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Case Studies with Tertiary Treatment

The effective integration of wastewater reuse into water resource management is based on the quantity of water required for a specific application, as well as the associated water quality requirements.

The key challenge lies in choosing the most appropriate process to meet local constraints. The technical tools available are those already used for wastewater or drinking water treatment.

The process of selecting a tertiary treatment system involves at least three steps, the first of which is to assess the performance of available processes in relation to the quality of the water to be treated and the end use. The next step is to analyze regulatory constraints. The techno-economic assessment takes into account existing infrastructure and equipment, as well as sources of financing for investment and operation.

The quality requirements for each use are not the same. Generally speaking, non-drinking uses only require minor treatment.

A significant number of tertiary filtration-disinfection plants have been built for urban water reuse applications such as parks, school grounds and golf courses, as these processes involving solid/liquid separation and disinfection are simple and inexpensive.

There are significant regional and seasonal variations in water use models. For example, in urban areas, industrial, commercial and non-drinkable urban water requirements are the main demand for water. For agricultural applications in arid and semi-arid regions, irrigation is the main reason for water demand. Water

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For a color version of all figures in this chapter, see www.iste.co.uk/gaid/reuse2.zip.

requirements for irrigation applications tend to vary seasonally, while industrial water needs are more constant.

Tertiary treatment can therefore be used for a variety of purposes, as summarized in Table 1.1.

Use categories	Uses
Non-drinking, urban	Water for public parks, sports facilities, private gardens, roadsides, street cleaning, fire hydrants, vehicle washing, air conditioning and dust control
Agricultural uses	Non-commercially processed food crops, commercially processed food crops, dairy pastures, forage, fibers, seed crops, ornamental flowers, orchards, hydroponics, aquaculture, greenhouses and viticulture
Industrial uses	Cooling water, recirculating cooling towers, washing water, washed aggregates, concrete making, soil compaction and dust control
Recreational areas	Golf courses, recreational ponds with/without public access (e.g. fishing, canoeing and swimming) and aesthetic reservoirs without public access
Environmental areas	Wetlands, swamps, marshes, flow augmentation, wildlife habitat and forestry

Table 1.1. *Uses with tertiary treatment*

The choice of tertiary treatment includes the following processes:

– membranes included in secondary treatment (membrane bioreactor (MBR));

– simple disinfection: chlorine, peracetic acid, performic acid;

– combined disinfection: ozone-chlorine, UV-chlorine;

– tertiary filtration-disinfection: chlorine tertiary filtration, ozone-chlorine tertiary filtration, UV-chlorine tertiary filtration;

– quaternary treatment: ozone-granular activated carbon, advanced chemical oxidation;

– microfiltration (MF) membranes, ultrafiltration (UF) membranes, MF or UF followed by nanofiltration (NF) or reverse osmosis (RO) membranes;

– MF and UF can be coupled with advanced oxidation, ozone-GAC, etc.

The choice of process depends on a number of factors, the most important of which are effluent quality, type of use, quality requirements and plant size.

Depending on local conditions and technical and economic criteria, different processes can be considered.

Combined filtration-disinfection technologies or MF membranes guarantee improved water quality for the various uses listed in Table 1.1. Their implementation is helping to ensure better environmental protection and new applications in urban areas.

They reliably ensure good water quality (removal of suspended solids, viruses and pathogens). The most common method of disinfecting wastewater is chlorination. In some countries, the potential toxicity of chlorine by-products makes this technique less appealing. Ultraviolet irradiation appears to be an emerging method. Its efficacy is comparable, if not often superior, to the elimination of viruses and bacteria, but it has no residual. Ozone disinfection is not widely used, but it is gaining ground due to its excellent effectiveness in inactivating pathogens.

Tertiary treatment therefore allows direct reuse, in other words, the immediate use of treated wastewater, without passing it through or diluting it in the natural environment.

Due to consumer quality requirements, this treatment can only be applied for non-drinkable uses in the agricultural (irrigation), industrial and urban sectors.

The microbiological guarantees expected for each use are summarized in Table 1.2.

Uses	**Reduction of viruses Log 10**	**Reduction of protozoa Log 10**	**Reduction of bacteria Log 10**
Irrigation of food crops	7.0	6.5	7.0
Car washing	5.5	4.5	5.5
Laundry	4.5	3.5	4.5
Cooling towers	4.5	4.0	4.5
Irrigation of non-food crops	3.5	2.5	3.5
Recreation and leisure areas	4.0	3.5	4.0
Toilet flushing	5.5	5.0	5.5

Table 1.2. *Reduction across the entire chain: from raw water to water for reuse*

Treatment systems must contain both design and operating requirements, so as to ensure treatment reliability. Reliability features, such as alarm systems, emergency power supplies, duplication of treatment processes, emergency storage or disposal of inadequately treated wastewater, monitoring devices and automatic controllers, are important. From a public health perspective, measures must be taken to ensure reliable disinfection.

1.1. Limited urban use, irrigation of non-food or processed crops[1]

These applications are relatively common examples of water reuse in areas of restricted access or activity. Typical examples of this category are as follows: landscape irrigation (golf courses, cemeteries, road verges and highway medians), restricted recreational uses (recreational fishing, canoeing and other non-contact recreational activities), agricultural irrigation (forages, fibers, grain crops, pastures, nurseries, sod farms and commercial aquaculture). Water quality requirements are the same for all uses in this category.

1.1.1. *Irrigation*

The aim is to reduce the number of pathogens in treated wastewater by installing several barriers designed to reduce the likelihood of microorganisms being present.

The main health risk control measures for irrigation with treated and reused wastewater include the following:

– wastewater treatment and quality control during distribution and in storage facilities;

– the choice of appropriate irrigation methods and cultivation practices, such as irrigation of restricted areas (such as freeway landscapes, other areas where the public has limited access or exposure to reclaimed water) and irrigation in areas with free public access (such as golf courses, parks, playgrounds, schoolyards and residential landscape);

– public access conditions (recreational areas, parks, green spaces, etc.);

– other measures, including control of human exposure (e.g. protective measures for farm workers such as gloves and masks), harvesting measures, education of the public concerned and promotion of good hygiene practices.

1 Some of the technical and scientific descriptions presented in this book have been partly taken from *Drinking Water Treatment 4 and 5* (Gaid 2023), as the processes used in the two applications are very similar.

