UNIVERSITAT DE BARCELONA

MASTER FINAL PROJECT

MASTER OF ENVIRONMENTAL ENGINEERING

Water deficit fighting in Catalonia: comparison of intervention actions

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June 2017

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MASTER THESIS

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UNIVERSITAT DE BARCELONA | MASTER IN ENVIRONMENTAL ENGINEERING

In collaboration with Agència Catalana de l'Aigua, Aigües Ter Llobregat and AITASA

June 20th, 2017

ACKNOWLEDGEMENTS

I would like to thank my tutor, Carmen Sans, for her orientation on the approach of the thesis and design of the comparison, as well as for her guidance and corrections.

I would like to thank Joan Dosta, coordinator of the Master in Environmental Engineering at UB, for his great assistance and support in finding an offer for an internship at ACA.

I would like to thank Montserrat Iglesias and Rosa Teva, from ACA, for facilitating me the contact of the head of the department of water supply in ACA.

I would like to thank Isabel Gandullo, head of the department of regulation of the water supply systems in ACA, for her help and collaboration in the project. This project wouldn't have been possible without her putting me in contact with the head of the plant of the Llobregat desalination plant and the head of AITASA, as well as facilitating me the construction project from both plants that have been studied.

I would like to thank Carlos Miguel, head of the Llobregat desalination plant managed by ATLL, for receiving me and for the data supplied about the Llobretat desalination plant.

I would like to thank Daniel Montserrat and Irene Porras, director and executive secretary of AITASA, for the data supplied about the Camp de Tarragona reclamation plant.

I would like to thank Maximilian Krippl for his corrections and support in the tough moments.

I would like to thank my family for being there, by me.

ABSTRACT

Catalonia suffers from structural water deficit due to its climate and rain pattern, which is worsened by the fact that most of the population lives in the coastline, where water resources are poor. This situation has led to several difficulties in water supply during drought periods.

The region of Barcelona keeps growing enhancing territorial imbalances, and climate change makes drought periods much more likely. Therefore, a good water management is vital to ensure water supply to the population.

This project analyzes the regulations and organisms involved in water management in Catalonia, as well as studying the water deficit situation. The Catalan water management plans and programs have been studied, besides, the measures proposed in them to fight water deficit and the achievement of the objectives so far.

Water deficit is fought with the pursuit of new water resources, which can be technologically generated or by the improvement of the water quality in the environment and decontamination of aquifers. The two main techniques, which suppose a new production of water resources, are desalination and reclamation *or water reuse.*

The technology used in water reclamation plants and in desalination plants is very similar, consisting on a pre-treatment by coagulation-flocculation, followed by sand filters and microfiltration. Then, water is passed through reverse osmosis filters, where salts and microorganisms are eliminated from the permeate. This water is then disinfected and it can be given several uses according to its quality.

Desalinized water is intended for water consumption, and thus, is distributed through water supply systems. However, the current legislation does not contemplate direct human consumption of reclaimed water. Therefore, it is reused for other purposes, such as industrial uses, urban cleaning, environmental purposes or agricultural irrigation.

The Camp de Tarragona reclamation plant and the Llobregat desalination plant are two examples of how these technologies have been implemented in Catalonia to fight water deficit, the first in an industrial area and the second in the metropolitan area of the city of Barcelona. The technologies used at each plant are compared as well as the costs of the water produced.

Each technology has pros and cons, but both contribute to the production of new water resources that can be given several uses, and contribute to alleviating the human pressure on those rivers and aquifers that are already overused.

All in all, regeneration and desalination, not only provide a solution to water deficit, but also allow the improvement of the quality of the water ecosystems.

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Water deficit fighting in Catalonia: Comparison of intervention actions

We never know the worth of water till the well is dry

Thomas Fuller

A drop of water, if it could write down its own story, it would explain the universe to us.

Lucy Larcom

Many lived without love, not one without water.

W. H. Anden

1. INTRODUCTION

Catalonia hosts an enormous variety of landscapes in its 31,896 km^2, from the driest to the most humid, and with diverse geologic formations (1). Its territory is prone to floods and droughts, as the Mediterranean rainfall pattern is irregular and presents a high inter-annual variability (2).

Moreover, land occupancy is irregularly distributed through the territory's water resources, generating important imbalances (1). Drought risk is especially notable in the inner basins, where 90% of the Catalan population is concentrated with only 40% (drawn from the reservoir's capacity) of its water sources (3). Thus, this region is notably vulnerable to drought periods.

In fact, Catalonia is considered a pioneer in terms of responsible and efficient water consumption. It has been reported that 75% of the Catalan population consume an average of 102 to 115 liters per inhabitant per day (3), while the average water consumption in Western Europe in 2003 was around 273 liters per inhabitant per day (4). According to the United Nations, the country with higher water consumption is the USA, with an average water use of 575 liters per person per day, while the country with the lowest water consumption is Mozambique, with an average use of less than 10 liters a day (5). – *See Annex 2.*

However, climate change suggests the need of even higher efficiency in water management to compensate its effects in water availability in the long term, as there will be less rain and snow, and consequently, the river flows will decrease (2).

2. OBJECTIVES

Catalonia's conditions require a detailed water management plan, and more specifically, measures to deal with doughty periods. This project pursues to study, compare and evaluate the effectiveness of the two most important drought management strategies for the region of Catalonia: sea water desalination and wastewater reclamation or reuse.

The objectives of this thesis are:

1. Firstly, the water management plan in Catalonia is reviewed, focusing on the management of drought periods and the proposed measures to deal with it.
2. Secondly, the technology of the two main strategies or techniques for water deficit fighting in Catalonia is described: Desalination of seawater and wastewater reuse by the production of reclaimed water.
3. Then, two cases of the application of those techniques in Catalonia are studied: the Llobregat desalination plant and the Camp de Tarragona regeneration plant.
4. Finally, both techniques are compared and their effectivity in water deficit fighting is discussed, defining in which situation should each technique be used.

3. *ANTECEDENTS: DROUGHT PERIODS IN CATALONIA*

Throughout history, Catalonia has suffered several drought periods.

For a long time, 1944 was considered the driest year in the Iberic peninsula, when the lack of rain had a strong impact on dry farming. In 1950 the water resources in Barcelona were almost exhausted and night stoppages in water supplies were carried out in July and August, as water consumption increased due to a heat wave. In May 1953, stoppages in water supplies were also done 30% of the hours a day, achieving 20% water saving. Neither 1950 nor 1953 were extremely dry, but the growth of Barcelona increased the water demand, revealing the deficit of the water system in the city. As a result, the Sant Joan Despí water purification plant was built in 1955-1962, and in 1966 water was brought to Barcelona and Girona from the Ter river (6).

During the years 1973, 1985, 1988 and 2003, Catalonia suffered severe drought periods, with stoppages in the water supplies until it rained (2). Therefore, in the following years, prevention decrees were signed to attenuate those critical situations of urban water supply (6).

The drought period of 2007-2008 was the most severe and recent drought period in Catalonia. It was an extraordinarily dry year, where despite the population's water saving, in March 2008 only 20% of the water resources were left. To face this drought period, water was brought in boats and trucks from the Ebro river to Barcelona, with an economic impact of 19.2M€. Moreover, 63M€ were invested in structural measures for drought management (7).

Through all these years, water supply infrastructures have been developed to provide an answer to the structural deficit of the system with the objective of guaranteeing water supply. Over 300 wells have been recuperated throughout the territory, the desalination plant of el Prat de Llobregat is now a reality, as well as the expansion of the Tordera desalination plant and the connection of the Trinitat and Fontsanta deposits (2).

4. *REGULATIONS OF THE SECTOR*

The water regulations consist on European Directives, which are concretized in Spanish laws and developed into Regional (Catalan) regulations. Water management plans are also defined in laws, and developed by the Spanish or Catalan government, according to the river basin organism.

4.1. *CURRENT LEGISLATION*

The issue of this project is concerned by the legislation related to the topics: water reuse and water planning, water reuse and water intended for human consumption – See annex 3.

In this section, those regulations are classified according to their level of application.

At European level:

- *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy* (Directive 2000/60/EC).
- *Directive 91/271/EEC of 21 May concerning urban wastewater treatment.* (Directive 91/271/EEC).

At Spanish level:

- *Real Decreto Legislativo 1/2001, de 20 de julio, por el que se aprueba el texto refundido de la Ley de Aguas* (RDL 1/2001).
- *Real Decreto-Ley 11/1995, de 28 de diciembre, por el que se establecen las normas aplicables al tratamiento de las aguas residuales urbanas.* (RD-L 11/1995).
- *Real Decreto 509/1996, de 15 de marzo, de desarrollo del Real Decreto-ley 11/1995, de 28 de diciembre, por el que se establecen las normas aplicables al tratamiento de las aguas residuales urbanas.* (RD 509/1996).
- *Real Decreto 1620/2007, de 7 de diciembre, por el que se establece el régimen jurídico de la reutilización de las aguas depuradas.* (RD 1620/2007).
- *Real Decreto 140/2003, de 7 de febrero, por el que se establecen los criterios sanitarios de la calidad del agua de consumo humano.* (RD 140/2003).

At Catalan level:

- *Decret Legislatiu 3/2003, de 4 de novembre, pel qual s'aprova el text refós de la legislació en matèria d'aigües de Catalunya* (DL 3/2003).
- *Decret 103/2000, de 6 de març, pel qual s'aprova el Reglament dels tributs gestionats per l'Agència Catalana de l'Aigua* (Decree 103/2000).

4.2. WATER MANAGENMENT PLAN

The National Water Management Plan stated in the Water Framework Directive was materialized in the *Ley 10/2001, de 5 de julio, del Plan Hidrológico Nacional* (Law 10/2001). This plan gathers the criteria for the coordination of the multiple River Basin Management Plans.

Catalonia is regulated through three water management plans, two from interregional basins (Ebro and Júcar) and one of the inner basins. The Water Management Plan for the Ebro and Júcar river are defined in the *Real Decreto 1/2016, de 8 de enero, por el que se aprueba la revision de los Planes Hidrológicos de las demarcaciones hidrográficas del Cantábrico Occidental,* *Guadalquivir, Ceuta, Melilla, Segura y Júcar, y de la parte española de las demarcaciones hidrográficas del Cantábrico Oriental, Miño-Sil, Duero, Tajo, Guadiana y Ebro* (RD 1/2016). The Water Management Plan for the Inner Basins in Catalonia is defined in the *Decret 380/2006, de 10 d'octubre, pel qual s'aprova el Reglament de planificació hidrologica* (Decree 380/2006).

5. PUBLIC ORGANISMS AND COMPETENCES DISTRIBUTION

In the case of Catalonia, the regional authorities are responsible for the water cycle management. However, some river's flow goes across more than one region. These rivers are regulated by their river basin organism.

The main public organisms regulating the water cycle in Catalonia are: – *See Annex 4.*

- Catalan Water Agency (ACA)
- Ebro Hydrographic Confederation (CHE)
- Júcar Hydrographic Confederation (CHJ)

The Catalan government's public company is the Catalan Water Agency (ACA) was founded in the year 2000. Its mission is to guarantee present and future water supply and water quality at source (groundwater and surface water) in the territory of Catalonia.

The Ebro Hydrographic Confederation (CHE) and the Júcar Hydrographic confederation (CHJ) are river basin organisms, which play an important role in the water planning of the resources from these interregional rivers.

Consequently, in terms of water management, Catalonia is divided into two separated areas: the inner basins or the Catalan river basin district (rivers that begin in Catalonia and flow into the Mediterranean), and the interregional basins (rivers that pass through different regions, such as the river Ebro and the river Júcar) (3).

The inner basins include 634 municipalities, with a surface of 16,600 km^2, which represent 52% of the Catalan territory. The interregional basins include 312 municipalities, with a surface of 14,000 km^2, which represents 48% of the Catalan territory (8). – *See Annex 5.*

ACA has full authority in the inner basins, but its authority in the interregional basins is shared with the Spanish government through the Ebro Hydrographic Confederation (CHE) and the Júcar Hydrographic Confederation (CHJ) (3).

In practice, ACA writes and approves the Inner Basin Water Management Plan. In the interregional basins, however, the state administration (CHE or CHJ) is responsible for the approval of the water management plan for interregional rivers (Ebro or Júcar). Yet, those plans can incorporate specific measures proposed by ACA (9).

6. WATER BALANCE IN CATALONIA

The Catalan inner basins suffer of chronical water deficit, and it can worsen as the population grow and the economic activity raise.

6.1. WATER RESOURCES

Water resources in Catalonia are essentially those in water reservoirs and those in aquifers or water wells (2).

On the one hand, groundwater reserves in aquifers contribute an average of 580 hm^3 of water to the inner basins (3). On the other hand, reservoirs perform a double function: water storage and retaining floods to prevent damage. The inner basins have 17 reservoirs with a total capacity of 694 hm^3, while the Ebro basins have 14 reservoirs with a total capacity of 3,803 hm^3 (3).

6.2. WATER DEMAND

The Catalan rivers are submitted to a high pressure. The water demand in Catalonia is 2,965 hm^3 per year (9), with strong differences throughout the territory in its uses. In the inner basins, where water resources are scarce, urban and industrial uses predominate. In the Ebro basins, however, the major water use is for agriculture.

In addition, 700 hm^3 per year are streamed to the Ebro Delta to preserve its agri-environment ecosystem. In Catalonia, there are 40 hydroelectric power plants that produce 2,300MW in total, which may impede the achievement of the preservation water flowrates.

The Catalan river basins are divided in management systems. – *See Annex 6.*

The systems Fluvià and Garona are balanced. The Baix Ebre system has the handicap of the implementation of the preservation water flowrate in the delta. The Segre system needs improvement of the irrigation systems. The system of La Muga has a 26 hm^3 deficit in dry years, and the system Sud (Tarragona) has a 12 hm^3 deficit in dry years.

The most deficient system is the Ter-Llobregat, with a deficit of 176 hm^3 per year in 2008. With the last year’s investments, the deficit has been reduced to 68 hm^3 per year and the rest of the actions in this plan should solve this deficit in the 2027 horizon.

7. WATER MANAGEMENT IN CATALONIA

The hydrographical planning of the Catalan inner basins is composed by a group of plans and programs that, in accordance with the Water Framework Directive, fix the objectives regarding water management and designs measures to achieve them.

The documents that define water management in Catalonia are:

- Water management plan and measures programs.
- Control and follow-up programs.
- Drought period exceptional plan.
- Flood risk management plan.

7.1. CATALAN INNER BASINS WATER MANAGEMENT PLAN

The Inner Basins Water Management Plan (WMP_{IB}) is structured in two cycles or periods (2006-2015 and 2016-2021), and is developed in two documents: The Management Plan itself and the Measures Program, which consists of an Economic-financial Plan and a Strategic Study.

The first period WMP_{IB} was approved by the Decree 188/2010, and its corresponding Measures Program by the Governance Agreement 238/2010. It was designed following the principles of the Water Framework Directive, and renewed the water management approach in Catalonia (9).

The plan follows a double objective:

- Guarantee of water supply and resources.
- Quality of the aquatic environment.

The specific objectives and measures to accomplish the goal of the WMP_{IB} are divided into scopes of action: environment and water resources.

7.1.1. Environment

The first cycle WMP_{IB} establishes environmental quality objectives for each water body in Catalonia. Improving the water resources' quality is a way of increasing the available water resources. Accordingly, achieving a good condition of the water bodies is the main objective of the plan. To evaluate water quality, several indicators are defined (biological, physicochemical and hydromorphological) to define the ecological, chemical and quantitative state of the waters.

Technology would not allow the achievement of a good water quality in all water bodies before the end of the planned period. Thus, the plan aimed to accomplish those objectives within reach, pursuant to the defined quality standards in the Water Framework Directive. – *See Annex 7.*

In order to achieve those objectives, several actions were designed in the Measures Program. They are encompassed according to their purpose.

a) Decreasing water contamination:

- Wastewater treatment.
- Contamination's reduction at its source.
- Reduction of dangerous substances.
- Reduction of saline contamination in the Llobregat basin.

b) Decreasing the damage caused by floods:

- Flood prevention.

c) Improvement of the ecosystems:

- Settlement of preservation water flowrates.
- Improvement of the river connectivity.
- Recuperation of shores and riversides.
- Control and eradication of invasive species.
- Wetlands recuperation.
- Improvement of the coast
- Management and protection of aquifers.

