module, as this creates a risk of explosion. Furthermore, these reactors need temperatures higher than 19°C in order to function optimally. In parallel, this solution produces a clean energy that aligns with circular economy principles and reduces the amount of sludge produced. Depending on the island's specific characteristics, it may be necessary to run a technico-economic analysis with regard to using sludge digestion with biomethane harnessing.

The sludge can also be treated (by drying) and utilised locally after being turned into compost, which would avoid the significant cost of transporting the sludge to the mainland and having it treated there. This approach would also require an impact study, in conformity with the regulations in effect.

GOOD PRACTICE

Treated wastewater reuse on the island of Lesbos (Greece)

As part of the European project "HYDROUSA", an innovative action funded by the Horizon 2020 Research and Innovation programme (2018-2023), several solutions for treating wastewater and for boosting agricultural produce and energy generation have been demonstrated at actual scale on Greek islands. Replication of these solutions on islands and in isolated areas across the world has also been analysed.

On the island of Lesbos, a wastewater purification system uses a UASB reactor in combination with a reed bed constructed wetland. Thanks to this joining of two complementary technologies, energy can be generated by the reactor and the footprint of the wetland area can be reduced (950 m² for a capacity of 400 PE), meaning that the system is self-sustaining. In order to handle the surplus volume produced during the tourist season (25 to 100 m3/d during the summer), two reactors have been connected in parallel.

The treatment is set up to yield water rich in nutrients (nitrogen and phosphorus) and thereby provide "fertigation" for an agri-forestry area covering one hectare, created for the project. The treated wastewater is of sufficiently high quality for agricultural use, but it is also sand-filtered and exposed to UV radiation to ensure disinfection. The water obtained complies with water quality class A of Regulation (EU) 2020/741, rendering it suitable for use in irrigating any type of food crop.

This system delivers higher performance than activated sludge treatment, for less than one-third of the investment cost. The agri-forestry area produces more than 3 tonnes of vegetables, fruit, cereal grains and herbs per year (average based on two seasons).

Barley irrigated with treated wastewater (April 2022)

Barley irrigated with tap water (April 2022)

Layout of the wastewater treatment system

3.3 What about rainwater management?

Rainwater management is an opportunity to imagine surface water run-off as a resource, rather than as a waste flow to expel via a channel. By devising a network arrangement that can keep rain out of the treatment system, this water can be a free, beneficial resource sent to green spaces with a land hollow. Even in highly urbanised areas with little available space, rainwater can be held on a land plot using tanks constructed under a road, village square or car park.

The characteristics of rainy periods also need to be considered:

- does it rain a little, but regularly?
- or is the rain occasional but heavy, arriving as storms (which require storage or overflow containers)?
- or does rain come in large volumes, such as monsoons?

The network description is very important when defining wastewater treatment scenarios:

- a "single-unit" network transports rainwater that has run off roofs and roads in the same pipe as used water, to the treatment plant. The treatment facility must therefore be able to cope with water of a quality and quantity that varies with rainfall levels throughout the year.
- a "separating" network has two flow routes: one pipe collects rainwater and conveys it directly to the receiving environment, while another pipe collects used water from dwellings and sends it to be treated in the plant. The community must invest a large amount to create and maintain two networks in parallel, but the treatment facility is smaller due to the fact that it only receives and treats wastewater.

Principe, São Tomé and Principe

During a project's study phase, consideration of how to integrate different kinds of rain (from the routine to the exceptional) can lead to ideas for connecting urban fabric to the surrounding nature. With regard to exceptional rain, it is essential to start by identifying thalwegs in urban area (i.e. lowest-lying points, such as valley bottoms or the beds of water bodies). Effectively, this knowledge about the hydraulic behaviour of rain opens up options for devising systems that encourage the free, unobstructed flow of water.

Integrated water management also includes biodiversity considerations. It involves supporting ecological continuity (on land and in water) in urban environments. All these actions play a part in improving residents' quality of life.

Once the provisional action plan for wastewater treatment and rainwater management has been drafted, scheduling of works can begin.

Photo: Roger Estève, Nosy Hara, Madagascar

GOOD PRACTICE

Single-unit networks require a by-pass at the top of the plant. What are the consequences of this, and the solutions?

If the scenario does not allow for a dual-pipe separating network, meaning that the network is operated on a single-unit basis, a by-pass must be installed at the treatment plant entrance. The by-pass is mandatory, to limit the flow volume into the plant during periods of heavy rain. Consequently, it sends the wastewater – highly diluted – directly to the receiving environment.

To avoid the by-pass being used too frequently, or excessive volumes of wastewater being released into the environment, the best solution is disconnection at the source. This involves disconnecting the points where rainwater join**s the network** (e.g. diverting the flow from roofs and fountains) and storing the rainwater or letting it sink into the ground on each dwelling plot. This is beneficial in two ways:

- it keeps the treatment plant operating safely and protects the receiving environment (which benefits the natural water cycle);
- it collects the rainwater, which can be reused in dwellings (e.g. in toilets, washing machines), on gardens or to wash cars, for example.

3.4 Detailed table of the processes: identifying the most appropriate solutions

Every island is very different from others, and has its own specific constraints. This complicates the task of listing the most suitable processes for a territory. The following technologies are considered suitable to implement on an island:

Constructed wetlands with reed/plant beds (vertical downflow) - VFCWs

After passing through a simple screen to remove larger solids, the wastewater is treated physically by filtration through fine gravel, and biologically by bacteria fixed to the granular media. Several filters are placed in parallel, and they are alternately fed. A compost-like sludge layer forms on the surface of the filters. The plants play a mechanical role, ensuring that there is flow through the filters. If the ground slopes sufficiently, the process can work without energy input.

Sludge drying beds with plants work on the same principle: the sludge is filtered, dried and mineralised on the surface of the beds.

Rotating biological contactors - RBC

The wastewater is treated by bacteria fixed to the contactors. The contactors are constantly made to rotate in the water (which uses energy). Biological solids (biofilm) grow on the media, then drop off as sludge, which settles in a clarification step. There are two possible configurations:

- "Coarse screening → decanter-digester → biological contactors → clarifier." The treated water is separated from the sludge by a clarifier placed downstream, and there is a dedicated flow route solely for sludge;
- "Fine screening → biological contactors → constructed wetlands with reed/plant beds." A constructed wetland separates the treated water from the sludge.

Trickling filter - TF

Wastewater is treated by biofilm fixed to a bed of coarse media (volcanic stones or open plastic material) through which the water passes; this bed is aerated regularly by natural aspiration of oxygen. The effluents must be recirculated through the trickling filter (which consumes energy). Biological solids grow on the media, then drop off as sludge, which settles in a clarification step. There are two possible configurations:

- "Coarse screening → decanter-digester → trickling filter → clarifier." The treated water is separated from the sludge by a clarifier placed downstream, and there is a dedicated flow route for sludge alone;
- "Fine screening → trickling filter → constructed wetlands with reed/plant beds." A constructed wetland separates the treated water from the sludge.