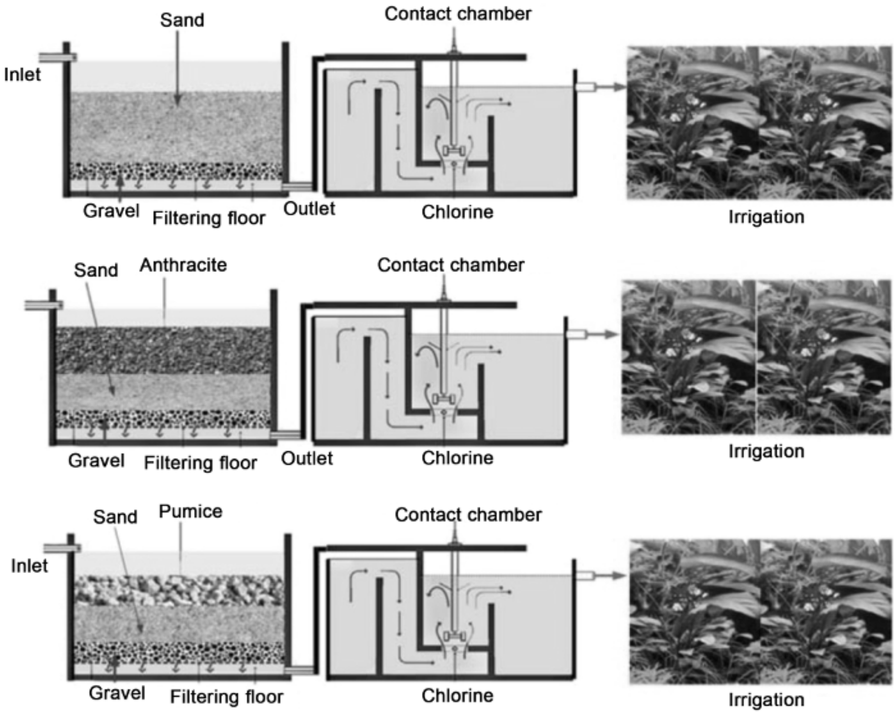

Figure 1.1. *Tertiary treatment with various filters and chlorine disinfection for irrigation purposes*

Non-drinking treated wastewater is used as a new water source to promote agricultural and aquaculture production, industrial uses, reclamation uses such as irrigation, washing and flushing, recreation and artificial recharge. The reuse of effluent from tertiary wastewater treatment increases water sustainability in an environmentally friendly way.

Tertiary treatment is essential for compliance with the World Health Organization (WHO) guidelines and European and national wastewater discharge standards. In other words, the removal of phosphorus and other pollutants from wastewater is a legal obligation. In France, treated wastewater is most often reused for agricultural irrigation and watering green spaces. The efficiency of tertiary treatment is therefore essential to guarantee water quality prior to reuse. The various methods used ensure the complete removal of undesirable substances, allowing predefined quality objectives to be met.

For example, if wastewater is to be reused for vegetable irrigation, pathogens must be removed. In urban reuse, on the other hand, nitrogen and phosphorus are targeted during treatment. The same applies to groundwater recharge. This avoids any risk of eutrophication.

1.1.2. *Industrial reuse and recycling*

Industrial reuse of treated wastewater and internal recycling are now a technical and economic reality. Thermal and nuclear power plants (cooling water) are among the sectors that use wastewater in large quantities. Other applications are possible when the quality of the reused water is not very demanding, such as the mechanical and metal industries, construction (aggregate washing, concrete manufacture, equipment cleaning, cooling tower feed, excluding evaporative cooling), chimney cleaning and manufacturing water (excluding food processing).

1.1.3. *Urban non-drinking water*

In urban and suburban areas, treated wastewater reuse can be highly beneficial for municipalities. The most common uses are irrigation of green spaces (parks, golf courses, sports fields), landscaping (waterfalls, fountains, ponds), street or vehicle washing and fire protection, amenity ponds, swimming pools, ponds for fishing and boating, etc.

Figure 1.2. *Reusing water for non-drinking urban use*

1.1.4. *Storage*

All wastewater reuse plants require a certain amount of storage, in order to regulate daily variations in production flow. In certain sensitive cases, storage is needed to cope with the risk of interrupted production of treated wastewater or failures in the treatment plant. In water-deficient regions in particular, storage is seasonal: it will store water that is not needed in winter, to be used as and when required. It will even out daily variations in the flow from the treatment plant and store the surplus when the average wastewater flow exceeds irrigation requirements.

Storage is therefore an essential link between the treatment plant and the irrigation system. It is also used to provide insurance against the possibility of inappropriate wastewater entering the irrigation system.

1.2. Nosedo plant (Milan, Italy): irrigation

The Nosedo wastewater treatment plant (Milan, Italy) treats the wastewater of 1,250,000 population equivalent (P.E.) with nitrification and denitrification. It is the largest plant in Europe, with almost 60–70% of treated wastewater destined for agricultural use:

– 432,000 m^3 treated per day;

– 5 m^3/s treated in dry weather;

– 15 m^3/s in rainy weather;

– 60–70% of treated water is used for agricultural purposes.

Urban wastewater comes from the central-eastern area of Milan, from the discharger emissary of Nosedo and the Ampliamento Est collector.

The Milano-Nosedo wastewater treatment plant is one of Europe’s largest. It treats 50% of Milan’s wastewater, in particular from the central and eastern parts of the city. The plant is capable of treating around 157,000,000 m^3/year of wastewater, which is then returned to the water system (Roggia Vettabbia), but also reused for irrigation purposes.

During the design phase of this plant, great attention was paid to certain aspects related to energy efficiency, such as the choice of equipment with inverters, the installation of a high-efficiency fine-bubble aeration system for oxygen transfer, and O_2 probes to monitor and control oxygen concentration in each biological treatment line. It should also be noted that the Nosedo plant features biological oxidation/

nitrification stages with a high sludge age, tertiary sand filtration and high-level disinfection.

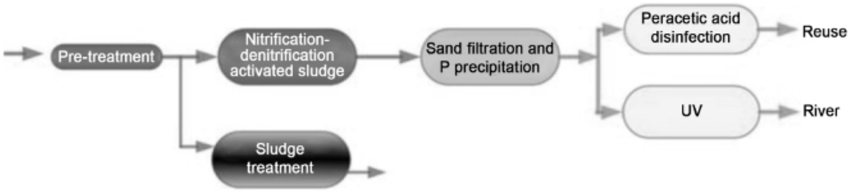

Figure 1.3. *Wastewater treatment plant with reuse (Nosedo, Milan)*

The plant was commissioned on October 30, 2004.

Treated wastewater is used to irrigate rural areas and is accepted as a valuable resource by farmers.

The wastewater treatment plant is an excellent example of how to reduce the demand for water from conventional sources and make efficient use of water resources in many areas. Indeed, the project also includes improvements to the surrounding areas aimed at recomposing the landscape and environmental features of part of the historic Vettabbia valley, dominated by the Chiaravalle Abbey, and creating diverse habitats that are interconnected to maximize biodiversity.

Figure 1.4. *Nosedo wastewater treatment plant including tertiary treatment*

During the irrigation period (April–September), water is discharged into a ditch called Roggia Vettabbia Bassa. This water is then diverted to the fields through channels.

In the area served by the Emissario Nosedo, Roggia Vettabbia and Redefossi agricultural water networks, the farming system is mainly extensive and traditional, with forage crops (grass, corn), rice and cereals.

Parameters	**Raw water inlet ($mg.L^{-1}$)**	**Treated water outlet ($mg.L^{-1}$)**	**% of reduction**
BOD5	170	<5	99
COD	300	<15	97
Total N	27	6.5	76
Total P	3.5	0.9	74
TSS	190	<5	99
Microorganisms (CFU per 100 mL)			
Total coliforms	10^5	40	–
E. coli	10^4	<10	–

Table 1.3. *Water quality at the outlet of the Nosedo tertiary treatment plant*

Water quality parameters for influent and effluent are shown in Table 1.3.