7.1.2. Water resources

Catalan rivers are under pressure, as water demand in Catalonia is higher where water resources are scarcer. To solve this water deficit, the plan proposes some technology based solutions, which, in many ways, aim to guarantee water supply.

a) Measures to generate more water:

- Reused or reclaimed water

Reutilization is a valuable method. In the past 30 years, many wastewater treatment plants have been built. An additional tertiary treatment (called reclamation) allows the production of a good quality water, which can have multiple uses.

In Catalonia, reutilization has two main objectives: On the one hand, substituting part of the industrial and irrigation water. On the other hand, recharging aquifers to improve their water quality, avoid saline intrusion and increase the possibilities to use subterranean water as a resource in drought periods (9).

The measures proposed in the plan will generate 101 hm^3 per year of new available water (9).

- Aquifer recovery

The recovery of subterranean water resources will allow the operation of wells that were abandoned due to contamination problems. Technology makes it now possible to recover these water sources, and over 200 wells have already been recovered.

The measures proposed in the plan will allow the accessibility to up to 43 hm^3 per year of subterranean recovered water in a dry year (9).

- Seawater desalination plants

The desalination of seawater allows the production of an excellent quality water with full guarantee. Moreover, this is an autonomous solution, which is not concerned by territorial conflicts and relatively economic in terms of initial inversion.

This plan foresees the investment on desalination plants as an economic effort that will complete the guarantee of water resources in dry years. It will contribute with up to 25% of the urban water demand, which represents 7% of the total water consumption in Catalonia (9).

Desalination plants would only be used to provide urban water supply, but industries and agriculture also benefit from this, as they share water resources with domestic users.

Catalonia has two installed desalination plants, Llobregat and Tordera, which can produce up to 80 hm^3 per year. The plan foresees the construction of two additional plants, a second one in Tordera, and one in Foix, which will allow a production increase up to 200 hm^3 per year (9).

Desalination plants are scalable and adapt perfectly to variable weather such as the one in Catalonia. In dry years, the plants will work at full scale with a maximum production of 200 hm^3 per year. In humid years, the plants will have a production of around 70 hm^3 per year (9).

b) Measures for a higher efficiency in water management: – *See Annex 8.*

- Management of the industrial and urban demand
- Improvement of the irrigation technology.
- Improvement of the distribution network

c) Measures for a better water supply: – *See Annex 9.*

- Improvement of the water transport network
- Improvement of the treatments
- Increase of the regulations
- Integrated management of the resources

7.1.3. ***Measures plan***

According to the first period plan, the measures regarding water supply and reutilization would allow a total of 389 hm^3 per year new resources in the Catalan inner basins, 75% of which will come from desalination and reutilization. This estimation was done by considering that every year, 101 hm^3 reclaimed water would be produced, 43 hm^3 would be generated by aquifer recovery, 55 hm^3 would be gained by the improvement of water supply infrastructures, and 190 hm^3 of desalinated water would be produced (10).

- Desalination

According to the measures plan, 851.4 million euros should have been invested in desalination in the period 2006-2015. The program foresees a new input of 190 hm^3 per year, in addition to the 10 hm^3 per year that are already being produced in the Tordera desalination plant since 2002.

The desalination plants should work at full scale when the water reservoirs are low, and partially or at maintenance scale when the reservoirs are full (9).

- Reclamation

The measures plan foresees to develop the Program of Reutilization of Water in Catalonia (PRWC) in within the period 2009-2015. The measures suppose a 368.1 million euros' inversion which should allow reaching 209 hm^3 per year of reclaimed water, 101 hm^3 per year of which represent a new resource, and the rest come from the introduction of tertiary treatments in **steams** that were already indirectly being reused (9).

7.1.4. ***Economic aspects***

The measures proposed in the first period plan suppose a total inversion of 9,405 million euros in the overall water cycle in Catalonia. ACA was supposed to invest 4,092 million euros and Aigües Ter-Llobregat 1,429 million euros (which represented a total of 59% of the cost of the measures plan). The rest was distributed between the administration, local government, local institutions and users. (9)

However, ACA's only money source is the income collected through the water bill, which in 2015 was of 1,145 million euros, while the costs of the water cycle were of 1,684 million euros. Considering ACA expenses, the depreciation of assets and the return of indebtedness, the difference between the income and costs was covered by increasing the indebtedness. This situation was unsustainable and led to a non-compliance of all the measures and objectives of the first period of the water management plan. (9)

7.1.5. Achievements

Only 40% of the measures planed for the first period have been executed, mainly because of the economic situation ACA had to face during the crisis.

However, some significant measures have been implemented, which allow an increase in the current water resources (7):

- Over 180 wells have been recuperated.
- The construction of the infrastructure that brings reclaimed water to the Llobregat river.
- The expansion of the Tordera desalination plant and its connection with the Cardedeu potabilization plant.
- The intensification of the start-up of the Baix Llobregat desalination plant.
- The implementation of the tertiary treatment in the Llobregat water treatment plant.

7.1.6. Future prospective

Nowadays, Catalonia has a structural water deficit of 2 m^3/s in the Ter – Llobregat system, which would increase up to 6-8 m^3/s in the future if no action is done to solve it.

The second period WMP_{IB} is already written and should be approved by the Council of Ministers in May 2017. It pursues the same objectives as the first period plan, to achieve a water quality standard according to the Water Framework Directive and to evaluate the water deficit according to the Spanish legislation.

Nevertheless, no measure for water deficit fighting is proposed, nor is in the water management plans from other regions in Spain. The two main reasons that justify this fact are the fact that such a global problem should be determined in the National Hydrographic Plan, and the fact that several strategies can be followed in order to solve this problem.

The idea of the second period WMP_{IB} is to maintain the technical level of the first period one, while adding a guarantee of success in 2021. Therefore, the second cycle plan is built on an economic and financial plan, which is based on the 500-600 million euros that ACA can invest in this period. This constrains the objectives of the plan, but makes it more realist.

Currently, all the water bodies have an ecological flow, and 36% of the water bodies have a good ecological status regarding environment water quality standards. Basing on the principle of non-deterioration, the objective of the plan is to reach 45% of the water bodies in a good ecological status in 2021, and try to reach 80% in 2027 (though this will be planned in the following cycle).

7.2. CATALAN PROGRAM FOR WATER RECLAMATION

Water reuse can be direct or indirect. Indirect water reuse is a historical fact in Catalonia, as depurated water is often dumped in rivers, and that water is then collected by the potabilization plant of the next town downstream. Direct water reuse is that where wastewater is treated up to a quality that allows its direct reutilization in the activities specified in the RD 1620/2007.

In 2008, the Catalan program for water reclamation was approved. At that point, 665 hm^3 of wastewater were treated every year in wastewater treatment plants (WWTP), from which only 51 hm^3 (7.6%) were directly reused (11).

The quality required to reclaimed water varies depending on its final use: urban uses, agricultural use, industrial use, recreational use or environmental use. – *See Annex 10.*

In Catalonia, most of the reclaimed water was used for environmental purposes. Therefore, the most potential for water reuse is foreseen in the industrial sector. In the Catalan program for water reclamation, nine projects were developed in different water management systems, which would allow 40 hm^3 per year to be reused in the industrial sector. The industrial water demand in Catalonia in 2007 was 179.2 hm^3 (12), so almost a quarter of the water consumed in the industrial sector would be reclaimed water.

7.2.1. Evaluation of the convenience of a reutilization project

Several factors need to be considered when evaluating the convenience and interest of a reutilization project. Those factors are summed up in Figure 1.

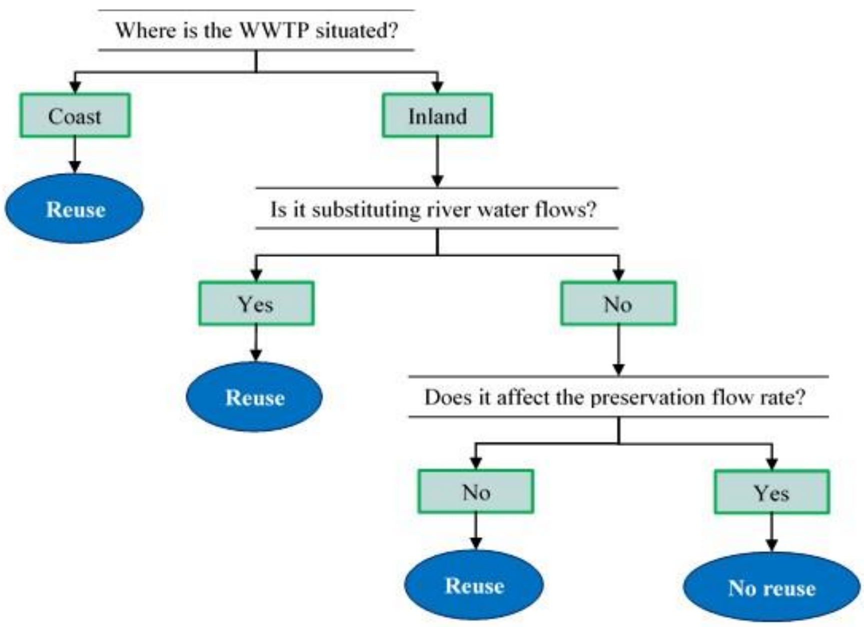

Figure 1. Logical scheme with the criteria to assess the convenience and interest of water reuse (11).

Littoral reutilization always supposes an increase of water resources, as otherwise, this water would go to the sea. Inland reuse, however, will happen indirectly in the downstream towns.

Inland reuse can be of interest when it avoids the use of water from rivers with poor water resources, or to avoid the dumping of wastewater in a sensible river section by increasing the quality of the water.

7.2.2. Actions proposal and design

In 2008 there were 47 reuse systems in Catalonia. This plan foresees a total of 124 reuse systems, which will be developed in 109 actions (52 promoted by ACA and the other 57 promoted by the interested party). – *See Annex 11.* ACA planned the 52 actions in three time horizons, determining to each of them its interest and costs (inversion, exploitation and maintenance).

At the end of the application of this program, it is foreseen that 229 hm^3 per year of water will be treated with a tertiary treatment, and that 204 hm^3 per year of reclaimed water will be produced (excluding sludge).

This reclaimed water should be used for the following purposes:

- Farming: 45.7 hm^3 per year (30%)
- Industry: 39.7 hm^3per year (26%)
- Environment: 38.6 hm^3 per year (25%)
- Municipal: 18.5 hm^3 per year (12%)
- Recreation: 10 hm^3 per year (7%)

From the increase of 153 hm^3 of reused water planned in the program, 101 hm^3 would be a new resource (would be generated by the production of reclaimed water).

7.2.3. Achievements

Despite the implementation of the plan, the highest production of reclaimed water was in 2008, during the severe drought period. – *See Annex 12.* This happens because the production of reclaimed water is expensive and its potential is not exploited until it is needed, thus, in drought periods.

Industrial water reuse started to be effective in 2013 (13). However, most of the reclaimed water is still used for environmental purposes.

7.3. EXCEPTIONAL PLAN FOR DROUGHT PERIODS IN CATALONIA

This plan defines 3 drought states: alert, exceptionality and emergency, as well as a transition state called Pre-alert. Each of them supposes more intense measures for drought fighting. The plan also defines the thresholds for each state in each water body in Catalonia (14).

Moreover, the plan sets the rules for water exploitation during drought periods: limitation on conventional water uses (rivers and reservoirs).

7.3.1. Production of unconventional water resources

The plan bases water supply in drought periods on the production of unconventional water resources through seawater desalination and water reuse. These water sources cannot be exhausted; however, its production costs are higher and more variable than conventional ones. Therefore, they are enhanced in drought periods.

- Seawater desalination

In Catalonia, there are two working desalination plants: Llobregat and Tordera. Their exploitation regime is planned regarding the water resources available. The water resources of the Ter-Llobregat system are evaluated and reclaimed water is produced as stated in Table 1.

Table 1. Desalinated water production according to the water resources in the Ter and Llobregat reservoirs. (14)

Ter – Llobregat water reservoirs	Production in the desalination plants in Llobregat and Tordera
Over 75%	0.22 m^3/s
Between 50% and 75%	0.76 m^3/s
Between 25% and 50%	2.18 m^3/s
Lower than 25%	2.53 m^3/s

The production of both desalination plants is planned globally, and they are distributed according to the circumstances of the moment and the necessities of re-equilibrating the water resources in the reservoirs from the Ter or Llobregat river basins.

- Reclamation

The station for water reclamation in Prat de Llobregat, the largest in Catalonia, can produce up to 3.5 m^3/s. The production of reclaimed water is regulated and scheduled according to the drought state. The reclaimed water produced can have many uses, but it cannot be purified and distributed in the water supply network – *See Annex 13.*

Other wastewater treatment plants through Catalonia also have a tertiary treatment. Farmers with connection to the reused water supply system must prioritize that water source before the conventional one. The same rule is applied for municipal uses such as the cleaning of streets.

Recreative uses prioritize the use of reclaimed water, but bearing always in mind their concession contract. Those environmental uses of reclaimed water are more flexible, as they need to adapt to the necessities of the environment.

7.3.2. Coordinated use of subterranean and surface water resources

The plan also points out the importance of a good coordination between the extraction of subterranean water and superficial water. The operation pattern of those users who use both kinds of water sources is based on the state of the aquifer they extract water from.

8. UNCONVENTIONAL WATER RESOURCES

In times of scarcity, the production of new water resources is key to guarantee water supply to the population and industry, without stressing the environment excessively. There are two technologies, which were introduced in the Catalan water management plans, which allow the production of new water resources: desalination and water reclamation. These processes are based on filtration technology, specifically, reverse osmosis. – *See Annex 14.*

8.1. DESALINATION

The practice of water desalination consists on separating the dissolved salts and minerals from seawater (15), which is then treated and distributed through the drinking water supply systems.

8.1.1. Desalination technology

Seawater desalination is carried out by membrane separation. These procedures require high driving forces, including pressure, electric potential and concentration, to overcome the natural osmotic pressures and effectively force water through the membrane (15).

For desalination processes, non-porous reverse osmosis membranes are used. – *See Annex 15* Those membranes can be symmetric or asymmetric, and the material they are made of can be made out of cellulose acetate, polyamide, polyether or combinations of those. Depending on the characteristics of the membrane, the rejection of salt and permeate flux vary. In Figure 2, reverse osmosis membranes are classified and their rejection and permeate flux are shown.

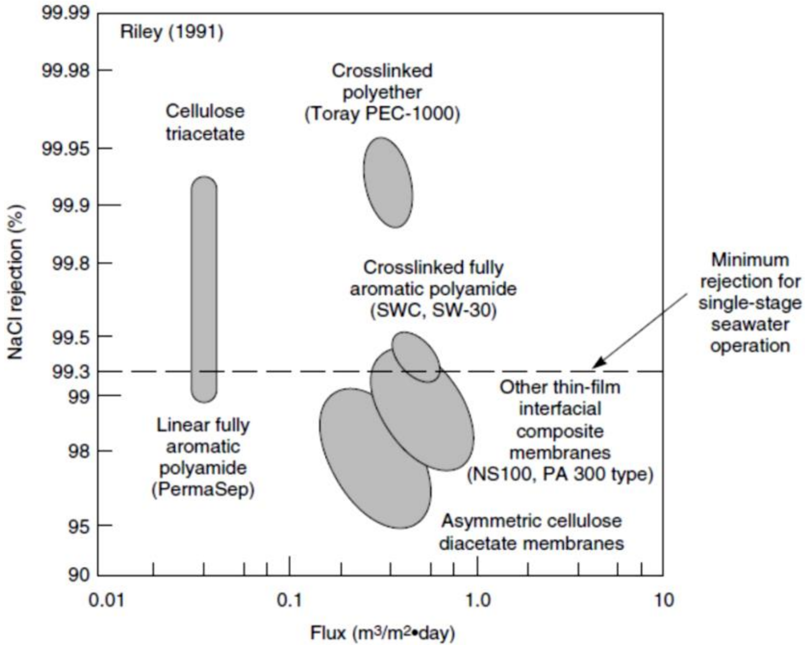

Figure 2. Water flux and NaCl rejections for reverse osmosis membranes (37).