Natural / aerated lagooning

The wastewater is treated by bacteria and algae present in the ponds. A series of several basins is required in order to perform the treatment. Most of the sludge is retained in the first pond.

If the ground slopes sufficiently, the process can work without energy input.
Aerating the first pond (using energy) adds to the oxygen input and boosts the treatment capacity.

Activated sludge - AS

The wastewater is treated by free growth culture maintained in the form of biological flocs ("sludge") in an aeration basin. The basin is by turns stirred and oxygenated using an aeration mechanism (e.g. turbines or air-blowing), which is needed for the bacteria's treatment activity but uses a lot of energy. The sludge must be recirculated. An automated system has to be installed in order to manage the facilities. A clarifier, placed downstream, separates the treated water from the sludge.

The typical configuration is as follows: "Screening → aeration basin → clarifier." There is a dedicated flow route solely for sludge.

Membrane bioreactors - MBR

The wastewater is treated by an aeration basin ("activated sludge") and then by filtration through submerged membranes (with no clarifier). This technology is high-performing, very energy-intensive, and requires everyday action to a qualified level (automated). The use of a buffer tank is recommended. Replacement of the membranes is to be expected. Chemicals are used in the regular washing of the membranes. This is a compact process.

The typical configuration is as follows: "Screening-sifting → aeration basin → membranes." There is a dedicated flow route solely for sludge.

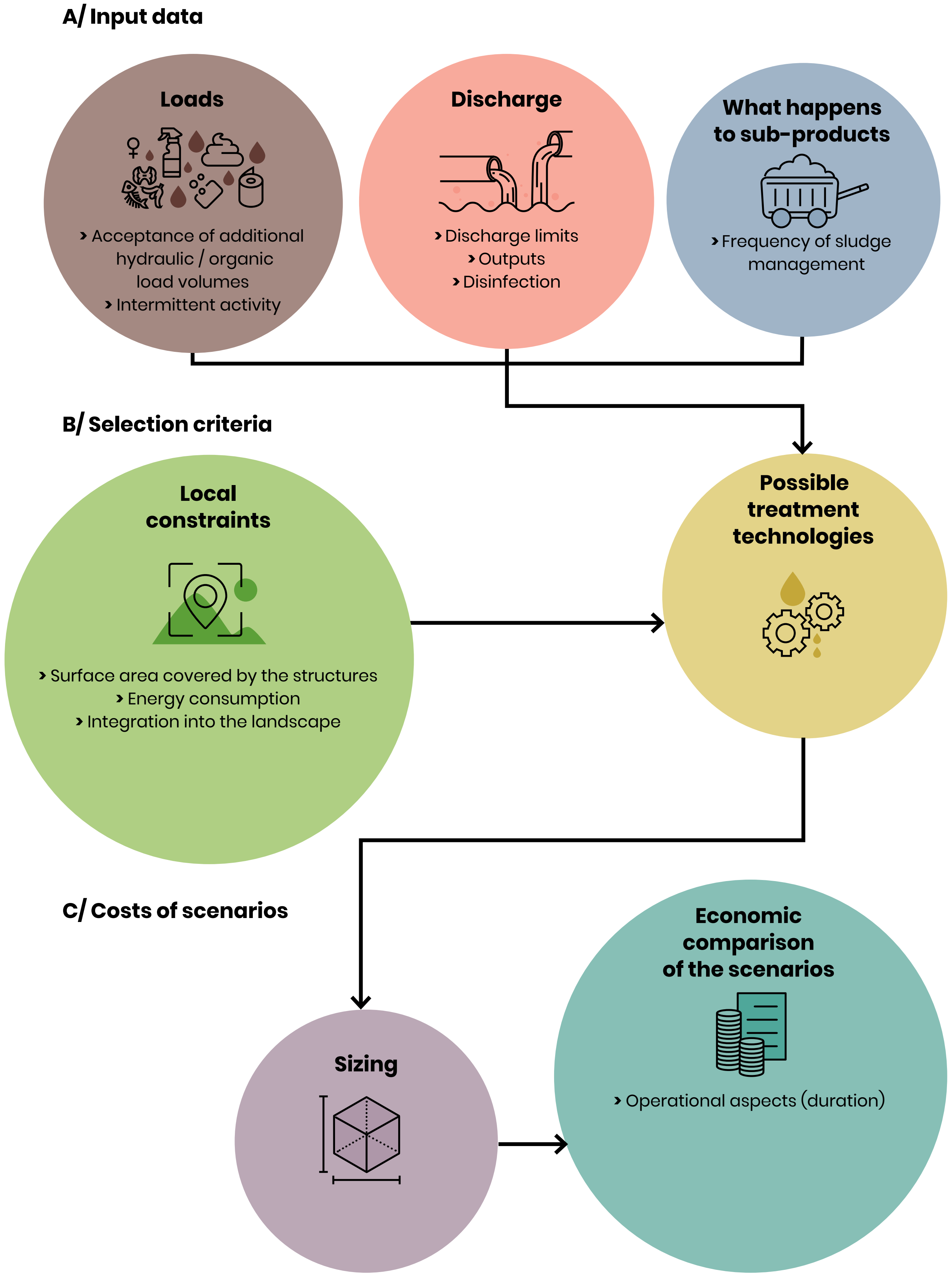
Sequencing batch reactor - SBR

The wastewater is treated by bacteria ("sludge") in an aeration basin ("activated sludge"). This basin is the sequencing batch reactor, which operates in cycles comprising 4 phases: tank filling with wastewater / aeration / settling or decanting / emptying the treated water upper layer and sludge from the bottom. Several reactors are installed in parallel, and there is no clarifier. This technology is energy-intensive (due to the aeration) and requires everyday action to a qualified level (automated).

The typical configuration is as follows: "Screening → buffer tank → SBR." There is a dedicated flow route solely for sludge.

The proposed processes are mentioned in Appendix 2 in table format, with the rows matching the main flows in the flowchart (Figure 2). CAPEX (capital expenditure) and OPEX (operating expenses) indicators assist the process of comparing the scenarios in technical and economic terms.