Figure 1.5. *On-site spraying with reused water (Nosedo)*

Operating costs for the Nosedo wastewater treatment plant amount to €0.139/m^3. The main component of operating costs is the cost of chemicals (30%), including peracetic acid used for disinfection. Other operating costs include labor (20%), energy (20%), sludge disposal (15%) and maintenance (15%).

The main feature of the Nosedo plant is the large volume of treated water that is reused for agricultural purposes.

The Nosedo wastewater treatment plant is one of the best examples of water reuse in Europe. The challenge was to guarantee the best conditions for water reuse. This is why the treated wastewater complies with European directives.

The plant is equipped with software for real-time optimization of process performance. It provides control data to optimize the entire wastewater system, including the sewer network and treatment plant, energy consumption, chemicals, as well as biological and hydraulic capacity improvement.

The farmers' associations known as Consorzio Vettabbia comprise 84 member farms.

1.3. The Hermitage station (Reunion Island)

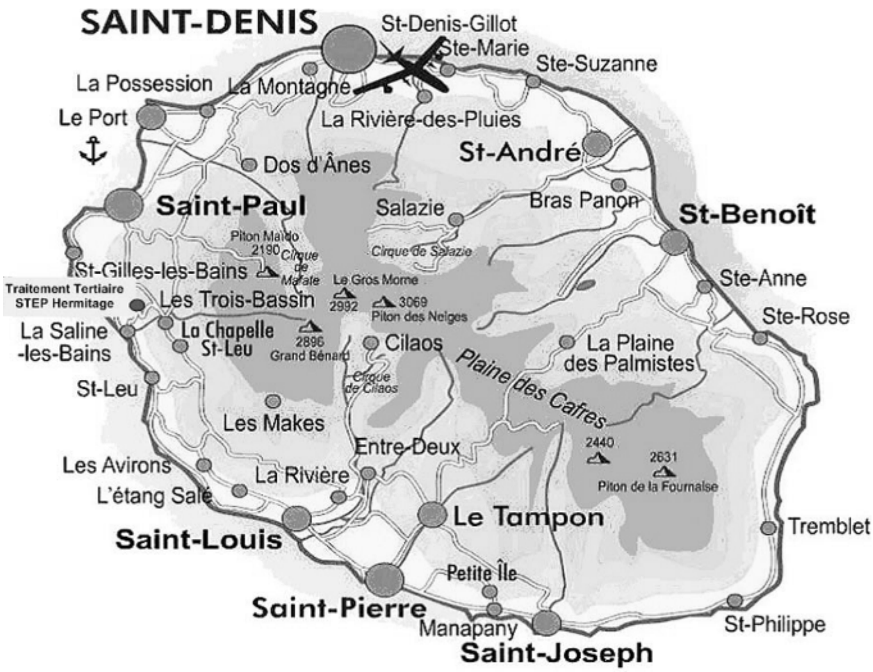

Figure 1.6. *Map of Reunion Island (France)*

Improving local management of water resources is one of Réunion's fundamental challenges in terms of sustainable development.

The targets set are still based on supplying the population with adequate quality drinking water, as well as on efficient wastewater treatment and reuse of treated water for irrigation or industrial purposes.

For example, the rehabilitation program for the Hermitage wastewater treatment plant involved bringing the plant's discharges up to standard, and doubling its treatment capacity from 12,500 to 25,000 P.E. in 2010.

1.3.1. *Pollutant loads*

The basic pollutant load data taken into account for tertiary treatment are defined by hydraulic load parameters.

1.3.1.1. *Hydraulic load*

The maximum hydraulic flow rate is 300 m^3/h for:

– 6,500 m^3/day for 22 h in dry weather;

– 14,000 m^3 for 47 h in wet weather.

1.3.1.2. *Treatment targets*

The system is designed to meet the requirements for water intended for irrigation and potentially for non-food industrial use.

The tertiary treatment process includes the following facilities:

– a lift station;

– a technical building with:

- electrical room, reagent room, air and backwash filter equipment,
- wash water tank,
- sand filter and UV reactor,
- venturi meter with discharge to existing drain,
- a wastewater discharge station.

The tertiary treatment lift station is fed by gravity from refining lagoon No. 3. A 3-mm mesh strainer is placed on the station's feed pipe to stop large particles and miscellaneous debris. This strainer is self-cleaning, thanks to a ramp equipped with nozzles for countercurrent injection of pressurized water. Pressurized water is drawn from the pumping station's discharge manifold through a "tapped" pipe.

The self-cleaning strainer is cleaned by a pump connected directly to the storage tank. Four pumps (3 + 1 back-up) supply the tertiary treatment system in 100 m^3/h flow steps. The start-up of one, two or three pumps is controlled by a level measurement on the infiltration lagoon.

The nominal flow rate of 300 m^3/h is discharged through two in-line, self-cleaning pre-filters with a mesh size of 50 µm, each rated at 150 m^3/h. Turbidity is measured downstream of the pre-filters, and a coagulant, such as ferric chloride, is injected at a configurable turbidity threshold.

Raw water and coagulant are mixed by an in-line static mixer. The pressurized sand filters are fed from a general feeder with pre-filtered and possibly pre-coagulated water.

1.3.2. *Tertiary filtration*

An in-line injection of ferric chloride upstream of the sand filters is therefore projected. Coagulation is triggered when the total suspended solids (TSS) concentration of the water pumped into lagoon No. 3 exceeds 25 $mg.L^{-1}$. Injection of ferric chloride is triggered by a turbidity threshold in the water pumped into lagoon No. 3. In addition to reducing particle-bound phosphorus, ferric chloride injection also slightly reduces dissolved phosphorus precipitated by the iron salt. Ferric chloride is delivered in 1 m^3 containers.

The coagulant is injected by a dosing pump (1 + 1 backup) into the main line, upstream of the static mixer. The static mixer, made up of helicoids, ensures turbulence for homogenization and good coagulation. Reagent injection is not continuous and depends on the quality of the water fed to the tertiary filters.

Tertiary filtration is carried out using six pressurized filters, fed by the water lift station of lagoon No. 3, after pre-filtration and possibly pre-coagulation. The filter layer is made up of 1.35 mm expanded clay media (Biodagene) resting on a strained floor.

1.3.2.1. *Choice of filtration*

The choice of particle size – 1.35 mm – and filter bed height – 2 m – offers the following advantages:

– prevents rapid clogging of the surface filter, by favoring a higher layer height for TSS trapping;

– prevents significantly reduced filtration cycles in the event of TSS peaks, and limits degradation of the filtered water;

– prevents filtration speeds of 15 $m.h^{-1}$.

Stable filtered water quality is also beneficial for UV disinfection.

The water to be treated is fed into the filters through a gully at the top, which has a dual role: intake of the water to be filtered and discharge of the wash water.

The filter media consists of a 2-m thick layer of Biodagene (Table 1.4). Beneath the filter layer is a 10-cm layer of gravel and a metal floor fitted with nozzles.

The floor ensures perfect homogeneity of fluid distribution within the filter mass, both during filtration itself and during washing operations.