The reverse osmosis membranes are packed into modules, with spiral wound, hollow fiber, and sheet with spirals being the most widely used configurations. – *See Annex 16 and Annex 17.*

In seawater desalination, the water that reaches the reverse osmosis membrane can contain nothing more than water and salt. Pre-treatments are required in order to minimize the fouling of the membranes, usually sand filter, coagulation-flocculation and microfiltration. In addition, the produced water undergoes post-treatments to make it potable: remineralization and disinfection.

8.1.2. Desalination costs

The first period WMP_{IB} plan, foresees an initial inversion of 851 million euro for the construction of the two desalination plants, including also the construction of the distribution pipelines. This represents 9% of the total costs of the investments in the water cycle for that plan.

A transfer from the Roine river for the same water flow would cost approximately 2,000 million euros, but its shelf life would also be longer, as pipelines tend to deteriorate less than electrotechnical equipment.

Desalination supposes a moderate initial investment, but its operating costs are relatively high.

The production of 1 m^3 (1,000 L) costs (9):

- Desalination: 0.4€
- Potabilization: 0.05€ (Ter) or 0.27€ (Llobregat)

In both cases, the costs are affordable. If all the water consumed by a 4-member family was produced through desalination, it would cost 2 €/week. In fact, the impact is smaller, as it is not planned that desalination will overcome 25% of the water consumption in the Catalan cities (9).

8.1.3. Desalination energy consumption

Desalination consumes electricity, as high pressure needs to be applied for the seawater to pass the inverse osmosis membrane. The total energy necessary to produce 1 m^3 of desalinated water is decreasing thanks to novel technologies. In the eighties, it costed around 20 kWh/m^3, and nowadays around 3.3 kWh/m^3. Consequently, the application field of this technology has spread and nowadays it is used in places with Mediterranean climate, such as Australia, Israel or California. (9)

8.2. RECLAMATION

The practice of water reclamation and reuse consists on considering municipal wastewater as a vital resource, which can be treated and reused for applications, including agricultural and other irrigation, industrial and domestic uses (16).

8.2.1. Reclamation technology

Many factors influence the choice of which technology is used for the water reclamation, but the most important one is the type of water reuse application, as it defines the reclaimed water quality objectives according to the criteria defined in the RD 1620/2007. – *See Annex 10*.

Other important factors to take into consideration are the compatibility with the existing conditions, flexibility of the process, the operating and maintenance requirements, energy and chemical requirements, personnel and staffing requirements, residual disposal options, and environmental constraints. Decisions on treatment design are also influenced by water rights economics, institutional issues and public confidence (17).

All water treatment technologies can be applied for water reclamation. These technologies are characterized as preliminary, primary, secondary and advanced. In Catalonia, the water reclamation plants (WRP) and the WWTP are usually connected. Primary and secondary treatments are done at the WWTP, while the WRP focuses on the advanced treatments.

Nevertheless, water reclamation process can also be done directly from waste water of all characteristics. All treatments that can be done to waste water in order to improve their quality to the required standards for its reuse are summarized in Figure 3.

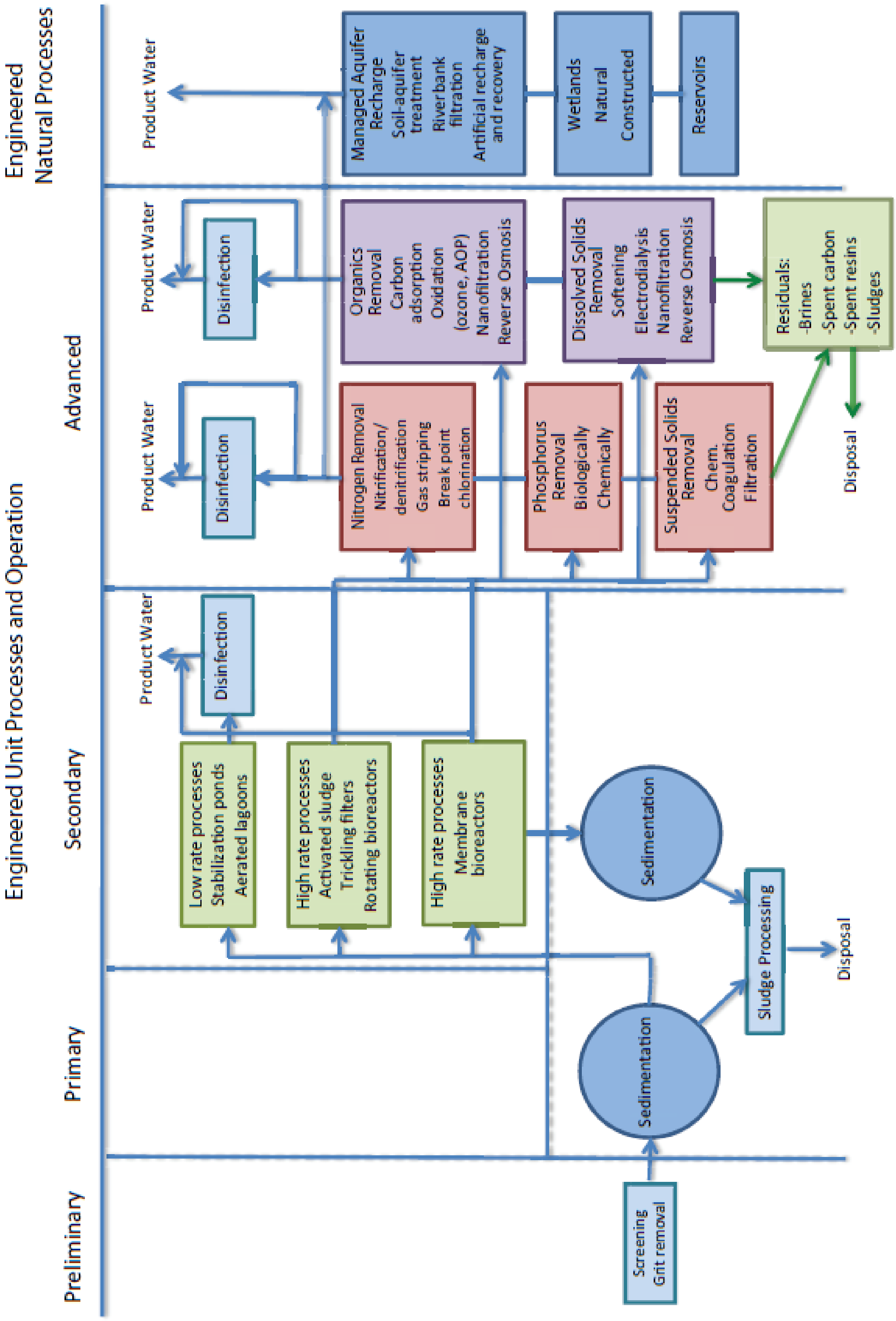

Figure 3. Treatment processes commonly used in water reclamation. (17)

8.2.2. Sanitary considerations

It is important to point out the relevance of the disinfection procedure in reclamation plants, specially, considering the origin of the water and the associated risks for human. Waste water contains bacteria, protozoa and viruses that may result pathogenic to human such as the ones in Table 2.

Table 2. Example of pathogens associated with municipal wastewater (18).

Waterborne bacteria	Salmonella sp., Vibrio cholera, Legionellaceae
Protozoa	Giardia Lamblia, Cryprosporidium sp.
Helminths	Ascaris, Toxocara, Taenia (tapeworm), Ancylostoma (hookworm)
Viruses	Hepatitis A virus, Rotaviruses, Enteroviruses

Some filtration technologies such as nanofiltration and reverse osmosis eliminate not only suspended solids, but also microorganisms (including viruses), as their particle size is smaller than the pore size of the filter. – *See Annex 18.* However, not all techniques eliminate pathogens, or not with the same efficiency. – *See Annex 19.*

The most commonly used disinfection procedure is chlorine treatment, as it is relatively inexpensive, can be produced easily as a by-product from other industrial processes and has residual power, meaning that the chlorine residuals that remain in the waste water can prolong disinfection (18).

Other widely spread disinfection techniques are ultraviolet (UV) radiation, which penetrates the cell wall of the microorganisms in the waste water and impedes the cell's reproduction cycle, and ozone (O_3), which oxidizes all organic matter (18) and thereby damaging the cells. These treatments are effective and do not produce toxic sub-products like chlorine does. However, they have no residual effect, which could lead to microorganisms reproducing in the distribution systems.

8.2.3. Reclamation costs

Because of the wide variety of technologies and combinations, the costs of producing reclaimed water can vary a lot. The costs of the treatment also depend on the quality desired for the reclaimed water. In Catalonia, most WRP operate using membrane technologies.

Several studies have been done on cost estimations of the different water treatment techniques used in water reclamation. – *See Annex 20.*

9. DESALINATION AND RECLAMATION CASE STUDIES

In this chapter, a Catalan desalination plant and a reclamation plant are studied. Their technology for water treatment is described and both processes is compared.

9.1. LLOBREGAT DESALINTION PLANT

The Llobregat desalination plant was built between 2007 and 2009 and it supposed an inversion of 230 million euros. It was constructed to increase the amount of drinking water that was distributed to the Metropolitan Area of Barcelona in 200,000 m^3.

9.1.1. Plant design and technology

Up to 450,000 m^3 of seawater can be taken 2,200 m from the shore at 30 m depth, and will be treated to produce drinking water, with a 45% recovery. This water will go through a pre-treatment, followed by a filtration process, reverse osmosis and a post-treatment before being distributed through the water supply systems.

- Pre-treatment

The pre-treatment consists in the following: First, the water passes through a 3 mm roughing and, if necessary, is disinfected with NaClO. Afterwards, a coagulation-flocculation process is carried out by adding $FeCl_3$ and polidadmac, which enable the formation of scum that is then retrieved from the water stream (19).

- Filtration

Because of the membrane's requirement, there must not be any suspended solids in the water that enters the reverse osmosis filters. Therefore, there is a previous filtration process, which consists of 20 open-air sand and anthracite filters, followed by 20 covered sand and anthracite filters with a smaller particle diameter, through which water is passed through. The water is pressed through a cartridge filter that can be linked to a microfiltration before the reverse osmosis (20).

- Reverse osmosis

The reverse osmosis filtration is the heart of the desalination procedure. Here, 99.7% of the salt is eliminated from the main flow and concentrated in a brine that will then be returned to the sea. This process consists of two stages, each of them with 7 membrane modules. On the first stage, most of the salt is eliminated. The second stage is only necessary in summer, where the boron concentration in the product water is too high.

The membranes used at the first stage are SWC4+ and SWC5 models, and at the second stage ESPAB models are used, all from the brand “Hydronautics”. The cleaning of the membranes can be done with caustic soda, citric acid or EDTA, however, according to the head of the plant, it has never been necessary to clean them up to now (June 2017). The annual replacement rate of the membranes is 3-5%.

A flow diagram scheme of the reverse osmosis procedure is shown in Figure 4, together with the current flows and concentration of each stream at nominal design.

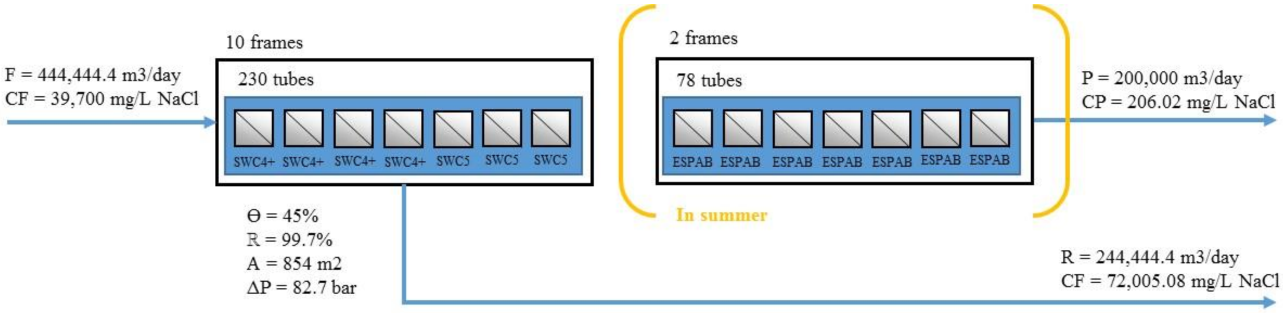

Figure 4. Reverse osmosis at the Llobregat desalination plant.

After the reverse osmosis filtration, the brine flow passes through a pressure exchanger, which transmits the energy in the brine to the feed flow of the reverse osmosis. This procedure allows an energy saving of 53.5% in the first stage filtration (21).

- Post-treatment

The water produced by reverse osmosis lacks salts and minerals and cannot be consumed. Therefore, a remineralization process is carried out through ascendant flux marble filters and the addition of CO_2. This procedure increases the bicarbonate concentration in the drinking water up to 75 mg/L, consuming CO_2 and increasing the pH to 8.2 (22).

Afterwards, 0.6 ppm NaClO is added to the drinking water to maintain the level of chlorine in the distribution system.

- Waste management

The main residual flows from the desalination plant are the brine and the water originated from the counter washing of the sand filters. Both streams are treated equally.

The plant has a sludge treatment unit, through which the sludge is concentrated and separated from the stream. However, it has never been necessary (June 2017) to use this technology, as the concentration of suspended solids in the residual flow was too low.

The output brine stream is returned to the sea by a submarine emissary, where the brine is mixed and diluted with the residual water from the waste water treatment plant.

9.1.2. <u>Flow diagram of the process</u>

The Llobregat desalination plant process is shown in Figure 5.

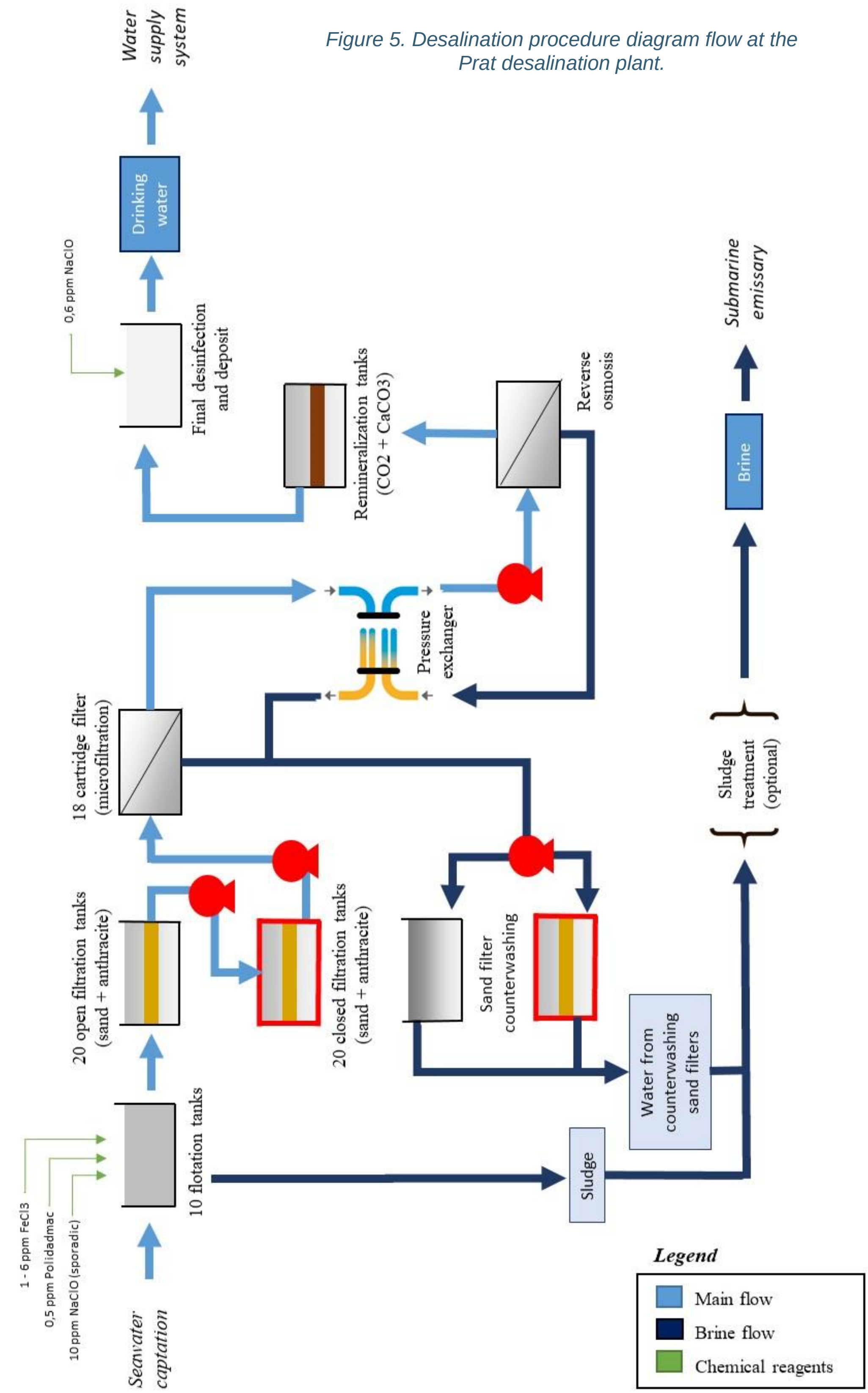

Figure 5. Desalination procedure diagram flow at the Prat desalination plant.