Methodology for specifying a collective sanitation project in a remote island location



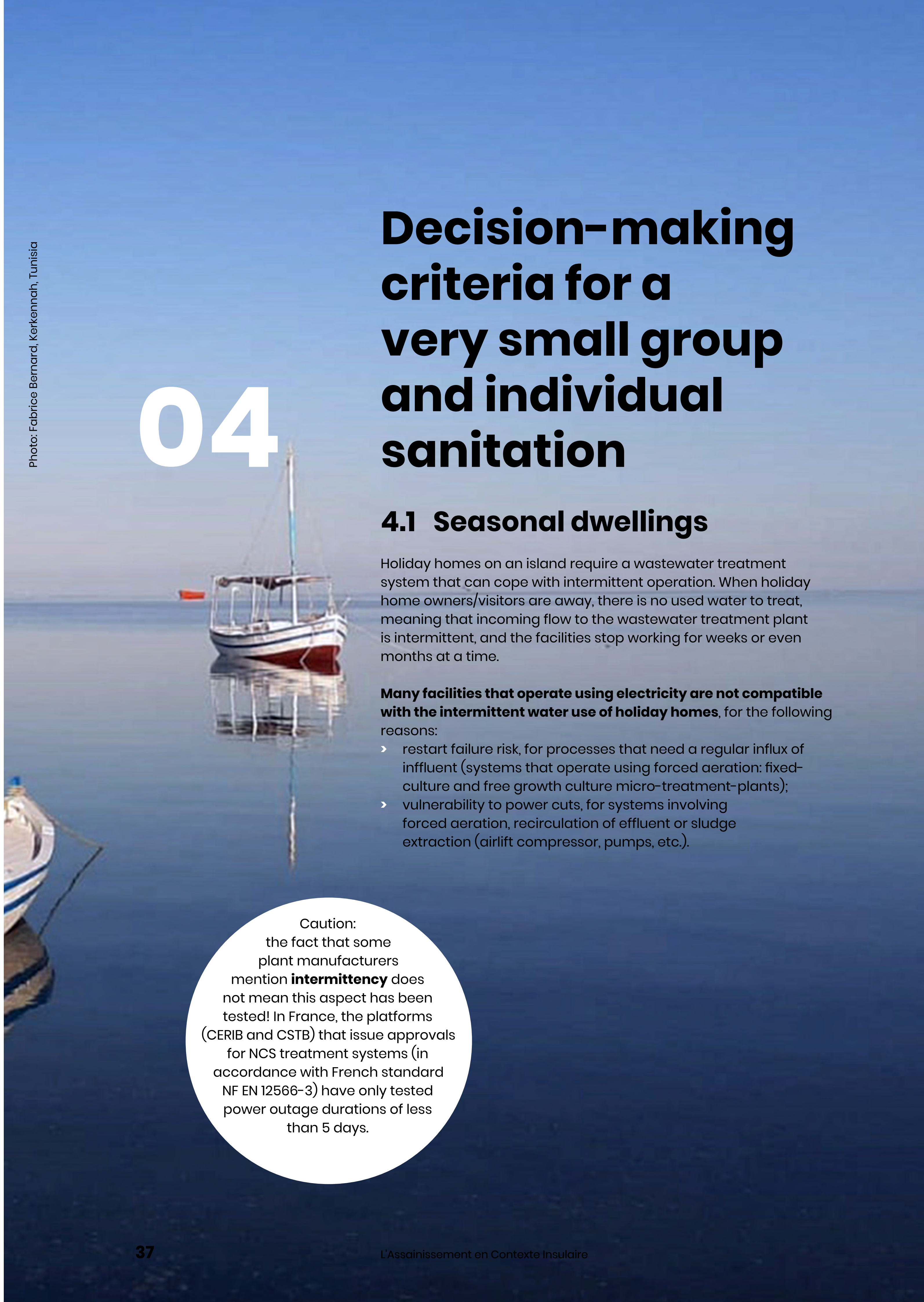


Photo: Fabrice Bernard, Kerkennah, Tunisia

04 Decision-making criteria for a very small group and individual sanitation

4.1 Seasonal dwellings

Holiday homes on an island require a wastewater treatment system that can cope with intermittent operation. When holiday home owners/visitors are away, there is no used water to treat, meaning that incoming flow to the wastewater treatment plant is intermittent, and the facilities stop working for weeks or even months at a time.

Many facilities that operate using electricity are not compatible with the intermittent water use of holiday homes, for the following reasons:

- restart failure risk, for processes that need a regular influx of influent (systems that operate using forced aeration: fixed-culture and free growth culture micro-treatment-plants);
- vulnerability to power cuts, for systems involving forced aeration, recirculation of effluent or sludge extraction (airlift compressor, pumps, etc.).

Caution: the fact that some plant manufacturers mention **intermittency** does not mean this aspect has been tested! In France, the platforms (CERIB and CSTB) that issue approvals for NCS treatment systems (in accordance with French standard NF EN 12566-3) have only tested power outage durations of less than 5 days.

4.2 Encourage grouping of dwellings

In a sector where wider collective sanitation is not possible (for technical, financial and/or environmental reasons) the recommended route is to connect multiple dwellings to the same treatment plant. Grouped wastewater treatment, whether collective or non-collective, offers the following advantages:

- Fewer hydraulic peak loads (an indicator of flow variability over one day): the peak flow factor drops below 4 as soon as 5 or 6 dwellings are connected, compared to 8 for individual NCS. However, for small groups of dwellings it is still wise to include a buffer chamber upstream of the plant, to spread incoming flows over the course of the day and avoid hydraulic peaks.
- Constructed wetlands (the 1^{st} stage in vertical-flow filters) can be smaller: NCS setups need at least 2 m^2/PE, while for 5 or more connected dwellings in temperate climates the required surface area is only 1 to 1.5 m^2/PE (even 0.6 m^2 if there is no nitrogen treatment). However, in tropical climates the recommended surface area is 0.8 to 1 m^2/PE, irrespective of the facility's capacity.

It is generally beneficial to group dwellings for the purposes of treating their wastewater, but this raises the issue of managing the structures. In a group of dwellings using an NCS option, the roles and responsibilities of the co-owners of the treatment facility must be formalised. Facilities with a PE higher than 20 are usually managed by a local public-sector structure (e.g. the town council or local council community).

GOOD PRACTICE

Focus on discharge: onto the land or as infiltration... An example from France

In an NCS arrangement, infiltration of the treated effluents is mandatory if the ground permeability is between 10 and 500 mm/hour (stipulated by art. 11, French order of 7 September 2009). Otherwise, the fluid is discharged into a shallow water environment (e.g. an infiltration ditch or a river) with permission from the owner or manager of the receiving environment (art. 12), or into a soakaway (art. 13).

For collective or non-collective wastewater treatment with a PE higher than 20 (as per the French order of 21 July 2015) effluent should ideally be discharged into shallow water environments (art. 8). Where this is not possible, infiltration into the ground may be feasible provided that studies of the soil, hydrogeology and environment have shown this to be possible and acceptable. Infiltration may also be envisaged if it presents a proven environmental benefit.