The filtered water is discharged through a pipe at the bottom of the filter. This pipe also serves as a water inlet for filter washing. The design of the system allows simultaneous washing and filtration. Filters are washed in turn during or outside operating periods.

Washing is triggered by a timetable, clogging threshold or operator decision. Filter pressure loss is checked by measuring the difference in pressure between the filtered water inlet pipe and the filtered water outlet pipe (contact differential pressure gauge).

Filters are preferably washed at night, when the flow treated at the WWTP is reduced. This will limit the hydraulic impact on the plant.

1.3.2.2. *Filter cleaning*

The various washing operations take place automatically. A wash cycle comprises several distinct phases:

– First phase: detasseling. Air is blown in at a rate of 50 $Nm^3.h^{-1}.m^{-2}$ for 1 min.

– Second phase: air + water. Air is blown in at a rate of 50 $Nm^3.h^{-1}.m^{-2}$ combined with a countercurrent of water limited to 8 $m^3.h^{-1}.m^{-2}$ for 8 min.

– Third phase: rinsing and evacuation of dirty water with water alone at a flow rate of 50 $m^3.h^{-1}.m^{-2}$ for 8 min.

Wash water is run through the same pipe as the filtered water outlet. Air is supplied through a pipe running under the floor. Wash water is supplied by a pump providing the required flow rate of 200 $m^3.h^{-1}$ for maximum manometric head.

The wash water is pumped into the 20 m^3 filtered water tank and disinfected. Dirty water is then collected in a station equipped with two 60 $m^3.h^{-1}$ unitary drainage pumps (1 + 1 backup) discharging to the biological tank.

Parameters	Unit	Values
Total incoming flow (over 15 h)	$m^3.h^{-1}$	300
Number of filters	u	6
Filtration rate on N filters	$m.h^{-1}$	13.2
Filtration rate on N^{-1}	$m.h^{-1}$	15.8
Unit surface area	m^2	3.8
Unit diameter	m	2.2
ES Biodagene	mm	1.35
Height of material (gravel + Biodagene)	m	0.1 + 2.0
Minimum cycle time (TSS input 25 $mg.L^{-1}$)	h	24

Table 1.4. *Tertiary filtration dimensions*

1.3.3. *UV disinfection*

Figure 1.7. *UV reactors and filters*

The principle of disinfection by UV radiation has developed considerably over the last few decades for wastewater treatment, and it is considered a good alternative to chlorination. With UV radiation, disinfection is not accompanied by the formation of any reaction products with organic matter in the water. UV rays are light waves with wavelengths between 100 and 400 nm. Their germicidal power depends on the wavelength emitted. UVC between 200 and 280 nm is the most germicidal.

Low-pressure lamp technology was chosen for this installation. These have the advantage of emitting maximum radiation in the wavelength corresponding to the optimum germicidal band (254 nm):

– long service life: 15,000 operating hours (12,000 guaranteed operating hours), 15,000 reported hours;

– low-power consumption;

– 96% of the spectrum is emitted at 253.7 nm for maximum efficiency;

– the applied dose is 400 $J.m^{-2}$ at the end of the lamp life.

Three lines (Figure 1.7), each equipped with a 100 $m^3.h^{-1}$ in-line low-pressure UV reactor, are installed downstream of the tertiary filtration unit. They are independent and can be isolated from one another. The system is controlled by an electrical cabinet, which switches on the lamps, operates them and counts up the operating hours, and is equipped with an alarm to indicate any malfunction.

The reactors (Table 1.5) feature automatic lamp cleaning by sweeping. The cleaning frequency is adjustable according to water quality and intensity measurement.

The UV reactors are as follows:

– arranged horizontally to facilitate inspection and maintenance operations;

– equipped with two draining and cleaning valves;

– equipped with three mixers to homogenize effluent and disinfection.

In addition, turbidity is measured to assess the presence of suspended matter in the filtered water, which is known to reduce UV efficiency. The UV disinfection stage can be bypassed by a set of manual valves in the event of significant degradation of the filtered water.

Treated and disinfected water is collected in a buried tank, and then pumped through a venturi channel. A flow-controlled refrigerated sampler is provided.

Parameters	Values
Flow rate	100 $m^3.h^{-1}$
Installed germicidal power	1,500 UVC watts
Water volume in chamber	107 L
Number of lamps per reactor	10 lamps
Average lamp life	15,000 h
Contact time	3.85 s
Installed capacity per reactor	3.7 W
Approximate pressure loss	0.06 bar
Number of UV reactors	3

Table 1.5. *UV reactor dimensions*

The results are as follows:

– The TSS concentration in produced water was always below 5 $mg.L^{-1}$, and most often around 2 $mg.L^{-1}$.

– The results obtained on the produced water, with regard to microorganisms, show that the concentrations obtained with the various microorganisms are well below the required thresholds in the majority of cases. Interestingly, the values for salmonella and enterovirus are zero. Helminth egg values were always below $1.L^{-1}$.

Concentrations of 0–1 CFU/100 mL were obtained with fecal streptococci, with a high value of 6 CFU/100 mL.

The expected bacteriological quality after UV treatment is shown in Table 1.6.

At certain short periods, higher suspended solids values in the treated water (>5 $mg.L^{-1}$) were observed, resulting in a slight deterioration in disinfection conditions. However, concentrations of fecal coliforms and streptococci remained below guarantee levels.

The UV transmittance value of the water ranged, most of the time, between 58% and 62%, indicating low suspended solids and low water coloration. These parameters justify the efficiency of filtration and their implications for UV disinfection performance.

Parameters	Water quality at wastewater treatment plant outlet	Values obtained at tertiary treatment outlet
BOD5	25 mg.L^{-1}	–
COD	125 mg.L^{-1}	–
TSS	35 mg.L^{-1}	<5 mg.L^{-1}
Total N	15 mg.L^{-1}	–
Total P	2 mg.L^{-1}	–
Turbidity	10 NTU	<3 NTU
Total coliforms (CFU/100 mL)	10^7	0–50
Fecal coliforms (CFU/100 mL)	10^6	0–20
Fecal streptococci (CFU/100 mL)	10^4	100
Salmonella (CFU/100 mL)	10^3	0–1
Enteroviruses (per L)	10^4	0 per 10 L
Intestinal helminth eggs (per L) ***Ascaris*** **and** ***Trichuris*** **species**	–	<1

Table 1.6. *Water quality at tertiary treatment inlet and outlet*

Figure 1.8. *Tertiary treatment plant (Reunion Island, France)*

1.3.4. *Educational aspect*

All tertiary treatment pipes have been painted with a very precise color code. The aim is to use this installation as an educational tool. The tertiary treatment plant is frequently visited by schools, colleges, universities, associations and teachers. Color-coded piping makes it easy for all visitors to understand.

This example of tertiary wastewater treatment at the Hermitage plant (Réunion) shows that it is one of the possible solutions for reusing this water to cope with recurring periods of drought and/or limit water withdrawals from a natural environment. In this way, the water produced can be reused for other purposes (such as irrigation) instead of drinking water resources.