9.2. CAMP DE TARRAGONA RECLAMATION PLANT

The province of Tarragona has a high economic activity and a developed tourism and chemical industry. Such activity, concentrated in less than 200 km^2 and scarcity of water resources led to a severe overuse of the water wells, which suffer from severe marine intrusion. The Tarragona water consortium (CAT) was founded in 1989, when a water transfer from the Ebro was done, supplying 72 municipalities and 34 industries with water from a better quality (23).

9.2.1. Motivation of the project

The water consumption at the Camp de Tarragona in 2009 was 27.7 hm^3 per year in the industrial sector, while the municipal water consumption was 43 hm^3 per year. However, industrial water consumption is stable through the year, while municipal water demand presents high seasonality, with the peak in the summer months (23).

The goal of the Camp de Tarragona reclamation plant is to reuse the water from the municipal waste water treatment plants as refrigeration water for the industries of the area. This would reduce the drinking water consumption of the industries, increasing the water resources available for the water supply of the population.

The foreseen demand of reclaimed water in the area is represented at Table 3.

Table 3. Reclaimed water demand of the industries in Camp de Tarragona (24).

	Industry	**Flow (m^3/h)**
Industrial Park South	DOW	100
	BASF	180
	ERCROS	90
	ADESA	10
	Total	**380**
Industrial Park North	REPSOL PETROLEO	260
	DOW	580
	REPSOL QUÍMICA	700
	Total	**1,900**
TOTAL		***2,280***

9.2.2. Plant design and technology

The Camp de Tarragona reclamation plant purifies the effluent from the secondary treatment of the Tarragona WWTP and the Vila-Seca and Salou WWTP. The project has been designed in three stages, increasing the dimensioning of the plant and, thus, its production.

Currently, the first stage has been done, with a flow of 30,000 m^3/day. In the third stage, water from the Tarragona WWTP will be added, increasing the flow up to 85,445.45 m^3/day (24).

Before entering the reclamation plant, the feed flow is stored for it to have homogeneous and constant characteristics. Then it undergoes a pre-treatment, filtration, reverse osmosis and disinfection before being distributed to the industries in the Camp de Tarragona.

- Pre-treatment

The first step of the reclamation process consists in a physicochemical (coagulation-flocculation) treatment based on the Actiflo® process, which uses microsand as a flocculation precursor. The flocks are then separated by lamellar clarification and pass two disc filters (25).

- Filtration

The same sand filter model, which is also used in the desalination plant, is used for the reclamation plant. First, the water passes through an open-aired sand and anthracite filter. Afterwards, through a similar one which has a smaller nominal size, and therefore, the water is bombed through the filter.

- Reverse Osmosis

A microfiltration is done to prevent the membrane from fouling. In this case, a double filtration is needed to fulfil the required levels of salt and pathogen removal in the reclaimed water. Figure 6 shows scheme of the reverse osmosis at the Camp de Tarragona reclamation plant (25).

- Desinfection

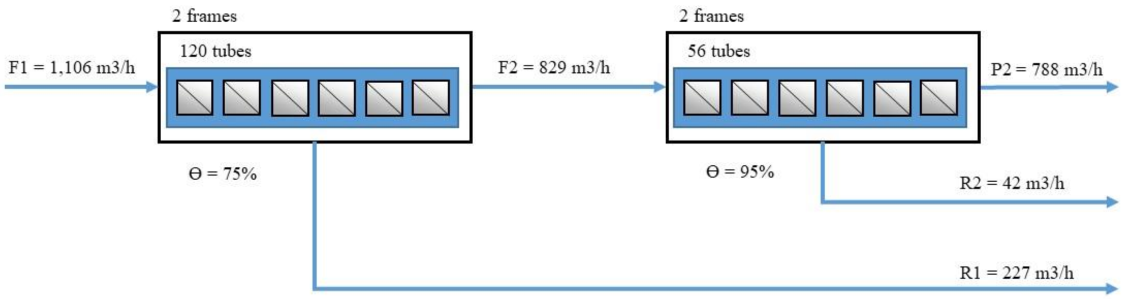

Figure 6. Scheme of the reverse osmosis procedure at the Camp de Tarragona reclamation plant.

Reclaimed water is disinfected with UV radiation and chlorine is added for its residual disinfection power.

9.2.3. Flow diagram of the process

The process carried out at the Camp de Tarragona reclamation plant is shown in Figure 7.

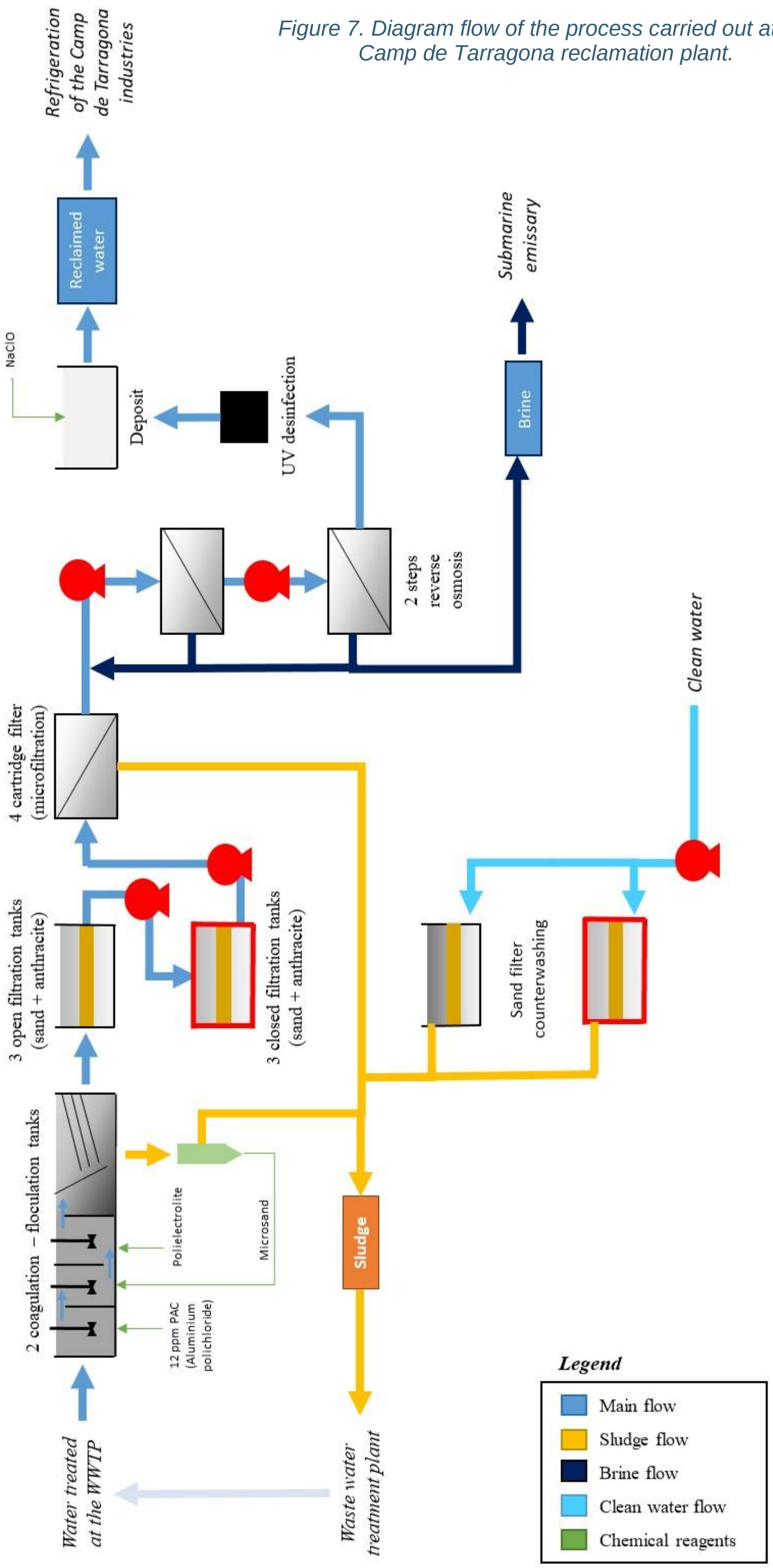

Figure 7. Diagram flow of the process carried out at the Camp de Tarragona reclamation plant.

9.3. DESALINATION AND RECLAMATION COMPARISON

Reclamation and desalination technologies are very similar. In this chapter, the characteristics of each case study are compared regarding the plant, technology, costs and production.

Data of inflow water quality and technology used has been provided by the head of the Llobregat desalination plant. Economic data from the desalination procedure is the one stated in the Catalan Water Management Plan.

Data from the Camp de Tarragona reclamation plant has been obtained from the construction plan of the plant, which was provided by the head of water supply department at ACA.

9.3.1. Quality of the influent

On the one hand, the quality of the water inflow of a reclamation process is very distinct to the seawater quality that enters the desalination plant. On the other hand, the legislation settles stricter criteria for water quality for human consumption than for water reuse. As a result, both inflows are treated differently since they need to achieve distinct water quality according to their purpose.

Desalinized water needs to fulfil the quality standards for the human consumption defined in the RD 140/2003. Reclaimed water requires a different quality depending on the application field. Those quality standards and criteria are defined in the RD 1620/2007. – *See Annex 10.*

In the case of the Camp de Tarragona reclamation plant, the industries themselves asked for a water of higher quality in order to avoid problems in the cooling systems.

Table 4 shows the water quality of the inflows from the studied reclamation and desalination plants. The minimum water quality standards that need to be achieved in each plant for the corresponding water use are also displayed.

The parameters that need to be reduced to fulfil the regulated standards are different at each case. Water from the secondary treatment in the WWTP contains high levels of nutrients and suspended solids, as well as pathogens, while seawater has a high salinity.

As shown in Table 4, the quality reached by the reclamation process is slightly lower than the one of the drinking water, especially regarding microorganisms. The main reason for this are the requirements set by the industry at the Camp de Tarragona.

Therefore, reclaimed water has a relatively high quality and could easily reach the requirements for drinking water with some additional treatment, which would be provided in a water purification plant.

Table 4. Water quality of the in- and outflows of the Camp de Tarragona reclamation plant and the Llobregat desalination plant.

	units	Reclaimed water		Desalinized water	
		INFLOW	*OUTFLOW*	*INFLOW*	*OUTFLOW*
pH				8.12	6.5 - 9.5
Temperature	ºC			12.00 - 25.50	
Total Dissolved Solids (TSS)	mg/L	23.00	5	39,700	
Total Organic Carbon (TOC)			15*		
DBO_5	mg/L	19	4*		
DQO	mg/L	97	20*		
Ammonium (NH_4^+ + NH_3)	mg/L	11	0.8*	0.03	0.5
Nitrate (NO_3)	mg/L			1	
Total nitrogen	mg/L	18			
Phosphorous (P)	µg/L			194	
Phosphates	mg/L		3*		
Potassium (K)	mg/L			523.16	
Sodium (Na)	mg/L			12,094.94	200
Calcium (Ca)	mg/L		350*	515.39	
Strontium (Sr)	mg/L			9,562.91	
Barium (Ba)	µg/L			42.16	
Carbonate (CO_3^{2-})	mg/L				
Bicarbonate (HCO_3^-)	mg/L			158.73	
Chloride (Cl)	mg/L		175*	21,700	250
Fluoride (F)	mg/L			1,700	
Sulfate (SO_4^{2-})	mg/L		300*	2,658.33	250
Boron (B)	mg/L			5.16	1
Alcalinity	mg/L		200*		
Conductivity	µS/cm		2,000*		2,500
Turbidity	NTU		1	0.47	1
Coliformes totals				28.00	0
E. Coli	UFC/100mL		absence		0
Enterococcus	UFC/100mL				0
Clostridium perfingens	UFC/100mL				0
Legionella spp.	UFC/100mL		absence		
Intestinal nematode	egg/10L		1		

Input data: values found at the pilot plant (40) and described in the project of the reclamation plant, and data supplied by the head of the Llobregat desalination plant.

Output data: values stated in the legislation, RD 1620/2007 for water reuse as refrigeration, and RD 140/2003 for drinking water.

* Standard value set as a requirement of the industrial sector

9.3.2. Technology

Reclamation technology offers a wide range of combinations and possibilities. However, in the studied cases, reclaimed water has to reach such high-quality that the technology used is similar to the one used in desalination procedures.

Both the Camp de Tarragona reclamation plant and the Llobregat desalination plant have the technology showed in Table 5, even though they differ in the dimensioning.

Table 5. Technology comparison and dimensioning of the Camp de Tarragona reclamation plant and the Lobregat desalination plant.

	Camp de Tarragona reclamation plant (30,000 m^3/day)	**Llobregat desalination plant (445,000 m^3/day)**
Coagulation – Floculation (Pre-treatment)	2	20
Open filtration tanks	3	20
Closed filtration tanks	3	20
Cartridge filters	4	18
Reverse osmosis (step 1)	140	2,300
Reverse osmosis (step 2)	112	(156 in summer)

The Llobregat desalination plant has much higher production capacity than the regeneration plant at Camp de Tarragona. Considering the amount of treated water in both plants, the reverse osmosis procedure plays a bigger role in the desalination plant than in the reclamation one.

Probably, this happens because most of the load in seawater is salt, which has a particle size that is too small to be removed by filters in the pre-treatment and can only be eliminated through reverse osmosis. Therefore, in desalination procedures, the pre-treatment is only understood as a way to avoid foaming in the reverse osmosis filters.

In the reclamation procedure, substances that need to be removed from the water flow have a more diverse particle size, and can be effectively eliminated through the coagulation-flocculation or the filtration technologies, which are also cheaper.

9.3.3. Cost and production

Obtaining economic data from the enterprises was not possible. Therefore, the estimated costs from each plant project have been used to analyse the costs of each technology.

It is important to take into account that costs are not constant. The cost of producing water is linked to the production itself, as the higher the production, the better return on the investment.

At its time, the production of desalinized water is linked to the draughtiness and level of the water reservoirs.

On the other hand, most of the expenses are linked to the energy consumption required by the reverse osmosis high pressure bombs. It is difficult to estimate energy costs because the price of electricity fluctuates constantly.

Table 6 shows some production parameters together with the design economic data.

Table 6. Cost and production parameters of the Camp de Tarragona reclamation plant and the Llobregat desalination plant.