Discharge from a treatment plant into a shallow water environment (ditch) – photo credit: INRAE

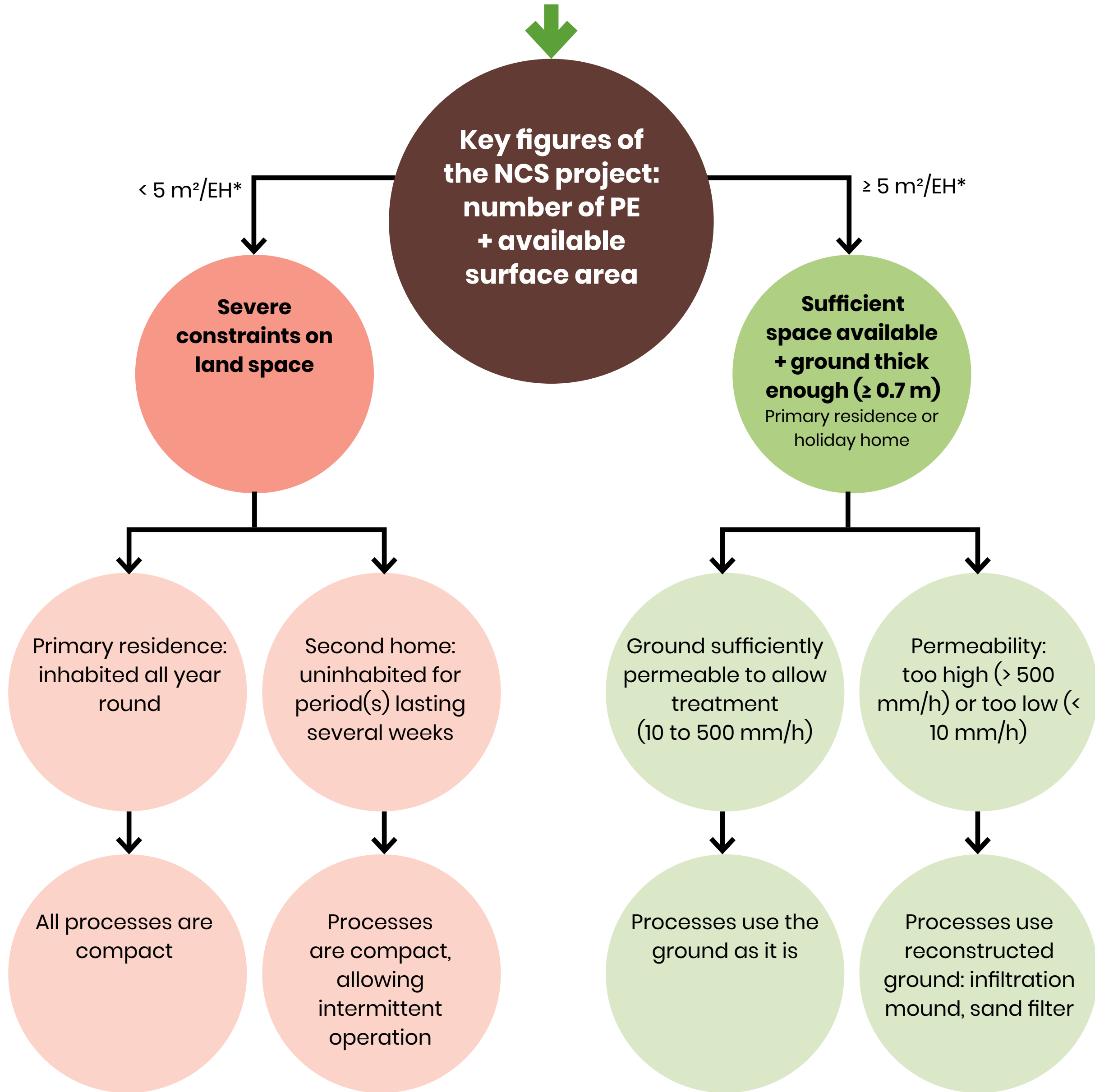
When it comes to selecting collection and treatment techniques, **consultation with the local population is essential**, to win their support for the project.

4.3 Methodology for an NCS project

When decentralised non-collective sanitation is the chosen option, suitable treatment technologies must be selected. There is a wide variety of individual water treatment processes, proposed by a great many companies, which adds to the difficulty of decision-making. The flowchart in Figure 3 presents a simple, practical approach based on two constraints: available space and ground permeability.

Figure 3.

Flowchart for selecting a suitable NCS process for the local context



*footprint of the treatment structures only

4.4 Technologies to promote on an NCS project

Thanks to a number of feedback reports, we can propose some processes suited to island contexts. Based on these reports, the following processes are recommended and robust in the face of substantial variation in load volumes:

All-water (septic) tank + vertical-drainage sand filters

Vertical downflow constructed wetlands

All-water (septic) tank + media fragments such as coconut husk, hazelnut shells, xylit

These processes should be the preferred option, if there is sufficient space. They also tend to be less cumbersome to operate and maintain than intensive processes (such as micro-treatment-plants), because they use very little energy and are easy to operate (factored in for a 15-year period).

If infiltration is not possible, discharge will be into the sea or a ditch.

The advantages and drawbacks of the main NCS processes are explained in detail below (Figure 4):

GOOD PRACTICE

Be careful when using soakaways! (or drainage wells / percolation wells)

A soakaway is a vertical rubble-filled hole, usually with concrete-reinforced walls, designed to receive rainwater run-off that can then infiltrate into the ground.

The use of this technique to dispose of wastewater is prohibited in many countries, as it risks contaminating the underground water (water table, wells containing water for human consumption, etc.). A wastewater treatment facility must be created (mandatory), and then the treated water may potentially be discharged into a soakaway if the ground and subsurface characteristics allow.

Figure 4.
Advantages and drawbacks of Non-Collective Sanitation (NCS) processes

	Advantages	Drawbacks
Sand filters	+ Underground process. + Can function intermittently.	× Space required: 5 m²/PE (filtering surface area only). × Management of liquid sludge: empty the septic tank when it reaches 50% full (on average every 4 years).
Filters using media fragments such as coconut husk, hazelnut shells, xylit...	+ Underground process. + Compact process. + Can function intermittently.	× Management of liquid sludge: the septic tank needs emptying when it reaches 50% full (on average every 4 years).
Constructed wetlands (fed directly with untreated wastewater)	+ No sludge to manage if the untreated wastewater is released to the 1st filter of constructed wetland with vertical-flow reed/plant bed (the sludge is stored and treated in the wetland over 10 to 15 years). + Blends into the landscape easily; vegetation-based process. + Can function intermittently. + Can be operated by gravity alone, with no energy input.	× Space required: 5 m²/PE. × Plant harvesting once a year (in a temperate climate) or 2-3 times a year (tropical climate). × Safety measures are required related to the proximity to untreated wastewaters, if this is released onto the surface.
Micro-treatment-plants: fixed culture and free growth culture (submerged)	+ Underground process. + Space saved: < 5 m²/PE.	× Management of liquid sludge: the septic tank needs emptying every 4 months to 2 years (or when the tank is 30% full). × Problem of the system being operated by householders with no training on organic treatment methods. × Cannot cope with large variations in load volumes, or intermittent functioning. × Poor-quality treatment of pathogens. × Uses electricity.
Separation at the source: dry toilets	+ See section 5, "Are dry toilets the best solution? "	