It also makes it possible to remove or defer discharges from the treatment plant into vulnerable environments. With conventional technologies such as sand filtration and UV disinfection, it is possible to respect water quality standards with a view to agricultural and industrial reuse, or to protect recreational areas (bathing waters, sporting activities). This is a major issue at the Hermitage station, which is a major tourist area on the island.

1.4. The Barcelona plant (Spain): regeneration of wetlands, irrigation

The Llobregat River is one of the main sources of water supply for the Barcelona metropolitan area. The Catalan Water Agency requires that a minimum water flow of 3.5 $m^3.s^{-1}$ be maintained in summer. Irregular rainfall in the Llobregat watershed has led to a profound water deficit in the river and in the surrounding areas. As a result, emergency measures were implemented, with seasonal restrictions on irrigation water.

A wastewater reuse project was therefore planned with the aim of:

– replenishing the water resources vital to Spain's Mediterranean coast, particularly in the metropolitan area of Barcelona, home to 4 million inhabitants;

– improving the environmental balance in the Llobregat delta by finding an alternative to discharging 153 million m^3/year of fresh water into the sea;

– solving the growing problem of water shortages in the dry season, while preserving the ecology of the Llobregat delta and river, and protecting groundwater that has been overexploited or degraded by saline intrusion. To achieve this, it was necessary to find an additional 50 million m^3 of water per year.

With a capacity of 302,400 $m^3.day^{-1}$, it is the largest wastewater reuse plant in Europe and one of the largest in the world. This treatment process is designed to:

– increase available water resources: 64,800 $m^3.day^{-1}$ to irrigate agricultural areas;

– restore and recharge 34,560 $m^3.day^{-1}$ of wetlands in the delta;

– return 172,800 $m^3.day^{-1}$ to the Llobregat river to restore environmental balance.

The water recycled in this way maintains the river's flow at an ecologically satisfactory level and meets the water requirements for agricultural irrigation and recharging the delta's wetlands.

The quality of reused water is different for each use. The criteria used for the various applications are shown in Table 1.7.

Wetlands and irrigation	Salt water intrusion barrier
BOD5: ≤10 $mg.L^{-1}$ TSS: ≤5 $mg.L^{-1}$ Turbidity: <5 NTU Fecal coliforms: <10 UFC/100 mL Intestinal helminth eggs: <1 u/100 mL Residual chlorine : >0.6 $mg.L^{-1}$ Dissolved oxygen: ≥7.5 $mg.L^{-1}$	TSS ≤ 1 $mg.L^{-1}$ Turbidity: <0.1 NTU Organic matter: <10 $mg.L^{-1}$ Fecal coliforms: 0 per 100 mL

Table 1.7. *Water quality requirements for wastewater reuse at the Barcelona site*

Depending on the uses of the reused water, two technical solutions are applied at the Catalan wastewater treatment plant.

The first solution consists of a conventional tertiary treatment process comprising coagulation-flocculation-settling (3 Actiflo), followed by mechanical filtration (10 Hydrotech disk filters) and ultraviolet disinfection, and lastly, post-disinfection with chlorine.

The second solution uses a double-membrane solution (see Chapter 4) that delivers a more stringent water quality, intended for reinjection into the ground and to restrict salt intrusion.

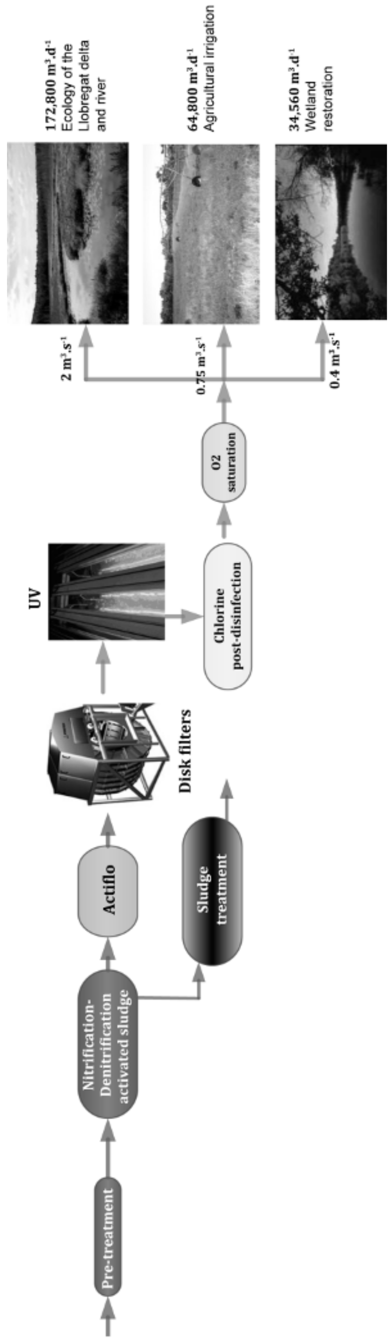

Figure 1.9. *Treatment plant for wastewater reuse in Barcelona*

Figure 1.10. *Barcelona plant with tertiary treatment*

The results obtained show that the quality of treated water intended for various reuse applications meets the expected objectives. Microbiological quality is excellent after the two stages combined: UV disinfection followed by chlorination.

Parameters	Units	Values
TSS	mg.L^{-1}	3.0–5.0
Turbidity	NTU	1.0–1.6
BOD5	mg.L^{-1}	< 3
COD	mg.L^{-1}	22–44
N-NH$_4$	mg.L^{-1}	0.9–2.5
N-NO$_3$	mg.L^{-1}	4.2–6.9
Total N	mg.L^{-1}	6.9–10.4
Total P	mg.L^{-1}	0.6–1.5
Escherichia coli	CFU.100 mL^{-1}	<1
Helminth eggs	u.10 L^{-1}	<1
Fecal coliforms	CFU.100 mL^{-1}	<1
***Legionella* spp.**	CFU.L^{-1}	<100

Table 1.8. *Performance of the Barcelona wastewater reuse plant*

In the reused effluent, a variety of contaminants, such as pharmaceuticals and personal care products (PPCPs) and disruptive compounds (EDCs), have been detected in a wide range of concentrations. A quaternary RO membrane treatment ensures their removal, with the produced water reinjected into the subsoil.

1.5. Ajman (United Arab Emirates): irrigation and non-drinkable urban use

The United Arab Emirates has one of the highest water consumption rates in the world, with each person using an average of 550 L of water per day. Total annual water demand is expected to reach 8.8 billion cubic meters by 2030, almost double what is consumed today.

As an alternative to the consumption of non-renewable sources, a comprehensive wastewater reuse plan has been drawn up for use in residential and recreational areas, green spaces and for industrial purposes. The wastewater treatment plant has a capacity of 140,000 $m^3.day^{-1}$. As a result, one-third of the treated wastewater is reused to irrigate various areas of the Emirate of Ajman or for industrial applications.

The authorities' aim is to make reused water a norm throughout the Emirate of Ajman, and for the general public to accept it as one of the best available sources for sustainable water use. The general idea is that the people of Ajman and the United Arab Emirates will be more open to the idea that treated wastewater can be reused.