	Reclaimed water	**Desalinized water**
	Camp de Tarragona reclamation plant	Llobregat desalination plant
Water origin	Vilaseca-Salou and Tarragona WWTP	Mediterranean sea
Use of the water produced	Industrial refrigeration processes	Human consumption
Inpt design flow rate	30,000 m^3/day	445,000 m^3/day
Output design flow rate	19,000 m^3/day	200,000 m^3/day
Global recovery	63%	45%
Energy consumption	2.5 kWh/m^3	3.5 kWh/m^3
Initial inversion	42 million €	230 million €
Cost of the product	0.4 €/m^3	0.4 €/m^3

Data regarding design data, energy consumption and initial inversion were supplied by the head of the Llobregat desalination plant and the Camp de Tarragona reclamation plant.

Data regarding the cost of the product has been obtained from the project of the Llobregat desalination plant (24), and the water management plan for the inner basins in Catalonia (9).

The design flowrate is 10 times higher for the Llobregat desalination plant than for the Camp de Tarragona reclamation plant. The initial inversion is higher in the desalination plant, as it is bigger, but considering the production, the initial inversion is relatively higher for the reclamation plant. It is thought that this is only related with the dimensioning of the plant.

Energy consumption is higher for the production of one cubic meter of desalinized water than of reclaimed water. This can be explained by the higher importance of the reverse osmosis procedure in the desalination plant than in the reverse osmosis one. Reverse osmosis requires high pressure bombs, which have high energy consumption.

The difference in energy consumption makes it expectable that a desalination would be more expensive than reclamation. However, reported data show that the costs for a unitary production of water (1m^3) are very similar. It is believed that this unexpected similarity is caused by the variability of the sources, their interests and the lack of reliable data.

Figure 8 shows the evolution of the production of desalinized and reclaimed water in Catalonia in the last five years (2012 – 2016).

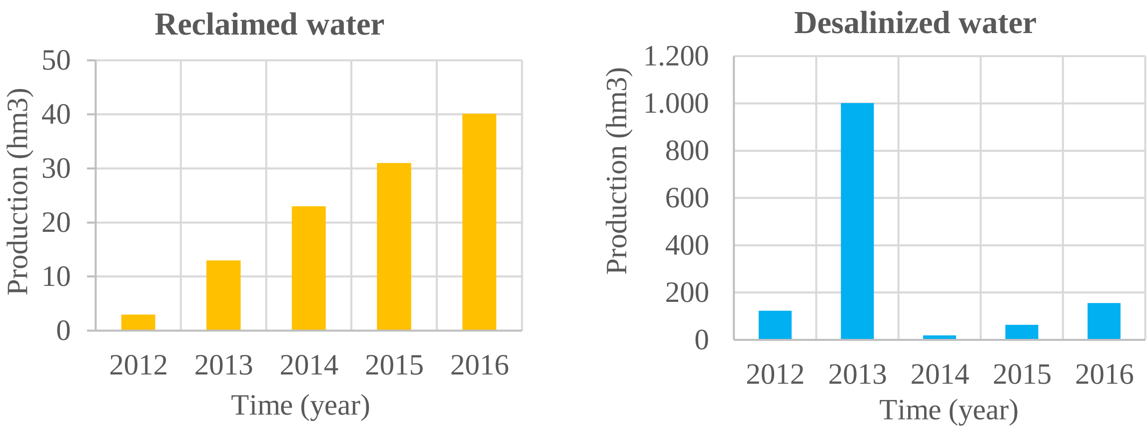

Figure 8. Evolution of the production of reclaimed water in the Camp de Tarragona reclamation plant and evolution of the production of desalinized water at the Llobregat desalination plant.

Data regarding production of the plants have been supplied by the heads of the plants.

The production of reclaimed water is lower than the production of desalinized water. This can be explained by the dimensioning of each plant. The design flow of the Llobregat desalination plant is ten times higher than the one from the Camp de Tarragona reclamation plant. Therefore, the production of desalinized water is higher than the one of reclaimed water.

However, the production pattern differs from a plant to the other. The production of desalinized water through the years is irregular, as it production depends on the draughtiness. It is observed that in 2013 the production was higher, as it was a dry year, while the rest of the years the activity of the plant is kept at a maintenance level. The production of reclaimed water, instead, shows a clear increasing tendency. As reclaimed water is produces by demand, this graphic shows that the demand of reclaimed water is increasing in the industries of the Camp de Tarragona.

10.CONCLUSIONS

Catalonia suffers from water deficit because of the irregularities of its climate and the different population density throughout its territory. This means that the water resources can be insufficient to satisfy the water demand required by the society in terms of quantity and quality.

In order to guarantee water supply, detailed water management plans have been designed and actions have been taken to generate new water resources. The inner basins water management plan points out the importance of recovering contaminated aquifers, which will represent an increase to the water resources available for consumption. However, 75% of the new water resources planned will be generated by desalination and water reuse or reclamation.

Only 40% of the measures planned for 2015 have been fulfilled due to economic difficulties. However, two desalination plants have been built (Tordera and Llobregat), and several wastewater treatment plants have incorporated a tertiary treatment to produce reclaimed water.

On the one hand, the production of water by desalination and reclamation technologies is more expensive than the conventional one; thus, these technologies are not exploited at full scale until it is needed: in drought periods. On the other hand, the technology to produce these unconventional water resources needs a continuous flow; therefore, desalination and reclamation plants must work continuously.

The law does not contemplate direct human consumption of reclaimed water. This makes the difference between both technologies. While desalinized water is used exclusively for domestic water consumption, reclaimed water is used in agriculture, industrial activities, as recreational water, for environmental purposes or to clean the streets in some cities.

Despite their regulatory differences and the associated risk to wastewater reuse desalination and reclamation are technologically very similar. The heart of both technologies is the reverse osmosis. However, in water reclamation, the pre-treatment and disinfection gains more importance because of the health risk associated to the reuse of waste water.

The Llobregat desalination plant is an example of how seawater is treated to increase the drinking water resources and then can be supplied to big metropolitan areas like the city of Barcelona. The Camp de Tarragona reclamation plant shows how waste water can be reused for industrial purposes such as refrigeration, decreasing the demand of potable water.

Desalination technology has a higher energy consumption than reclamation. However, both techniques are equally competitive in the market, as their production costs are very similar. Their main differences lay on the fields of applications that can be given to the water produced by each technique, and on the demand for each of them.

Water desalination provides a solution to grant water supply to the population in drought periods in coastal cities. Water reclamation and reuse allows water resources to be diversified and conserved, and thus, it is an effective technique to protect the fluvial ecosystems and adapt to climate change. By substituting potable water for reclaimed one, the maintenance of the water bodies' ecological levels can be achieved, their quality improved and their lifespan prolonged.

This leads to the final conclusion that water desalination should be a technique used at full extent only in drought periods, and it should be kept at a maintenance level the rest of the time. In contrast, water reclamation should be enhanced in order to decrease the amount of water that is taken from the environment, for it to be available for potabilization plants, and for the improvement of the quality of the fluvial ecosystems.

11.APPENDIX

Annex 1. Basic concepts and definitions

Reuse: The act of using treated wastewater as a water resource.

Reclamation: The process or treatment that is done to wastewater in order to reach a water quality good enough for it to be reused. The obtained water is called reclaimed water.

Tertiary treatment: Additional treatment that some wastewater treatment plants incorporate in addition to the primary and secondary treatment, in order to produce reclaimed water.

Balanced system: System where the water demand is not higher than the water resources available.

Water body: Volume of water which is found in a limited space. Water resources in Catalonia are divided into 53 water bodies. The water body defines the system in which water quality is analyzed to determine its environmental quality.

Environmental quality: Characteristics of the water body, determined by the analysis of several indicators, which will define the quality of the water body.

Indicator: Tools that allow, by the analysis of several parameters, the allocation of a quality value to a water body. The indicators analyze biological, hydromorphological and physicochemical parameters. Biological parameters are based on the analysis of diatom algae (IPS index), macroinvertebrates (IBMWP index) and fishes (IBICAT index). The hydromorphological parameters include the fulfillment of the ecological flow, the state of the shore and riverside species (QBR index) and the continuity of the river flow. The physicochemical parameters include pH, conductivity, total organic carbon (TOC), nutrients such as nitrates and phosphates, ammonia and chloride.

Environmental objective: Regulated environmental quality which the water body should achieve by the application of the measures detailed in a water management plan. The quality of the indicators is described in the legislation (in this case, the Water Framework Directive). The objective is that all water bodies are in a good ecological status.

Good ecological status: A water body reaches a good ecological status when all the indicators measured to determine its environmental quality fulfill the standards stated in the current legislation (Water Framework Directive).

Technical difficulties: The available technology is not good enough to provide a solution to the problem. Research needs to be done to improve rehearsal of the available techniques or to decrease the costs of it.

Ecological flow: The flow regime consistent with the achievement of the environmental objectives of the Water Framework Directive.

Environmental purposes: When water is used with environmental purposes, it is not used for human consumption, but for purposes such as the regeneration of aquifers, the prevention of the sea intrusion, forestry or maintenance of ecological river flows, wetlands and river deltas.

Annex 2. The global water gap: inequality in water consumption

As it is shown in Figure 8, simple comparisons in water consumption between rich and poor countries highlight the scale of global inequality.

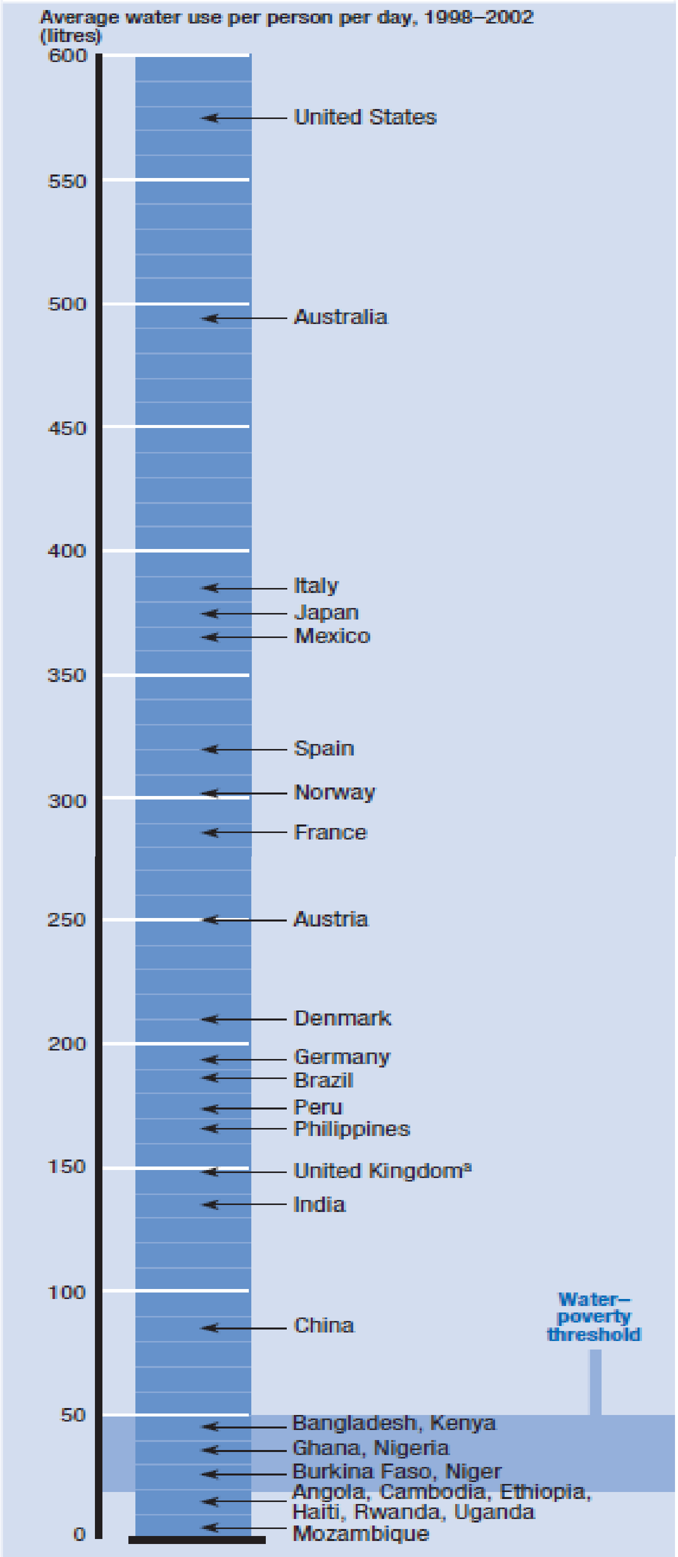

Figure 9. The global water gap. This Figure shows the scale of differences in water consumption between countries (5).

Average water use ranges from 200 – 300 litres a person a day in most countries in Europe to 575 in the United States. Residents pf Phoenix, Arizona a desert city with some of the greenest lawns in the United States, use more than 1000 litres a day. By contrast, average use in countries such as Mozambique is less than 10 litres.

National averages inevitably mask every large variations. People lacking access to improved water in developing countries consume far less, partly because they must carry it over long distances and water is heavy. Another problem is that poor households are often unable to afford more than a small amount of water purchased in informal markets.

Setting a water-poverty line is difficult because of variations relating to climate, seasonality, individual household characteristics and other factors. The World Health Organization (WHO) and the United Nations Children's Found (UNICEF) suggest a minimum requirement of 20 litres a day from source within 1 kilometre from household. This is sufficient for drinking and basic personal hygiene. Below this level people are constrained in their ability to maintain their physical well-being and the dignity that comes with being clean. Factoring in bathing and laundry needs would raise the personal threshold to about 50 litres a day.

"Not having access to clean water" is a euphemism for profound deprivation. It means that people live more than 1 kilometre from the nearest safe water source and that they collect water from drains, ditches or streams that might be infected with pathogens and bacteria that can cause severe illness and death. The problem is not that people are unaware of the dangers, but that they have no choice.

Annex 3. ***Legislation on water and water management***

- *Water framework directive*

On a European level, the most important law regulating water is the *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy* (Directive 2000/60/EC).

This rule sets a framework for water protection concerning inland surface water, transitional waters, coastal waters and groundwater. Its purposes are to prevent further deterioration of aquatic ecosystems and enhance its protection, to promote sustainable water use, to reduce groundwater pollution, and to mitigate the effects of floods and droughts.

It establishes the duty of the Member States to make operational measure programs specified in river basin management plans, and for each river basin, each Member State shall undertake an analysis of its characteristics, a review of the impact of human activity on the status of surface waters and groundwater, and an economic analysis of water use. Moreover, Member States shall ensure the establishment of a register of protected areas.

The Water Framework Directive was transposed into the Spanish legislation with the *Ley 62/2003, de 30 de diciembre, de medidas fiscales, administrativas y del orden social* (Ley 62/2003).

- *Spanish water law*

On a Spanish level, the *Real Decreto Legislativo 1/2001, de 20 de julio, por el que se aprueba el texto refundido de la Ley de Aguas* (RDL 1/2001) is the reference famework for water regulation. It defines the Water Public Domain and the spanish river basins, it sets the State's responsabilities and the legal regime of the autonomous communities. It also defines the National Water Council of Spain and the River Basin Authorities.

In addition, the RDL 1/2001 stipulates the procedure and content of the river basin management plans and the use of the Water Public Domain, and it regulates water concession contracts and the water register. Finally, this law fix the protection standards for the Water Public Domain and water quality.

- *Catalan water law*

On a Catalan level, the water legislation is divided in two main laws: the *Decret Legislatiu 3/2003, de 4 de novembre, pel qual s'aprova el text refós de la legislació en matèria d'aigües de Catalunya* (DL 3/2003) and the *Decret 103/2000, de 6 de març, pel qual s'aprova el Reglament dels tributs gestionats per l'Agència Catalana de l'Aigua* (Decree 103/2000).