Photo: Pedro Gomes, Príncipe, São Tomé and Príncipe

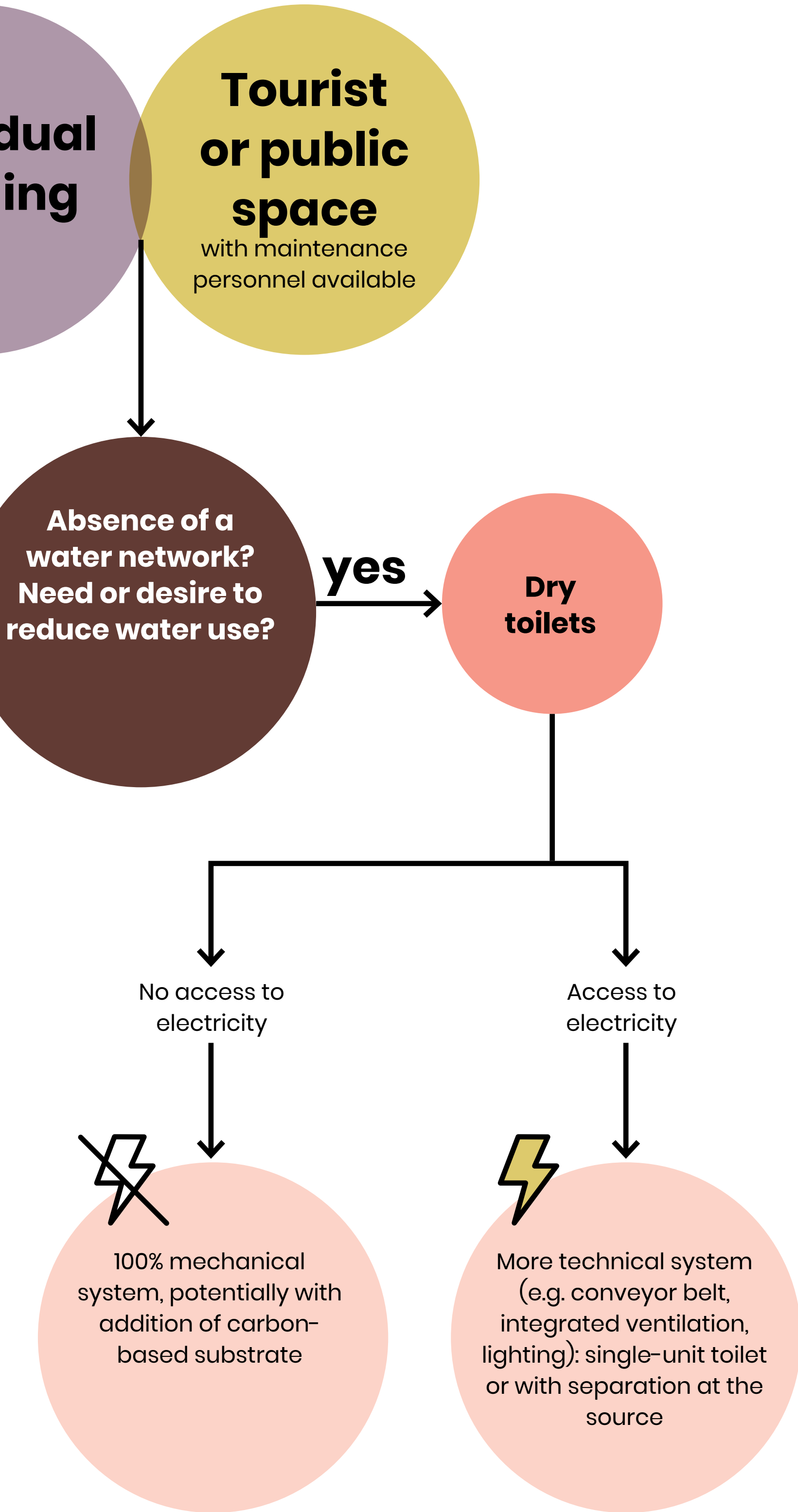
05 Are dry toilets the best solution?

The two biggest reasons to install dry toilets are usually the absence of a water network or a desire to reduce water use. Dry toilets can be installed:

- in a collective sanitation area where used water from households (greywater, i.e. from showers, sinks and washing machines) is sent to the wastewater treatment network;
- in an NCS area where all the households' wastewater is treated in a dedicated facility;
- in tourist areas, for temporary use during peak visitor season: for example, sport and leisure venues, festivals, village centres and beaches.

Figure 5.

Decision flow-chart for installing dry toilets



Dry toilets (photo credit: Eric MINO, HYDROUSA or SEMIDE, to be confirmed)

5.1 Advantages and drawbacks of dry toilets

advantages

Uses less water

No water flushing

Lower construction costs

Pipe-free operation: no incoming water or evacuation of wastewater.
For NCS, joint treatment of household wastewater (greywater) means that the treatment plant can be smaller, which reduces the construction costs (if < 20 PE).

Lower operating costs

Solid waste can be utilised as garden compost.
With NCS there is no septic tank to empty.

Treated wastewater reuse

Pathogens are retained in the dry toilets, while the treated household wastewater can be reused in the immediate surroundings, provided that it meets local regulations on treated wastewater reuse.

drawbacks

Must be installed in an impervious area

Criterion imposed by certain national laws (e.g. in France).

Regular maintenance needed

Solid waste to be removed regularly and taken to the composting location.

5.2 Setup, useful measures and sizing

This process is suitable for **primary residences and holiday homes** (it can cope with intermittent functioning), and it can be sized to suit **any size of dwelling**.

It is also in widespread use in **tourist sites that receive large numbers of visitors**, where dry toilets are **provided on a temporary basis**: for example, several months on a beach or in a village centre, or a few days for a festival.

These toilets can be installed in areas with sensitive activities, unless this goes against local regulations.

Flow diagram and vigilance points

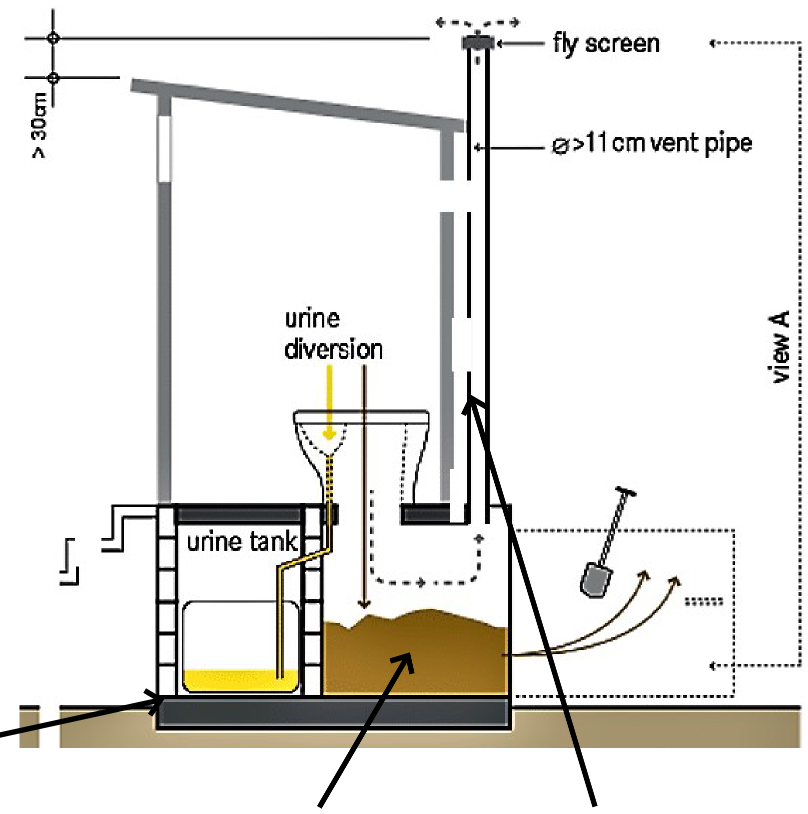
Two crucial criteria must be met to guarantee odour-free dry toilets:

+ First and foremost: a well-designed system of natural air ventilation (from inside the toilet cubicle to the composting location), for all types of dry toilet.
+ For toilets that do not separate urine and faeces, wood chips (crushed pieces / sawdust) must be added every time someone uses the toilet. When added in the correct quantities, this carbon-based substrate dries the faecal matter and thereby prevents odour-causing bacteria from breeding.

Figure 6.

Flow diagram and vigilance points for installing dry toilets.

Diagram taken from Tilley et al. (2014), Compendium of Sanitation Systems and Technologies, 2nd Revised Edition, Swiss Federal Institute of Aquatic Science and Technology (Eawag), Switzerland.



The **composting area** for treating faecal matter must be **impervious** to prevent the matter from coming into contact with the ground. Faeces contain large quantities of pathogens and contaminate the environment.

The system size must allow **sufficient residence time** for the matter to mature (become compost) and become hygienic.

An **effective ventilation system** must be installed. This is the main factor in the project's success (aiding its acceptance by the users).

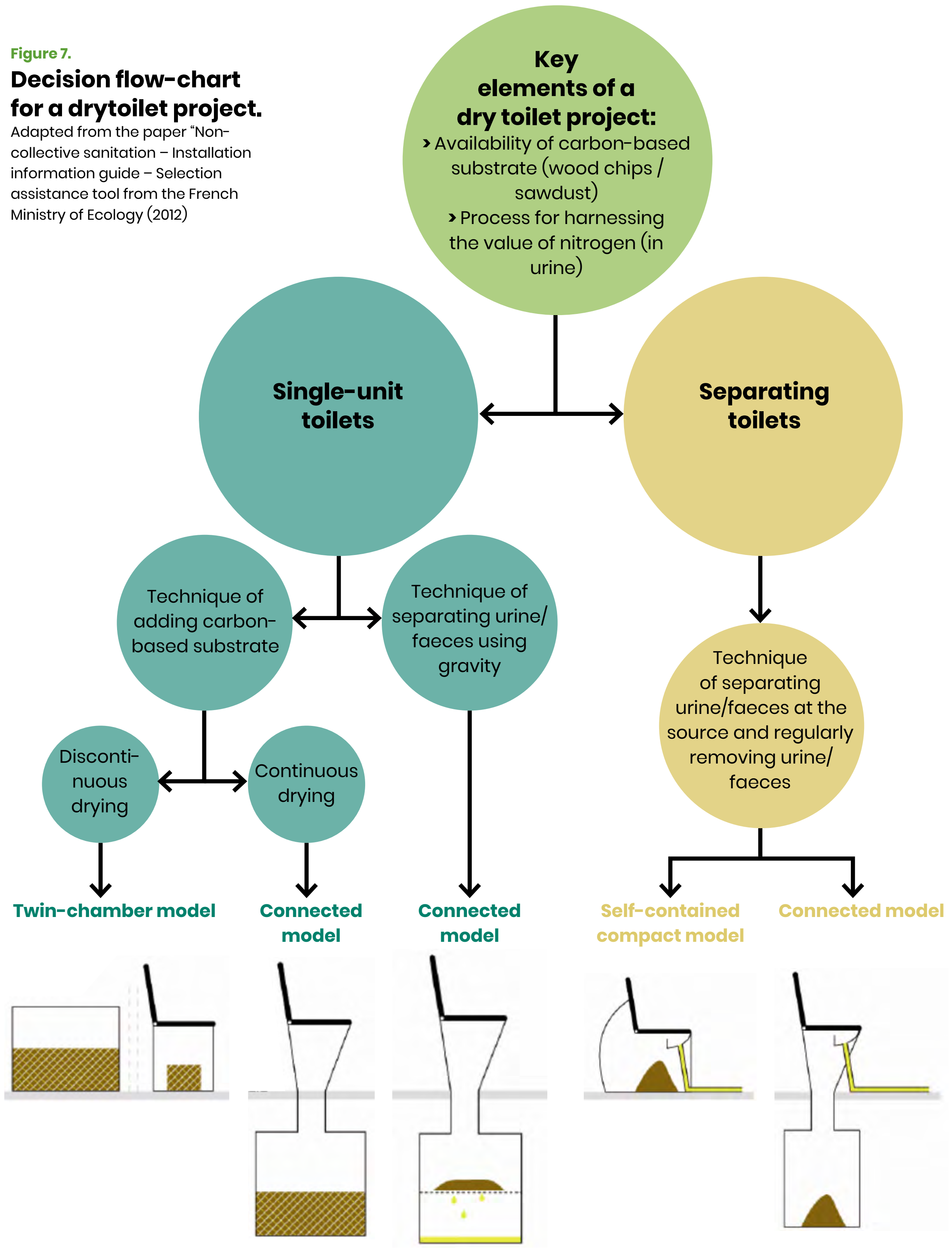
Selecting the toilet type

Separating the urine helps to dry the solid excreta, reduces the associated odours and also facilitates value-extraction options.

Figure 7.

Decision flow-chart for a drytoilet project.

Adapted from the paper "Non-collective sanitation – Installation information guide – Selection assistance tool from the French Ministry of Ecology (2012)



Maintenance recommendations for dry toilets

Routine upkeep of dry toilets in public spaces should be carried out by a local council team, who give the facility a "standard" clean several times a week (depending on how often it is used). The use of chemicals should be prohibited; they would obstruct the bacterial activity of the microorganisms that decompose the organic matters in the compost.

Dry toilets require little maintenance, and involve only one onerous task: regularly removing the solid waste and taking it to the composting location. This task can be made easier through good design of the facility. Regular emptying of dry toilets ensures that they will work well. The question of how frequently to empty them depends on the size of the matter container and how fast it fills up.

For systems that work using electricity, it is advisable to set up contract-based annual servicing with the supplier of the facility, to check the pedal of the mechanism and the condition of the compost.

Managing household wastewater (greywater)

When a dwelling has dry toilets, the used water it evacuates is greywater, from showers, hand basins, sinks, and washing laundry and crockery. This water is generally pathogen-free, but due to its pollutant load it must be sent to a treatment process:

- CS: wastewater is discharged into the treatment network.
- NCS: wastewater is treated via an appropriate process (e.g. sand filter, compact filter or constructed wetland), usually on the same land plot as the dwelling.