Figure 1.11. *Wastewater reuse in Ajman (United Arab Emirates)*

The Ajman wastewater reuse plant is based on the double-pass membrane principle, comprising a first microfiltration stage followed by a second RO stage. The water produced is used for various industrial and commercial purposes 24/7.

Distribution takes place via a tank-filling area that can simultaneously accommodate 12 tanks of different capacities based on the service-station model.

Water quality parameters such as TDS (total dissolved solids) are better than most commercial bottled waters, making it perfect for demanding industrial use.

Figure 1.12. *Reverse osmosis membrane and service station for reused wastewater*

Figure 1.13. *Distribution of treated wastewater by "non-drinking water" tanker trucks*

Once treated, the wastewater is reused for unrestricted irrigation of Ajman's entire landscape and greenery. As the plant produces high-quality water, it has been adopted by many industrial companies for non-drinking uses, as a substitute for groundwater. Customers include air-conditioning plants, civil engineering companies and non-food industries, all of which have the common requirement of very low salinity water.

1.6. Al Wathba treatment plant (Abu Dhabi): recreational areas, green spaces, industries

The Emirate of Abu Dhabi is an arid region with an average annual rainfall of less than 100 mm. The Emirates' water resources are traditional or conventional (rainfall, springs, wadis, sabkhas, lakes, ponds and groundwater) and non-traditional or non-conventional (desalinated water and treated wastewater).

Groundwater supplies are dwindling, and the imbalance between supply and demand is resulting in ever-increasing quantities of desalinated water.

Water shortages for irrigation are offset by desalinated water. Despite investments in desalination, this has had no impact on the desire to save drinking water, as it is free for municipal use.

This proved crucial for the United Arab Emirates, where groundwater resources are limited and the urban population is growing rapidly. The combination of high population growth and rapid urbanization meant that the United Arab Emirates had to meet two major challenges: to treat the growing quantity of wastewater produced and provide ever more water resources for its population, industry and agriculture. As part of its *Abu Dhabi Economic Vision 2030* development plan, the Emirates has made environmental management one of its top priorities. The treatment and reuse of wastewater has become a cornerstone of the Emirates' sustainable development.

In Abu Dhabi, to complement existing wastewater treatment facilities, large-scale plants have been built in joint venture with the private sector (BOOT mode). These include Al Wathba, Allahamah and Al Saad, which are designed to supply water for irrigation.

Tertiary treatment is the final wastewater treatment process at the Al Wathba 2 wastewater treatment plant. The tertiary treatment process comprises two stages: filtration and disinfection.

A two-layer filter (pumice and sand) is used to remove suspended particles larger than 10 μm. The filtered effluent is then disinfected by sodium hypochlorite injection. Sodium hypochlorite is generated on-site by electro-chlorination units.

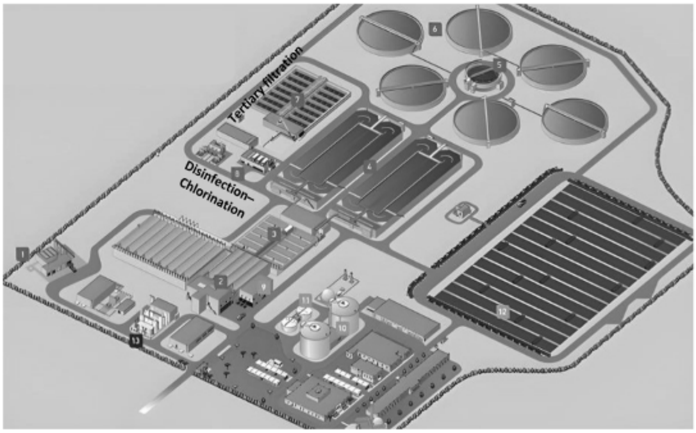

Figure 1.14. *Al Wathba wastewater treatment and reuse plant*

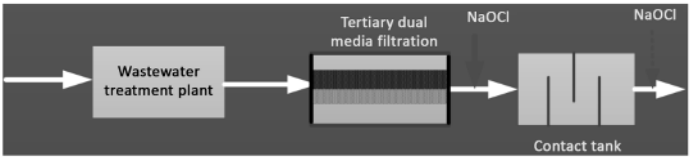

Figure 1.15. *Tertiary treatment plant (Al Wathba, Abu Dhabi)*

Parameters	Units	Values
Daily flow rate (contractual capacity)	$m^3.day^{-1}$	300,000
Hourly flow rate	$m^3.h^{-1}$	12,500
Fecal coliforms tertiary treatment inlet	CFU/100 mL	$\leq 10^7$
Contact tank volume	m^3	6,459
Average contact time	min	31
Minimum contact time	min	24.2
Chlorine consumption	$kg.h^{-1}$	203.8 Max.: 348.8

Table 1.9. *Operating conditions for tertiary treatment*

The disinfection step is based on the following operating conditions presented in Table 1.9.

Parameters	Unit	Guarantee (average sample 24 h)
pH	–	6.5–8.5
BOD5	mg.L^{-1}	≤10
TSS	mg.L^{-1}	≤10
N-NH$_4$	mg.L^{-1}	≤2
Dissolved oxygen	mg.L^{-1}	≥3
Turbidity	NTU	≤2
E. coli	CFU/100 mL	≤10
Free chlorine residual	mg.L^{-1}	≥1

Table 1.10. *Fecal coliform guarantees at the Al Wathba plant (Abu Dhabi)*

The results obtained show that guarantees are respected for all parameters. TSS is below 3 mg.L^{-1}, turbidity is below 2 NTU and BOD5 is well below 10 mg.L^{-1}. *Escherichia coli* concentrations are at 0 CFU per 100 mL more than 99% of the time.