The DL 3/2003 defines the competences of the Catalan local government, the Generalitat, and defines the Catalan Inner Basins as well as the water management administrative organisms: the Catalan Water Agency and the local institutions; and their competences. This law refers specifically to the inner basins water management plan and the measures program, it also develops specific water supply systems and infrastructures for water management, as well as it regulates irrigations systems. Moreover, the DL 3/2003 specifies financial details and defines the water surcharge.

The Decree 103/2000 develops the financial regime of the Catalan Water Agency, its tributary figures and how to calculate the water surcharge and other tributes, and documents surrounding the water bill. It also considers the task of the inspectors and fines.

Annex 4. ***Public organisms regulating the water cycle in Catalonia***

- *Catalan Water Agency (ACA)*

The Catalan Water Agency (ACA) is the Catalan government's public company, ascribed to the Department of Territory and Sustainability from the Generalitat de Catalunya, in charge of water planning and management in accordance with the basic principles of the Water Framework Directive. (3)

ACA was created in 2000, and it resulted from the fusion of the Sanitation board (Junta de Sanejament) and the Water board (Junta d'Aigües) (26). Since then, ACA promotes its own action plan to guarantee present and future water supply and water quality at source (groundwater and surface water) (3).

ACA is financed basically with the approximately 450 million € per year that are collected through the water rate, an environmental tax applied in the water bill. Nevertheless, the final bill is not determined by ACA, but by the town councils, who are the actual owners of water supply. In this sense, the water rate accounts for about 30% of the final water bill (3).

- *Ebro Hydrographic Confederation (CHE)*

The Ebro Hydrographic Confederation was created in 1926 (27). Its functions are the elaboration of the Ebro Basin Water Management Plan, administration and control of the Water Public Domain and general interest utilizations or that affect more than one Spanish region, realization of the project, construction and operation of the building projects with founding from the CH, those entrusted by the Spanish central government, and those that arise from agreements with the Autonomous Regions or local entities (28).

- *Júcar Hydrographic Confederation (CHJ)*

The Júcar Hydrographic Confederation was created in July 1934 (29). Its functions are the elaboration of the Júcar Basin Water Management Plan, and the same administrative and control tasks as the CHE (30). Those functions are designed in the 23rd Article in the RDL 1/2001.

Annex 5. Catalan territories in terms of water management

Catalonia is divided into two separated areas regarding water management: the inner basins and the interregional basins. These areas are represented in Figure 9. The inner basins include the rivers Muga, Fluvià, Ter, Daró, Tordera, Besòs, Llobregat, Foix, Gaià, Francolí and Riudecanyes. The interregional basins include the Catalan part of the basins of the Ebro river and its efluents, the river Júcar, and the river Garonne, which belongs to an international basin. (8)

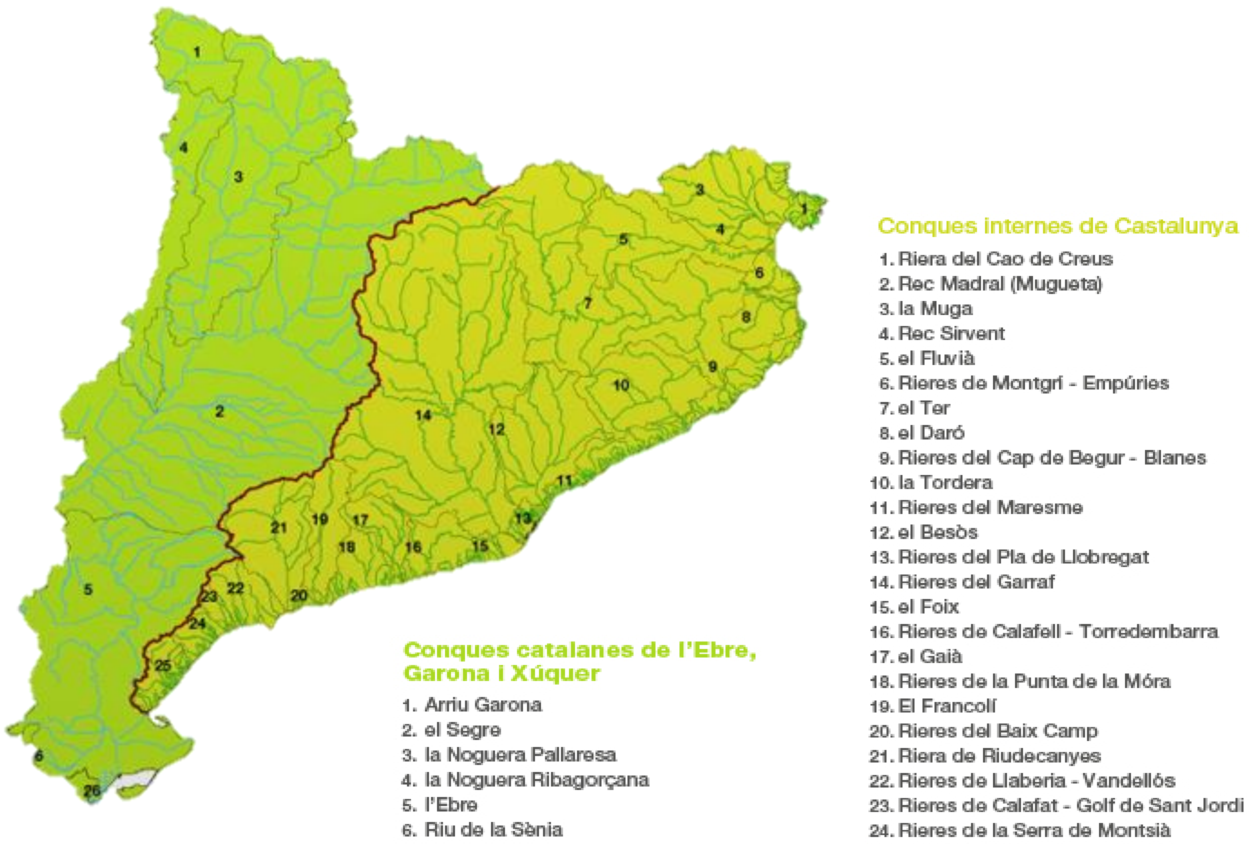

Figure 10. Water districts and river basins in Catalonia. Map of the inner basins and Interregional basins (33).

Annex 6. Water management systems structure in Catalonia

The Catalan inner basins are divided into systems to facilitate its water management. Those systems are represented in Figure 10.

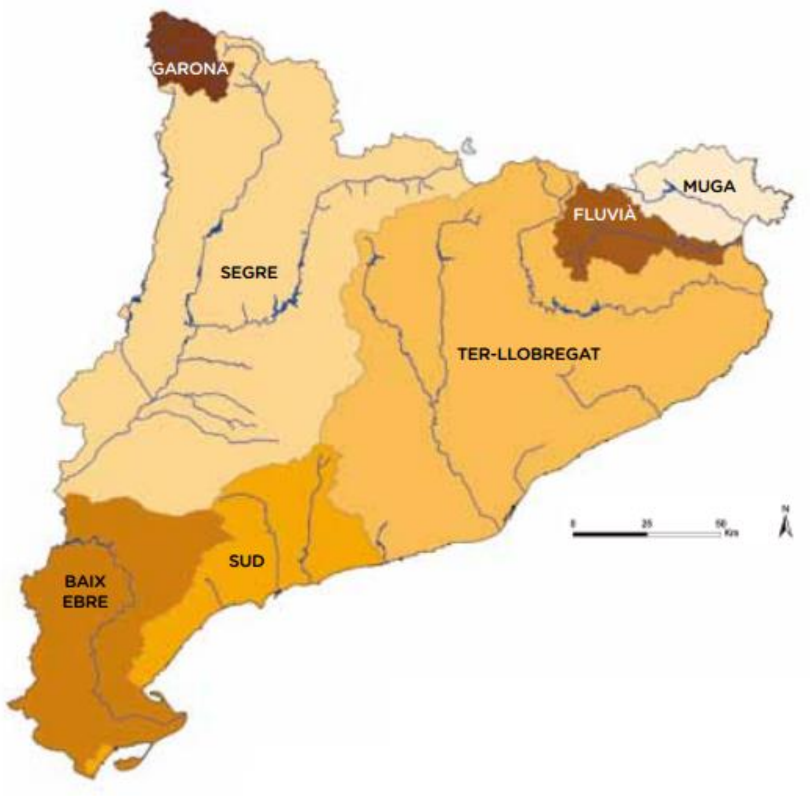

Figure 11. Water management systems in Catalonia (9).

Annex 7. Water quality objectives for 2015 in the first cycle WMP$_{IB}$

The inner basins water management plan sets the objectives for water bodies quality in 2015. These objectives are shown in Figure 11 and Figure 12.

Figure 12. Quality objective for surface waters stated in the inner basins water management plan for 2015 (9).

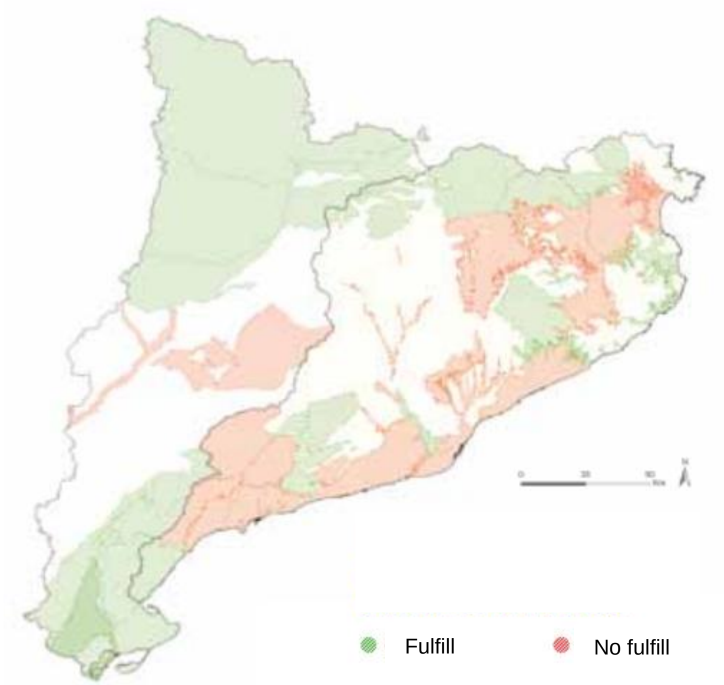

Figure 13. Quality objective for subterranean waters stated in the water management plan for 2015 (9).

Annex 8. Measures designed in the first cycle WMP_{IB} for a higher efficiency in water management

- Management of the industrial and urban demand

Unitary water consumption has decreased since 2003. Despite the population growth, total water consumption in Catalonia in 2007 was 4% lower than five years before. The challenge now is to maintain this moderate consumption in the years to come.

- Improvement of the irrigation technology

The implementation of modern irrigation technologies has a triple benefit: increase of the efficiency, maintain the water in rivers, to reduce the diffuse pollution of subterranean water due to the excessive use of fertilizers and pesticides.

The measures described in the plan will allow savings between 146 and 225 hm^3 of water in a dry year in the Ebro Catalan basins.

- Improvement of the distribution network

Despite the efficiency ratios of the distribution network are similar to the ones in other European countries, it is possible to improve. The Plan purposes some technical standards which need to be achieved by the municipal services.

Annex 9. Measures designed in the first cycle WMP_{IB} for a better water supply

- Improvement of the water transport network

This is a priority from the Plan, as 20% of the total inversions are foreseen with this objective. New conductions will allow a better distribution of the water resources, generating an updated flexible network which will be able to face possible eventualities.

It is notable the construction of the tunnel between Fontsanta and Trinitat, which will link the Ter and Llobregat rivers.

- Improvement of the treatments

This supposes a guarantee for more and more strict sanitary requirements for drinkable water. Membrane treatments were installed in the potabilization plants from Abrera and Sant Joan Despí, and will benefit a population of 4 million inhabitants.

- Increase of the regulations

This is difficult in Catalonia, as almost all the possible water reservoirs are already built, however, some minor actions are planned to rehabilitate some smaller dams and construction of some storage pool or pond.

- Integrated management of the resources

The incorporation of new water resources leaves the way open for new water management possibilities in the Catalan inner basins, and it evidences the necessary coordination between the different kinds of water resources: superficial, subterranean, reclaimed and desalinated. Depending on the climate situation, water will be taken from different resources.

Annex 10. Quality criteria for reclaimed water reuse

Reclaimed water is required a different quality depending on its final purpose. Those quality standards or criteria are defined in the RD 1620/2007, and correspond to the ones in the tables that follow: Table 7, Table 8, Table 9, Table 10, Table 11 and Table 12.

Table 7. Quality parameters for urban uses of reclaimed water.

ÚS DE L'AIGUA	VALOR MÀXIM ADMISIBLE (VMA)				
	NEMÀTODES INTESTINALS[1]	ESCHERICHIA COLI	SÒLIDS EN SUSPENSIÓ	TERBOLESA	ALTRES CRITERIS
1. USOS URBANS					
QUALITAT 1.1: RESIDENCIAL[2] a) Reg de jardins privats.[3] b) Descarrega d'aparells sanitaris.[3]	1 ou/10 L	0 UFC[4]/100 ml	10 mg/L	2 NTU[5]	ALTRES CONTAMINANTS[6] presents a l'autorització d'abocament d'aigües residuals: s'haurà de limitar l'entrada d'aquests contaminants al medi ambient. En el cas que es tracti de substàncies perilloses[7], caldrà assegurar-se de respectar les NCAs.[8] Legionel·la spp. 100 UFC/L.(si existeix risc d'aerosolització)
QUALITAT 1.2: SERVEIS a) Reg de zones verdes urbanes (parcs, camps esportius i similars).[9] b) Neteja de carrers.[9] c) Sistemes contra incendis.[9] d) Rentat industrial de vehicles.[9]	1ou/10 L	200 UFC/100 ml	20 mg/L	10 NTU	

[1]. Considerar en tot s els grups de qualitat al menys els gèneres: *Ancylostoma, Trichuris i Àscaris*.

[2]. S'han de sotmetre a controls que assegurin el correcte manteniment de les instal·lacions.

[3]. La seva autorització estarà condicionada a la obligatorietat de la presència d'un doble circuit senyalitzat en tots els trams fins al punt d'us.

[4]. Unitats Formadores de colònies.

[5]. Unitats Nefelomètriques de Terbolesa.

[6]. Veure l'Annex II del RD 849/1986, d'11 d'abril

[7]. Veure l'Annex IV del RD 907/2007, de 6 de juliol.

[8]. Norma de qualitat ambiental, veure l'article 245.5.a del RD 849/1986, d'11 d'abril, modificat pel RD 606/2003 de 23 de maig.

[9]. Quan existeixi un ús amb possibilitat d'aerosolització de l'aigua, es imprescindible seguir les condicions d'ús que assenyali, per cada cas, l'autoritat sanitària, sense les quals aquests usos no seran autoritzats.

Table 8. Quality parameters for agricultural uses of reclaimed water.

ÚS DE L'AIGUA	VALOR MÀXIM ADMISIBLE (VMA)				
	NEMÀTODES INTESTINALS[1]	ESCHERICHIA COLI	SÒLIDS EN SUSPENSIÓ	TERBOLESA	ALTRES CRITERIS
2. USOS AGRICOLES[1]					
QUALITAT 2.1[2] a) Reg de cultius amb sistema d'aplicació de l'aigua que permeti el contacte directe de l'aigua regenerada amb les parts comestibles per alimentació humana en fresc.	1 ou/10 L	100 UFC/100 ml Considerant un pla de mostreig a 3 classes[3] amb els següents valors: n= 10 m = 100 UFC/100ml M = 1.000 UFC/100ml c = 3	20 mg/L	10 NTU	ALTRES CONTAMINANTS presents a l'autorització d'abocament d'aigües residuals: s'haurà de limitar l'entrada d'aquests contaminants al medi ambient. En el cas que es tracti de substàncies perilloses, caldrà assegurar-se de respectar les NCAs. Legionel·la spp. 1.000 UFC/L.(si existeix risc d'aerosolització) És obligatori dur a terme la detecció de patògens Presència / Absència (Salmonel·la, etc..) quan es repeteixi habitualment que C=3 per M=1.000.