Photo: Mairie de Cannes Axis Drone

Gorée, Sénégal

06 Additional aspects linked to sustainable development and circular economy

Electrical energy

› For an island, this tends to be a high-stakes issue!
› Electricity is often generated by oil-fired power plants, which are costly polluters and rely on external inputs.
› There is a need to encourage renewable energy projects (such as solar, wind, and marine-based power).

Quality of natural water

› Good water quality (in coastal locations, freshwater bodies and underground) is always beneficial for the local economy, because it fosters activities around fishing and tourism.
› To restore the quality of bathing water, bacteria-treatment processes are necessary, which may lead to substantial investment and operating costs (for UV lamps, membranes, etc.).

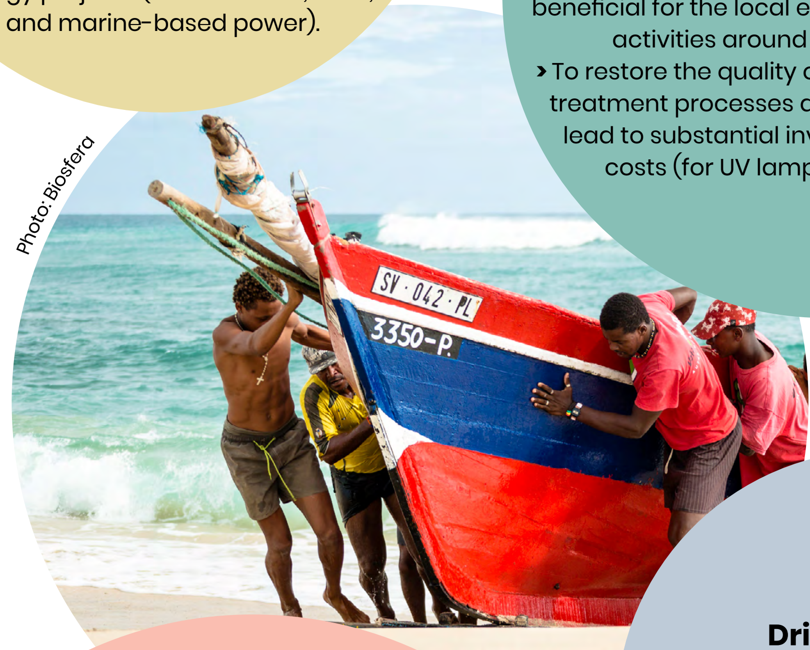


Photo: Biosfera

Drinking water

If there is insufficient drinking water, the idea of installing a sea water desalination unit to produce potable water can be tempting. However, this process consumes large amounts of energy and generates highly concentrated brines that must be dealt with.

Societal aspects of project integration

› The development of floating wastewater treatment plants, on boats, offers interesting potential for small, isolated coastal ports or villages with little available onshore space. It could be economically viable to deploy, import and operate this kind of system. Plants based on this model exist, and have been shown to work well using the constructed wetlands approach.
› Communication about projects is important, especially for small islands where it is not always possible to hide treatment facilities or build them far away from dwellings. When the local population and tourists have a better understanding of the challenges, implementation of wastewater treatment projects is always easier.

07 Conclusion

In order to select a wastewater treatment system suitable for small islands, many aspects must be taken into account, not just the cost. This guide makes simple and practical recommendations to help steer the choice, for either collective or individual systems.

Consultation with the local population is an essential part of the process, to win their support for the project.

Close collaboration with the relevant local authorities is also necessary, in order to establish the required discharge limits and decide how to split the expected incurred costs. In addition, and even though this represents extra cost, the community is strongly advised to bring in a lead contractor or a wastewater treatment expert, who will:

- run an audit of the existing wastewater management facilities: check the condition of the structures and determine the effectiveness of the current treatment. This situation review is an essential step for examining options to reuse the structures already in place;
- identify the most suitable technologies for the situation in question, based on shared criteria.

Appendix 1 Hydrogen sulphide (H_2S), a problem that can't be ignored!

Cause of H_2S formation: underloaded network; wastewater sitting too long in the pipes (residence time > 24h); and/or high temperatures (> 20°C). The substance appears at lift stations, in particular.

Consequences: unpleasant odour (rotten eggs); significant corrosion of the installations and equipment (e.g. cement, concrete, metal reinforcements and pumps) because H_2S oxidises to become sulphuric acid; health hazard for the operating personnel (H_2S is a lethal gas); wastewater treatment plant malfunction.

Solutions to explore:

Preventative approach:

- Choose gravity-fed networks wherever possible, and avoid having lift stations.
- Size the unit correctly for the water volume: empty feed tanks more frequently in the backup stations (= smaller variation in the tank fill level); keep lift stations small.
- Reinforced materials: concrete with a specific coating, plastics (PVC, polyethylene), reinforced stainless steel (316L; grade 304L is affected by H_2S), and epoxy resins.
- Design the facilities specifically for two types of use, summer *vs.* winter (risk of additional costs).
- Inject air into small stations (hydro-ejectors) or into a discharge line (compressors: a relatively noisy and bulky process).
- Inject calcium nitrate, $Ca(NO_3)_2$: as a preventative measure, since it obstructs H_2S formation.

Curative approach:

- Inject iron chloride ($FeCl_3$): this is an effective and inexpensive option, but strongly discouraged for discharges into brackish water or the sea, as it could react with the salt in the water.

Appendix 2

Criteria for assessing process performance and operation

Definition of acronyms

Name of listed processes:	Name of listed analytical parameters:
VFCW: vertical flow constructed wetlands (French system)	SS: suspended solids
RBC: rotating biological contactor	BOD_5: biological oxygen demand (over 5 days)
TF: trickling filter	COD: chemical oxygen demand
AS: activated sludge	KN: Kjeldahl nitrogen (KN = organic nitrogen + ammonium $N\text{-}NH_4^+$)
MBR: membrane bioreactor	TN: total nitrogen (TN = KN + nitrites $N\text{-}NO_2^-$ + nitrates $N\text{-}NO_3^-$)
SBR: sequencing batch reactor	TP: total phosphorus

N.B. The ecological aspect of the processes is excluded, as it involves exhaustive studies (e.g. life cycle analyses) not just simple biodiversity indicators. Such data is practically non-existent for wastewater treatment processes. Also, the cost-benefit analysis is highly dependent on the local situation, and therefore difficult to generalise. The benefits of the treatment technologies are mentioned in the CAPEX and OPEX criteria, but the costs are not indicated since they vary greatly in different parts of the world.

Main criteria used for calculating CAPEX (capital expenditure) and OPEX (operating expenses)

Legend: High constraint | Constraint not to be ignored | Good acceptance

* Possible with a gradual restart (slow ramp-up over several weeks). Impossible on a weekly scale.