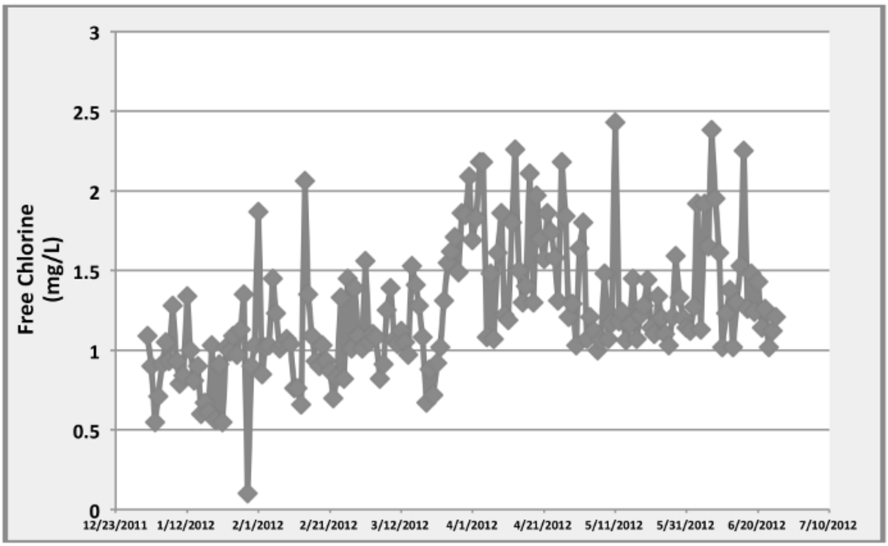

Figure 1.16. *Free chlorine residual at tertiary treatment outlet*

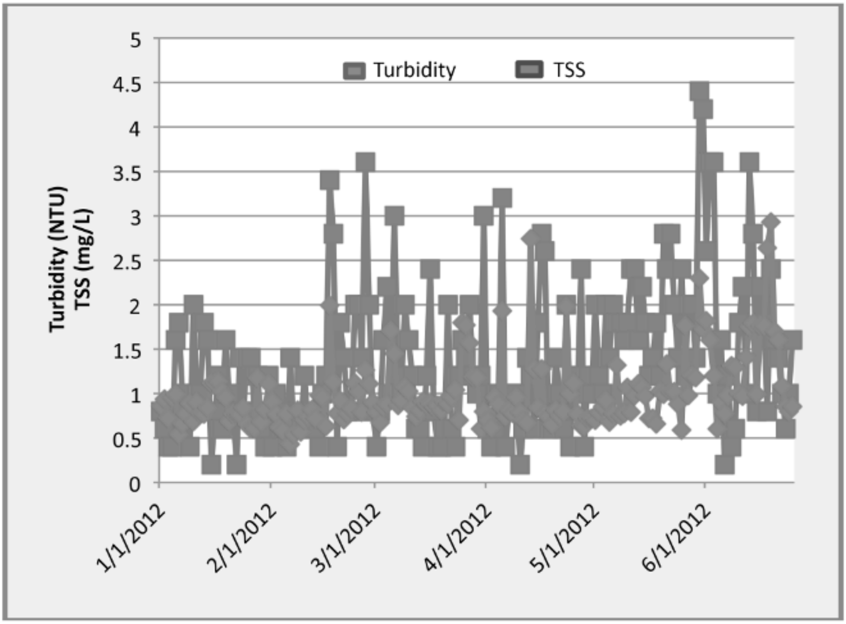

Figure 1.17. *Changes in turbidity and TSS in reused water*

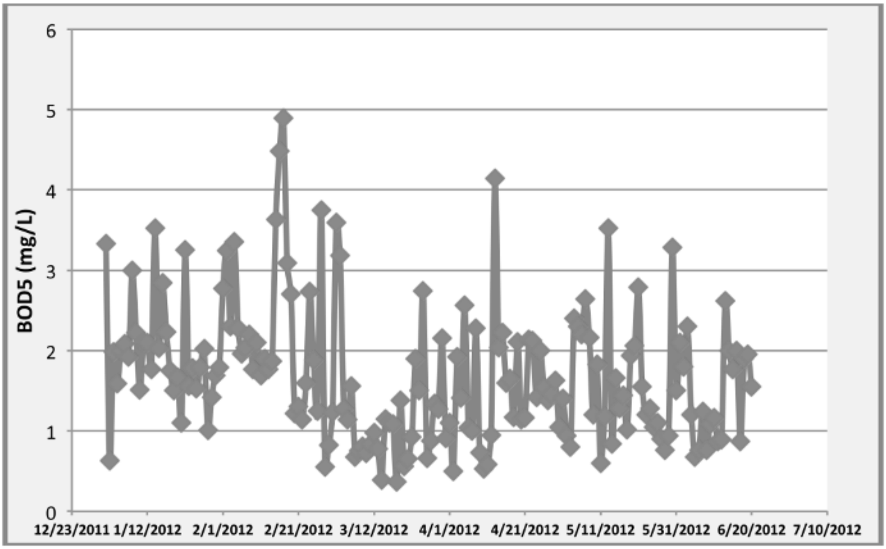

Figure 1.18. *Changes in BOD5 at tertiary treatment outlet*

Figure 1.19. *Applications for reused wastewater*

Reused wastewater from the Al Wathba 2 plant produces around 300,000 cubic meters of water a day and is distributed to consumers for use in agriculture, livestock farming and the capital's parks and gardens.

1.7. Burj Khalifa lake (Dubai): reuse wastewater for a recreational area

The project involves reusing rainwater and concentrate from a demineralization plant to supply the Burj Khalifa lake (Dubai). The requirements of the specifications are strict:

– The treatment system must maintain water clarity and ensure that microorganisms, algae, fungi, etc., do not grow in the lake.

– The water must, at all times, be free of harmful bacteria, pale blue in color, dull in appearance and odorless.

– Biocides and algaecides are permitted where necessary.

The treatment process includes:

– feed water pumping;

– coagulation-flocculation-settling with ballasted flocs (Actiflo®) during rainwater periods;

– mechanical filtration on disk filters (10 µm cut-off);

– transfer to the lake.

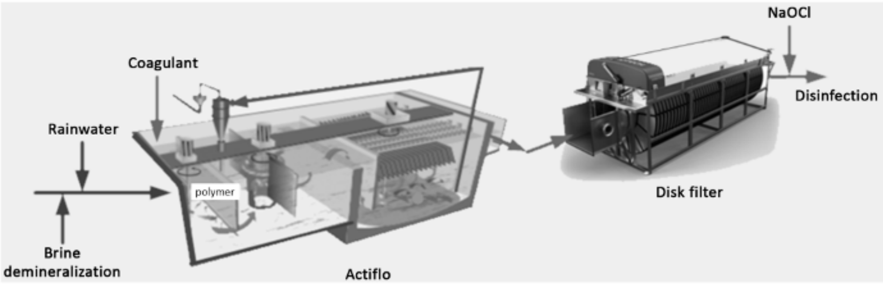

Figure 1.20. *Treatment plant for Burj Khalifa lake (Dubai)*

To prevent dissolved salts from demineralization brines from accumulating in the lake, the Actiflo® does not operate continuously. It only operates during storms, when the water is loaded with suspended solids.

No chemicals such as PACl (polyaluminum chloride) are injected into the water treatment line under dry conditions. PACl is dosed during storm conditions, so as to limit the concentration of salts in the lake.

The injection of chemical reagents during stormy periods is necessary, but does not lead to an increase in salts, as rainwater dilutes the water present in the lake.

When stormwater arrives at the treatment plant, Actiflo® units treat it as a priority. The inlet system can handle a total flow of 2,600 $m^3.h^{-1}$.

1.7.1. *Treatment plant dimensions*

1.7.1.1. *Recreation area (lake)*

Water level in lake	1.3 m
Lake surface area	127,875 m^2
Volume of water in lake	166,238 m^3 (treated in 3 days)
Water flow to be treated in lake	2,309 $m^3.h^{-1}$ = 166,238 m^3/3 days

Table 1.11. *Dimensions of the recreational lake*

1.7.1.2. *Actiflo*

Actiflo® units	4 units
Mirror surface	12.40 m²
Mirror speed	51.0–53.5 $m^3.h^{-1}$
Unit flow per Actiflo	630 $m^3.h^{-1}$ on average, up to 664 $m^3.h^{-1}$
Coagulation tank volume	22,45 m^3 (contact time: 2.03 min)
Injection tank volume	25.54 m^3 (ct: 2.28 min)
Flocculation tank volume	38.70 m^3 (ct: 3.45 min)
Settling tank volume	67.50 m^3 (ct: 6.03 min)

Table 1.12. *Actiflo dimensions (Veolia)*

1.7.1.3. *Mechanical filtration*

Disk filter (Hydrotech)	4 units
Number of trays per unit	14 trays
Unit wash flow	14 $m^3.h^{-1}$ on average, 20 $m^3.h^{-1}$ max. per unit
Total wash volume	4 × 14 = 56 $m^3.h^{-1}$ (on average)
Wash flow rate	14 m^3/h per unit (continuous washing)
Maximum wash flow	20 m^3/h per unit (exceptional washing)

Table 1.13. *Disk filter dimensions (Hydrotech)*

1.7.1.4. *Disinfection*

NaOCl is injected into the water from the demineralization concentrates that feed the reuse treatment unit. NaOCl levels averaged 2.0 $mg.L^{-1}$, with a maximum of 3 $mg.L^{-1}$. Actiflo sludge and wash water are collected and sent to the sludge treatment plant.