[1] Característiques de l'aigua regenerada que requereixen informació addicional: Conductivitat 3,0 dS/m; Relació d'Absorció de Sodi (RAS): 6 meq/l; Bor: 0,5 mg/l; Arsènic: 0,1 mg/l; Beril·li: 0,1 mg/l; Cadmi: 0,01 mg/l; Cobalt: 0,05 mg/l; Crom: 0,1 mg/l; Coure: 0,2 mg/l; Manganès: 0,2 mg/l; Molibdè: 0,01 mg/l; Níquel: 0,2 mg/L; Seleni: 0,02 mg/l; Vanadi: 0,1 mg/l.

Pel càlcul de RAS s'utilitzarà la fórmula:

$$Ras\ (meq/L) = \frac{[Na]}{\frac{[ca] + [Mg]}{2}}$$

[2] Quan existeixi un ús amb possibilitat d'aerosolització de l'aigua, és imprescindible seguir les condicions d'ús que assenyali, per cada cas, l'autoritat sanitària, sense les quals, aquests usos no seran autoritzats.

[3] Sent n: nº d'unitats de la mostra; m: valor límit admissible pel recompte de bacteris; M: valor màxim permès pel recompte de bacteris; c: nombre màxim d'unitats de mostra, el nombre bacteris es situa entre m i M.

Table 9. Quality parameters for other agricultural uses of reclaimed water.

ÚS DE L'AIGUA	VALOR MÀXIM ADMISIBLE (VMA)				
	NEMÀTODES INTESTINALS[1]	ESCHERICHIA COLI	SÒLIDS EN SUSPENSIÓ	TERBOLESA	ALTRES CRITERIS
2. USOS AGRICOLES[1]					
QUALITAT 2.2 a) Reg de productes per consum humà amb sistema d'aplicació d'aigua que no evita el contacte directe de l'aigua regenerada amb les parts comestibles, però el consum no és fresc sinó amb un tractament industrial posterior. b) Reg de pastures per consum d'animals productors de llet o carn. c) Aqüicultura	1ou/10 L	1.000 UFC/100 ml Considerant un pla de mostreig a 3 classes[1] amb els següents valors: n= 10 m = 100 UFC/100ml M = 1.000 UFC/100ml c = 3	35 mg/L	No es fixa límit	ALTRES CONTAMINANTS presents a l'autorització d'abocament d'aigües residuals: s'haurà de limitar l'entrada d'aquests contaminants al medi ambient. En el cas que es tracti de substàncies perilloses, caldrà assegurar-se de respectar les NCAs. *Taenia saginata i Tenia solium*: 1 ou/l (si es reguen pastures per consum d'animals productors de carn) És obligatori dur a terme la detecció de patògens Presència / Absència (Salmonel·la, etc..) quan es repeteixi habitualment que c=3 per M=1.000.
QUALITAT 2.3 a) Reg localitzat de cultius llenyosos que impedeixin el contacte de l'aigua regenerada amb els fruits consumits en l'alimentació humana. b) Reg de cultius de flors ornamentals, vivers, hivernacles sense contacte directe de l'aigua regenerada amb les produccions. c) Reg de cultius industrials no alimentaris, vivers, farratges, ensitjats, cereals i llavors oleaginoses.	1ou/10 L	10.000 UFC/100 ml	35 mg/L	No es fixa límit	ALTRES CONTAMINANTS presents a l'autorització d'abocament d'aigües residuals: s'haurà de limitar l'entrada d'aquests contaminants al medi ambient. En el cas que es tracti de substàncies perilloses, caldrà assegurar-se de respectar les NCAs. Legionel·la spp. 100 UFC/L (*si existeix risc d'aerosolització*)

[1] Sent n: nº d'unitats de la mostra ; m: valor límit admissible pel recompte de bacteris; M: valor màxim permès pel recompte de bacteris; c: nombre màxim d'unitats de mostra, el nombre bacteris es situa entre m i M.

Table 10. Quality parameters for industrial uses of reclaimed water.

ÚS DE L'AIGUA	VALOR MÀXIM ADMISIBLE (VMA)				
	NEMÀTODES INTESTINALS[1]	ESCHERICHIA COLI	SÒLIDS EN SUSPENSIÓ	TERBOLESA	ALTRES CRITERIS
3. USOS INDUSTRIALS					
QUALITAT 3.1[1] a) Aigües de procés i neteja excepte en la indústria alimentària. b) Altres usos industrials	No es fixa límit	10.000 UFC/100 ml	35 mg/L	15 NTU	ALTRES CONTAMINANTS presents a l'autorització d'abocament d'aigües residuals: s'haurà de limitar l'entrada d'aquests contaminants al medi ambient. En el cas que es tracti de substàncies perilloses, caldrà assegurar-se de respectar les NCAs. *Legionel·la spp*: 100 UFC/L *(si existeix risc d'aerosolització)*
c) Aigües de procés i neteja per ús en la indústria alimentària.	1ou/10 L	1.000 UFC/100 ml Considerant un pla de mostreig a 3 classes[2] amb els següents valors: n= 10 m = 1.000 UFC/100ml M = 10.000 UFC/100ml c = 3	35 mg/L	No es fixa límit	ALTRES CONTAMINANTS presents a l'autorització d'abocament d'aigües residuals: s'haurà de limitar l'entrada d'aquests contaminants al medi ambient. En el cas que es tracti de substàncies perilloses, caldrà assegurar-se de respectar les NCAs. *Legionel·la spp*. 100 UFC/L *(si existeix risc d'aerosolització)* Es obligatori dur a terme detecció de patògens Presencia/Absència (Salmonel·la, etc.) quan es repeteixi habitualment que c=3 per M=10.000
QUALITAT 3.2 a) Torres de refrigeració i condensadors evaporatius	1ou/10 L	Absència UFC/100 ml	5 mg/L	1 NTU	*Legionel·la spp:* Absència UFC/L Per la seva autorització és requerirà: - L'aprovació, per part de l'autoritat sanitària del Programa específic de control de les instal·lacions contemplat en el RD 865/2003, de 4 de juliol, pel qual s'estableixen els criteris higiènic-sanitaris per la prevenció i el control de la legionel·losi. - Ús exclusivament industrial i en ubicacions que no estiguin en zones urbanes ni a prop de llocs amb activitat pública o comercial.

[1] Quan existeixi un ús amb possibilitat d'aerosolització de l'aigua, és imprescindible seguir les condicions d'ús que assenyali, per cada cas, l'autoritat sanitària, sense les quals, aquests usos no seran autoritzats.

[2] Sent n: nº d'unitats de la mostra; m: valor límit admissible pel recompte de bacteris; M: valor màxim permès pel recompte de bacteris; c: nombre màxim d'unitats de mostra, el nombre bacteris es situa entre m i M.

Table 12. Quality parameters for recreative uses of reclaimed water.

ÚS DE L'AIGUA	VALOR MÀXIM ADMISIBLE (VMA)				
	NEMÀTODES INTESTINALS[1]	ESCHERICHIA COLI	SÒLIDS EN SUSPENSIÓ	TERBOLESA	ALTRES CRITERIS
4. USOS RECREATIUS					
QUALITAT 4.1[1] a) Reg de camps de golf	1 ou/10L	200 UFC/100 ml	20 mg/L	10 NTU	ALTRES CONTAMINANTS presents a l'autorització d'abocament d'aigües residuals: s'haurà de limitar l'entrada d'aquests contaminants al medi ambient. En el cas que es tracti de substàncies perilloses, caldrà assegurar-se de respectar les NCAs. Si el reg s'aplica directament a la zona del sòl (goteig, microaspersió) es fixen els criteris del grup de qualitat 2.3. *Legionel·la spp*: 100 UFC/L (si existeix risc d'aerosolització)
QUALITAT 4.2 a) Estanys, masses d'aigua i cabals circulants ornamentals, en els quals està impedit l'accés del públic a l'aigua	No es fixa límit	10.000 UFC/100 ml	35 mg/L	No es fixa límit	ALTRES CONTAMINANTS presents a l'autorització d'abocament d'aigües residuals: s'haurà de limitar l'entrada d'aquests contaminants al medi ambient. En el cas que es tracti de substàncies perilloses, caldrà assegurar-se de respectar les NCAs. P_T: 2 mg P/L (en aigua estancada)

[1] Quan existeixi un ús amb possibilitat d'aerosolització de l'aigua, és imprescindible seguir les condicions d'ús que assenyali, per cada cas, l'autoritat sanitària, sense les quals, aquests usos no seran autoritzats.

Table 11. Quality parameters for environmental uses of reclaimed water.

ÚS DE L'AIGUA	VALOR MÀXIM ADMISIBLE (VMA)				
	NEMÀTODES INTESTINALS[1]	ESCHERICHIA COLI	SÒLIDS EN SUSPENSIÓ	TERBOLESA	ALTRES CRITERIS
5. USOS AMBIENTALS					
QUALITAT 5.1 a) Recàrrega d'aqüífers per percolació localitzada en el terreny	No es fixa límit	1.000 UFC/100 ml	35 mg/L	No es fixa límit	N_T[1]: 10 mg N/L NO_3: 25 mg NO_3/L Art. 257 a 259 del RD 849/1986
QUALITAT 5.2 a) Recàrrega d'aqüífers per injecció directa	1 ou/10L	0 UFC/100 ml	10 mg/L	2 NTU	
QUALITAT 5.3 a) Reg de boscos, zones verdes i d'altre tipus no accessible al públic. b) Silvicultura	No es fixa límit	No es fixa límit	35 mg/L	No es fixa límit	ALTRES CONTAMINANTS presents a l'autorització d'abocament d'aigües residuals: s'haurà de limitar l'entrada d'aquests contaminants al medi ambient. En el cas que es tracti de substàncies perilloses, caldrà assegurar-se de respectar les NCAs.
QUALITAT 5.4 a) Altres usos ambientals (manteniment de zones humides, cabals mínims i similars).	La qualitat mínima requerida s'estudiarà cas per cas				

[1] Nitrogen total, suma del nitrogen inorgànic i orgànic present en la mostra

Annex 11. Tertiary treatments in Catalonia

Catalonia had 42 water reclamation plants in 2009. The Catalan plan for water reuse designed 124 actions to increase the reuse of wastewater. Figure 13 shows water reuse systems which already exist, as well as the ones that are planned.

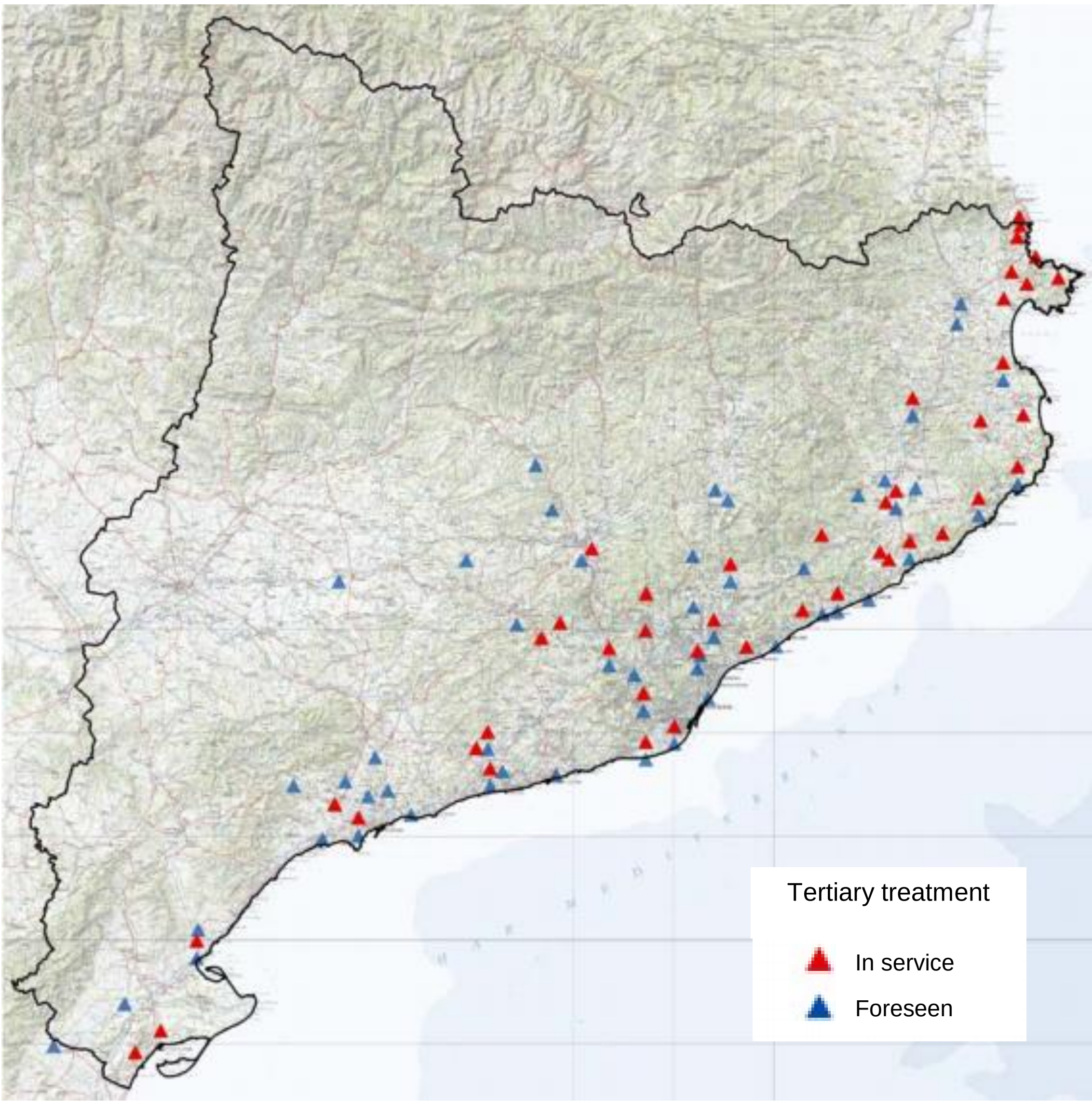

Figure 14. Location of the water reclamation plants or tertiary treatment plants and foreseen actions (11).

Annex 12. Production of reclaimed water in the Catalan inner basins

The highest production of reclaimed water in Catalonia took place during the drought period in 2007 – 2008 (13).

Figure 14 shows the evolution of the yearly produced volume of reclaimed water and its distribution on the uses of the reused water.

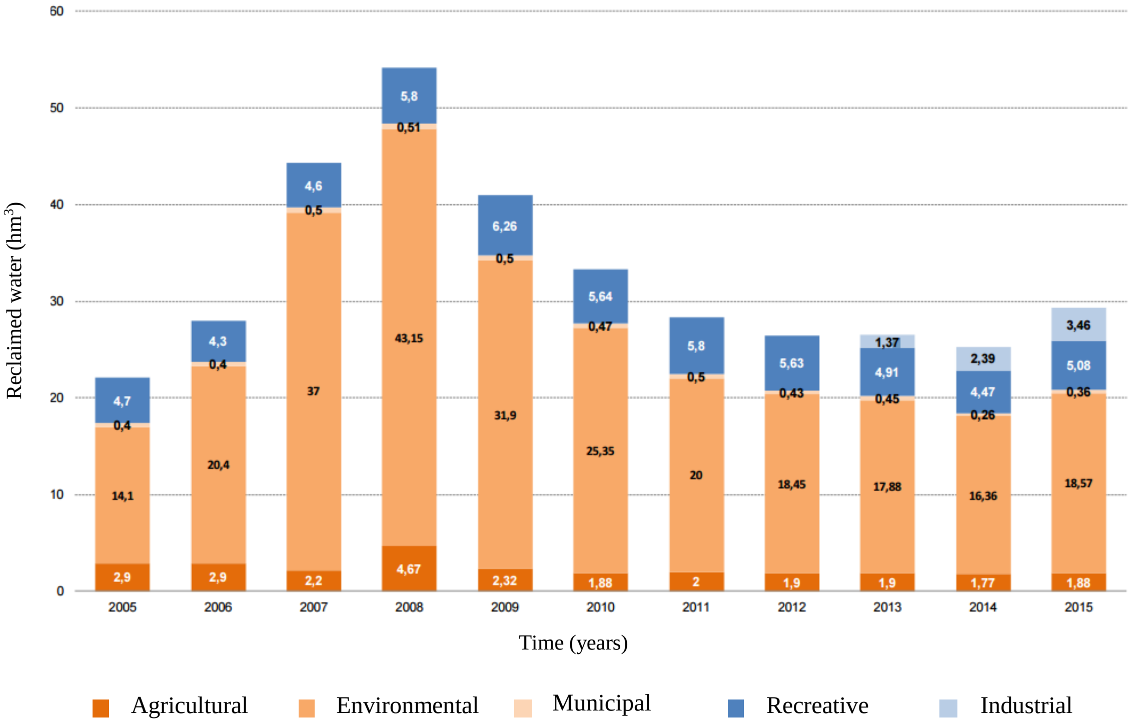

Figure 15. Water reuse evolution in the Catalan inner basins: Reclaimed water production and its uses (13).