** General Inspection, valve operation, cleaning water lift stations and structure, meter reading, mowing of vegetation (VFCW), equipment replacement, samples...

	Other Criteria of Interest	CAPEX: Surface structure m²/EH	CAPEX: Overload accept – hydraulic	CAPEX: Overload accept – organic	CAPEX: IIntegration into the landscape	CAPEX: Inter-mittency (seasonal residences)	OPEX: Operation (1 000 EH) h/an **	OPEX: Managing sludge	OPEX: Energy consumption (kWh) / kg DBO5 removal.	OPEX: Energy consumption (kWh) / m³ treated
Small and medium collective sanitation (until 5 000 max 10 000 EH)	**Fixed film treatments**									
	VFCW one stage	1,2	+	+	++	+	250	10 years	0 - 0.5	0 - 0.1
	VFCW one stage with recirculation	1,5	+	+	++	+	250	10 years	0 - 0.5	0 - 0.1
	VFCW one stage with forced aeration	1	+	+	++	+	250	10 years	0.3 - 0.6	0.2 - 0.3
	VFCW two stages (French system)	2	+	+	++	+	300	10 years	0 - 0.5	0 - 0.1
	VFCW small size (load variations, campsites)	1	+	+	++	+	250	10 years	0 - 0.5	0 - 0.1
	VFCW tropical climate	0,8	+	+	++	+	250	15 years	0 - 0.5	0 - 0.1
	RBC (8 g BOD5/m²/j)	0.3 - 0.5	rather yes	rather yes	×	×	250	3 mo. / 10 y.	1	0.2 - 0.3
	RBC (4 g BOD5/m²/j)	0.5 - 1	rather yes	rather yes	×	×	250	3 m. / 10 y.	1	0.2 - 0.3
	RBC + VFCW one stage	0.5 - 1	+	+	average	×	250	8 years	1 - 4	0.5 - 1.3
	TF	1 - 2	rather yes	rather yes	×	*	350	3 m. / 10 y.	0,6	0.1 - 0.2
	TF + VFCW one stage	0.4 - 0.8	+	+	+	*	300	8 years	2 - 4	0,5
	TF + VFCW two stages partially saturated	1 - 2	+	+	+	*	350	10 years	1 - 4	0.2 - 0.9
	Coconut fragment filters (25-300 p.e.)	0.5 - 1	×	rather no	+	+	200-300	3 years	0 - 0.5	0 - 0.1
	Free growth systems									
	Natural lagooning (ponds)	11	++	rather no	++	*	170	8 years	0	0
	Aerated lagooning (ponds)	8	++	rather no	+	*	170	8 years	2 - 3	0,7
	AS (extended aeration)	0.5 - 1	×	rather yes	×	×	430	Daily /10 years	2	0.6 - 1
Collec. sanitation (> 10 000 EH)	AS	0.5 - 2.5	×	rather yes	×	*	>400	Daily	2 - 5	-
	MBR	0.5 - 1	×	rather no	×	*	>400	Daily	5 - 8	1 - 2
	SBR	0,9	×	+	×	*	320	Daily	4 - 6	1 - 2
Additional treatments	**Disinfection**									
	UV lamps	<0.01	×	×	average	+	–	–	–	0.1 - 0.5
	Phosphate removal									
	Physico-chemical treatment	<0.01	rather yes	rather yes	×	+	-	Daily	-	0.1 - 0.5
	Natural apatites	0.5 - 0.7	×	×	average	+	0	No	-	0 - 0.1
	Denitrification									
	HFCW (horizontal flow)	2 - 3	×	×	++	+	50	-	-	0 - 0.1

Legend: Faible performance | Performance mediocre | Bonne performance

Average observed performances, which vary according to the system design, the climate and the rigour applied in operation

Concentration and Output		Required discharge limits (mg/L)						Output (%)						Disinfection
		SS	BOD	COD	KN	TN	TP							
Average concentration of raw wastewater		250-300	200-400	600-900	60-80	60-80	10	SS	BOD	COD	KN	TN	TP	Reduction E. coli
Small and medium collective sanitation (until 5 000 max 10 000 EH)	**Fixed film treatments**													
	VFCW one stage	35	-	130	30	-	-	85%	77%	77%	59%	-	-	-
	VFCW one stage with recirculation	35	35	<125	30	-	-	90%	90%	90%	30%	-	-	-
	VFCW one stage with forced aeration	<20	<20	<90	10	15	-	99%	98%	92%	>84%	88%	-	4 Ulog
	VFCW two stages (French system)	<20	<20	<90	<15	-	-	94%	94%	88%	82%	-	-	-
	VFCW small size (load variations, campsites)	20	15	85	35	-	-	>90%	>90%	>90%	75%	-	-	-
	VFCW tropical climate	<25	-	<125	40	50	-	90%	85%	85%	60%	50%	-	-
	RBC (8 g BOD5/m²/j)	45	50	150	40	-	-	80%	80%	70%	30%	-	-	-
	RBC (4 g BOD5/m²/j)	<30	<35	<125	10	-	-	>90%	>90%	>90%	80%	-	-	-
	RBC + VFCW one stage	30	-	-	10	-	-	>90%	>90%	>85%	80%	-	-	-
	TF	<30	<35	<125	<20	-	-	90%	90%	85%	40-70%	40-70%	-	-
	TF + VFCW one stage	<30	<35	<125	<20	-	-	90%	94%	85%	>70%	-	-	-
	TF + VFCW two stages partially saturated	<20	<20	<90	<15	<30	-	>95%	89%	96%	>90%	92%	-	-
	Coconut fragment filters (25-300 p.e.)	<25	<20	<200	<15	-	-	-	-	-	80%	-	-	-
	Free growth systems													
	Natural lagooning (ponds)	<150	-	140	20	20	-	-	-	70-80%	70%	70%	60%	3 - 5 Ulog
	Aerated lagooning (ponds)	30	<35	85	20	20	-	85%	90%	80%	60%	60%	30-50%	3 - 5 Ulog
	AS (extended aeration)	<25	<20	<90	<10	-	-	-	-	-	-	>80%	-	2 Ulog
Collect. Sanitation (> 10 000 EH)	AS	<35	<30	<90	<20	<15	-	-	>90%	-	-	-	-	2 Ulog
	MBR	10	5	25	-	<30	-	90%	95%	90%	-	50-80%	-	6 - 7 Ulog
	SBR	10	5	25	2	<30	5	90%	95%	90%	95%	50-80%	50-60%	1 - 3 Ulog
Additional treatments	**Disinfection**													
	UV lamps	-	-	-	-	-	-	-	-	-	-	-	-	5 - 5.5 Ulog
	Phosphate removal													
	Physico-chemical treatment	-	-	-	-	-	<2	-	-	-	-	-	>80%	-
	Natural apatites	-	-	-	-	-	2	-	-	-	-	-	>80%	-
	Denitrification													
	HFCW (horizontal flow)	-	-	-	-	15	-	-	-	-	-	60-99%	-	3 Ulog

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