1.7.1.5. *Reagent dosages*

Polyaluminum chloride (PACl), ferric chloride ($FeCl_3$) or ferric sulfate ($Fe_2(SO_4)_3$) reagents can be used as required.

Note that 207 $mg.L^{-1}$ of Al polychloride at 8.5% and 1.20 density are equivalent to 137 $mg.L^{-1}$ of $FeCl_3$ at 41% and 1.45 density.

A total of 137 $mg.L^{-1}$ of $FeCl_3$ at 41% and 1.45 density are equivalent to 160 $mg.L^{-1}$ of $Fe_2(SO_4)_3$ at 43% and 1.45 density.

1.7.1.6. *Quality of water produced*

TSS (average)	5 $mg.L^{-1}$
TSS (maximum)	8 $mg.L^{-1}$
Turbidity	<5 NTU
Color	<20 $mg.L^{-1}$ Pt/Co
Total coliforms	<100 CFU/100 mL

Table 1.14. *Quality of water produced*

Figure 1.21. *Burj Khalifa lake water quality with reused wastewater*

Figure 1.22. *Water features on the lake*

1.8. Darling Quarter (Sydney, Australia): wastewater reuse in a neighborhood

Sydney's newest landmark, Darling Quarter-Commonwealth Bank Place, consists of two new low-rise commercial buildings. It comprises an eight-storey Grade A office space (55,418 m^2), a commercial ground floor (3,789 m^2), 800 parking spaces, as well as a children's playground and multi-purpose theater.

Figure 1.23. *Darling Quarter (Sydney)*

Veolia was selected to design, build and operate a recycled water plant for the Darling Quarter. The project offered a 90% reduction in drinking water thanks to rainwater harvesting and on-site wastewater recycling.

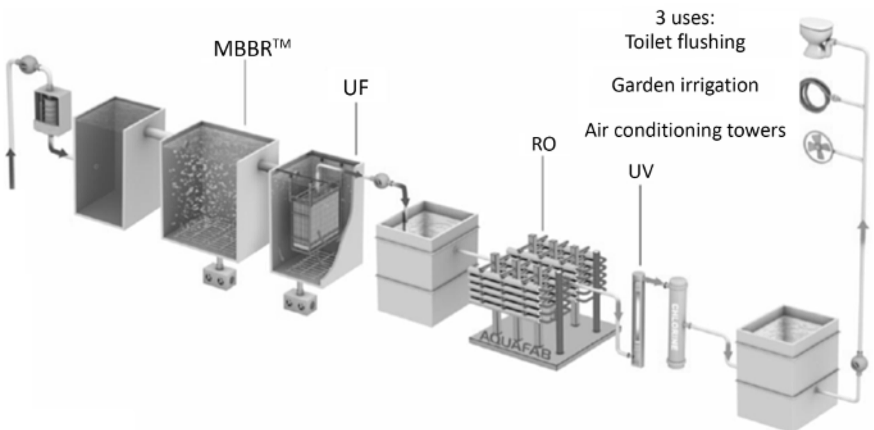

Figure 1.24. *Wastewater reuse in a neighborhood*

The treatment process combines the following stages involving innovative technologies:

– moving bed biofilm reactor (MBBR);

– Neosep® submerged MBR;

– RO unit;

– disinfection.

Figure 1.25. *Reuse station equipment*

Effluent is extracted into a sewer pipe running underground on the site, which diverts wastewater from the main pipe to a secondary pipe, using a weir bypass system. This solution was preferred to on-site pumping, as it allows for smaller storage and better control of the intake, so that if the treatment plant is offline, the intake is stopped.

The process treats 245 m^3 of wastewater per day through sewer extraction, producing 166 m^3 per day (60,000 m^3/year) of high-quality recycled water for reuse in flushing, irrigation and cooling tower make-up water. From this, 116 m^3 per day is for cooling towers and 50 $m^3.day^{-1}$ is for flushing and irrigation. However, these flows may vary according to the season.

MBBR and Neosep® MBR technologies are ideal for wastewater treatment to withstand load variations and can provide high removal of bacteria, viruses and suspended solids. RO removes salts from feed water. The recycled water plant has been designed to adapt to the spatial constraints of the site.

Figure 1.26. *Reuse for cooling towers, irrigation and toilet flushing*

Most of the BOD5, COD and microbiological constituents are greatly reduced in the MBR. The remaining constituents are then removed by RO membranes. Final disinfection ensures microbiological safety.

The quality of the water produced is well above Australian guidelines for wastewater reuse.

Recycled water quality is monitored 24/7, 365 days a year by critical control points and a remote monitoring system. Regular sampling is carried out, and online analyzers ensure that the reused water meets the required quality.

Wastewater reuse, as a sustainable and reliable concept, is a promising solution to alleviate water shortages.

Membrane-based treatment systems are selected on the basis of their hydraulic filtration performance, their capacity to remove various organic and inorganic substances, including micropollutants, their resistance to clogging and their energy consumption. Membrane processes, either alone or in conjunction with other possible processes (activated carbon and advanced oxidation), can be used to further guarantee the quality of the water produced.

The challenges still facing membrane technologies for drinking water applications include institutional constraints, funding and public acceptance.

Parameters	Produced water quality at Darling Quarter	NSW guidelines for private use of wastewater reuse	Australian guidelines for wastewater reuse
BOD5	<5 mg.L^{-1}	<10 mg.L^{-1}	–
TSS	<5 mg.L^{-1}	<10 mg.L^{-1}	–
pH	6.5–8.5	6.5–8.5	–
Turbidity	<0.2 NTU	<2 (95%ile), 5 NTU	–
Escherichia coli	<1 CFU/100 mL	<1 CFU/100 mL	<1 CFU/100 mL
Residual chlorine	0.2–2 mg.L^{-1}	0.2 mg.L^{-1}	–
Clostridium perfringens	<1 CFU/100 mL	<1 CFU/100 mL	–
Coliphages	<1 CFU/100 mL	<1 CFU/100 mL	–
Virus removal throughout the process	6.6 log	–	6.5 log
Bacteria removal for the entire process	12.1 log	–	5 log
Protozoa removal throughout the entire process	8.1 log	–	5 log

Table 1.15. *Comparison of parameters to be removed at the Darling Quarter plant*

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