Annex 13. Applications of the reclaimed water from Prat de Llobregat

The reclamation station in Prat de Llobregat is the most important in terms of production and because of its strategic situation. The uses that can be given to the reclaimed water produced there is regulated by concessions and can only be one of the following (14):

a) Water input to the Cal Tet lake, with environmental purposes.

b) Bring back water to the Llobregat river to increase the maintenance flow, downstream from the potabilization plant of Sant Joan Despí.

c) Agricultural watering of the Canal de la Dreta, with an additional desalination treatment to the reclaimed water.

d) Injection to the deep aquifer of the Delta del Llobregat, to generate a water boundary against marine water intrusion.

e) Superficial recharge of the aquifer in Sant Vicenç dels Horts.

f) Watering parcs and gardents, sewers and streets cleaning in Barcelona, through a conduction to the Montjuïc water deposit.

g) Bring back water to the Llobregat river in order to increase the availability of pre-potable water, 8 km upstream from the potabilization plant of Sant Joan Despí.

h) Input through two delivery points in Prat de Llobregat for all the authorized uses.

i) Industrial uses in the supply area of the reclamation plant of Prat de Llobregat.

Annex 14. Principles of membrane filtration

Membrane filtration is a physical separation, where both suspended and dissolved solids can be separated from water. The molecules with an effective diameter bigger than the membrane pores will be rejected, while those molecules with an effective diameter smaller than the membrane pores will permeate.

Chemical potential gradients across the membrane provide the driving forces for solute and solvent transport across the membrane, which include the applied pressure and the osmotic pressure.

The design of the filtration process consists of a feed water source, which often needs a pretreatment, and in some cases, post-treated. The membrane filtration generates two out-streams, the permeate and the concentrate or retentate. A schematic of the process is shown in Figure 15.

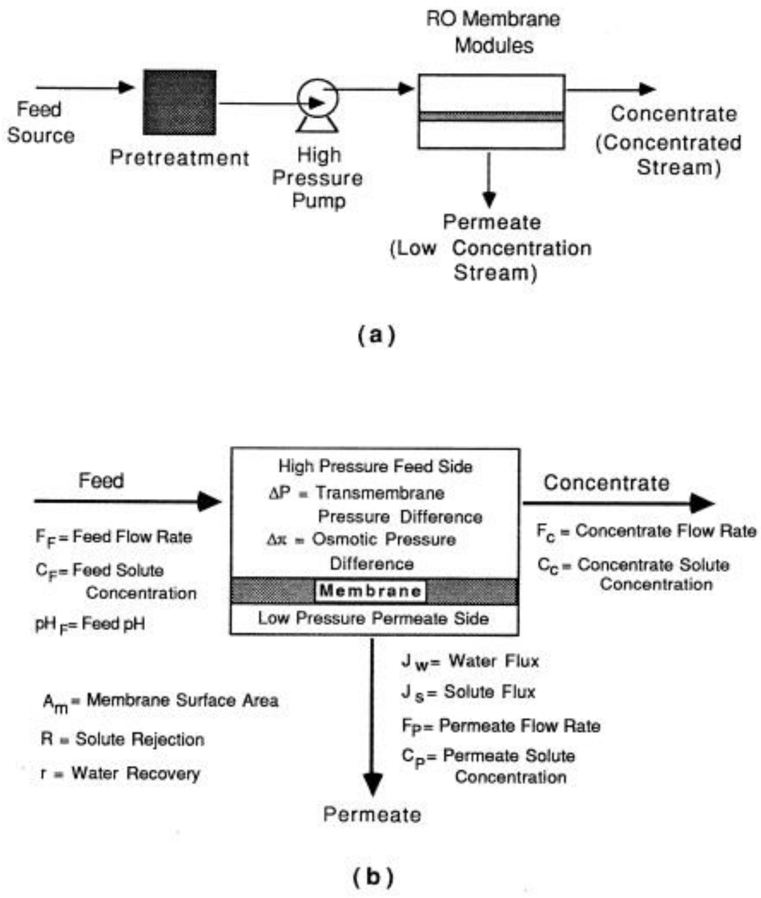

Figure 16. Scheme of (a) Membrane Process and (b) Process Streams (37).

Annex 15. Membrane filtration technologies

The Molecular Weight Cut-Off (MWCO) is the characteristic of the membrane that defines which substances can it separate.

It is an experimental data which corresponds to the higher molecular weight that did not permeate.

Figure 16 shows the particle distribution of a solution and its MWCO. The particles with a bigger pore size are retained while the smaller ones permeate.

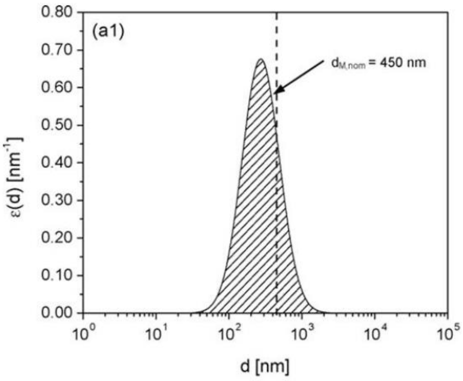

Figure 17. Pore size distribution of a microfiltration membrane (35).

There are four kind of filtration technologies according to their MWCO (31).

- Microfiltration (MF)

Microfiltration is a low-pressure membrane technology that allows the removal of particles in the range of approximately 0.1 to 1 micron. In general, suspended particles and large colloids are rejected while macromolecules and dissolved solids pass through the MF membrane.

- Ultrafiltration (UF)

Ultrafiltration provides macro-molecular separation for particles in the 20 to 1,000 Angstrom range (up to 0.1 micron). All dissolved salts and smaller molecules pass through the membrane. Items rejected by the membrane include colloids, proteins, microbiological contaminants, and large organic molecules. Most UF membranes have molecular weight cut-off values between 1,000 and 100,000. Transmembrane pressures are typically 15 to 100 psi (1 to 7 bar). Thus, UF is a selective separation step used to both concentrate and purify medium to high molecular weight components such as plant and dairy proteins, carbohydrates and enzymes.

- Nanofiltration (NF)

Nanofiltration is a filtration process that operates in-between UF and RO. NF rejects particles in the approximate size range of 1 nanometer (10 Angstroms). Organic molecules with molecular weights greater than 200-400 are rejected. Also, dissolved salts are rejected in the range of 20-98%. Salts which have monovalent anions (e.g. sodium chloride or calcium chloride) have rejections of 20-80%, whereas salts with divalent anions (e.g. magnesium sulfate) have higher rejections of 90-98%.

- Reverse Osmosis (RO)

Reverse Osmosis is a high pressure, energy-efficient means of de-watering process streams, concentration of low molecular weight compounds or clean-up of waste effluents. The RO membrane acts as a barrier to all dissolved salts and inorganic molecules, as well as organic molecules with a molecular weight greater than approximately 100. Water molecules, on the other hand, pass freely through the membrane creating a purified product stream. Rejection of dissolved salts is typically 95% to greater than 99%.

Figure 17 summarizes the kinds of membrane filtration technologies there are.

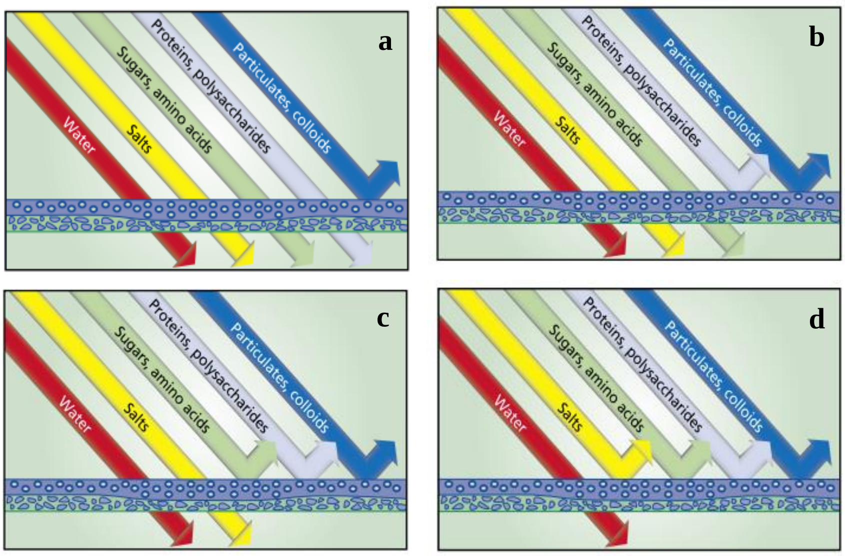

Figure 18. Retained and permeate substances in each membrane filtration technology (32). a) Microfiltration; b) Nanofiltration; c) Ultrafiltration; d) Reverse Osmosis.

Annex 16. Membrane configuration modules

The use of membrane technologies at industrials scale requires big surface areas. The smallest unit in which a membrane is packed is called module, which can be flat or tubular.

- Flat membranes

Flat membranes are those where the configuration consists of two flat membranes, in between which, the feed is introduced to the module, as shown on Figure 19. It is common to put a spacer between the membranes to facilitate the flux.

What is known as "Spiral membranes", is only the compaction of a flat membrane, which is rolled as a spiral, as shown on Figure 20. It supposes a cost-effective solution to high volume applications with minimal or no suspended solids, with the primary advantage of being both low capital investment and energy costs. They are available for all types of filtration, from microfiltration to reverse osmosis (32).

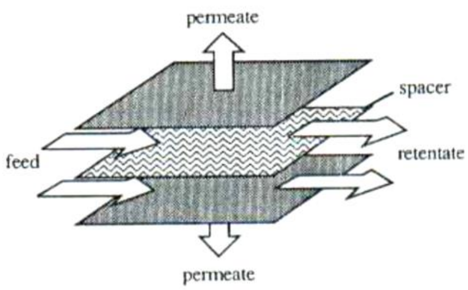

Figure 20. Scheme of a flat membrane.

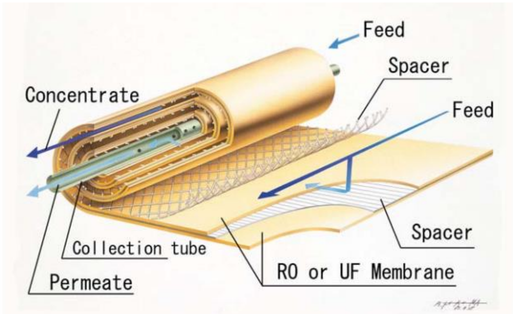

Figure 20. Scheme of a spiral module membrane (18).

- Tubular membranes

These membranes consist on a tube inside another tube. Figure 21 shows the inner configuration of a tubular membrane. These membranes are typically used when the feed stream contains large amounts of suspended solids or fibrous compounds.

What is known as "Hollow Fiber Membrane" is a kind of tubular membrane with very thin tubes inside, as shown in Figure 22. This extremely high packing density and open channel design offers the possibility of backwashing from the permeate side, particularly suited for low solids liquid streams.

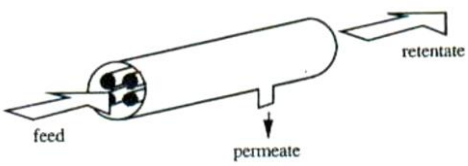

Figure 22. Scheme of a tubular membrane.

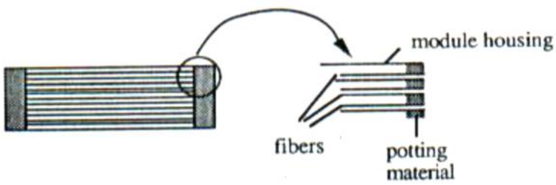

Figure 22. Scheme of a hollow fiber membrane.

Annex 17. Stages in membrane filtration

With big volumes of water to be treated, one module is not enough, and a larger filtration area is required. Thus, more than one module are used.

Modules are grouped into stages, which can be in series or in parallel (Figure 23). Serial operation allows an increase of the recovery, while parallel operation increases the permeate flow.

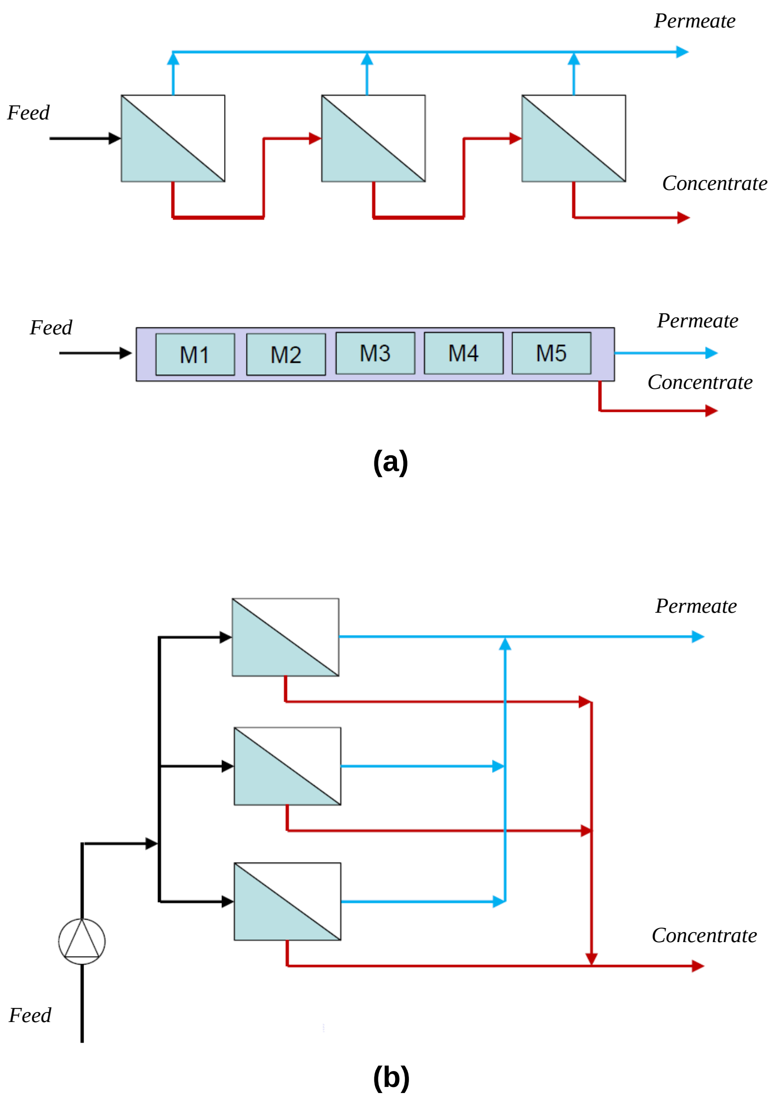

Figure 23. Scheme of a membrane filtration stage (a) in series and (b) in parallel.

Annex 18. Ranges of the membrane filtration processes

The filtration technique used, and thus the pore size of the membrane, determine which substances will be retained and which will permeate.

Figure 24 represents the size of some substances and which technique would be required to eliminate them from the water stream.

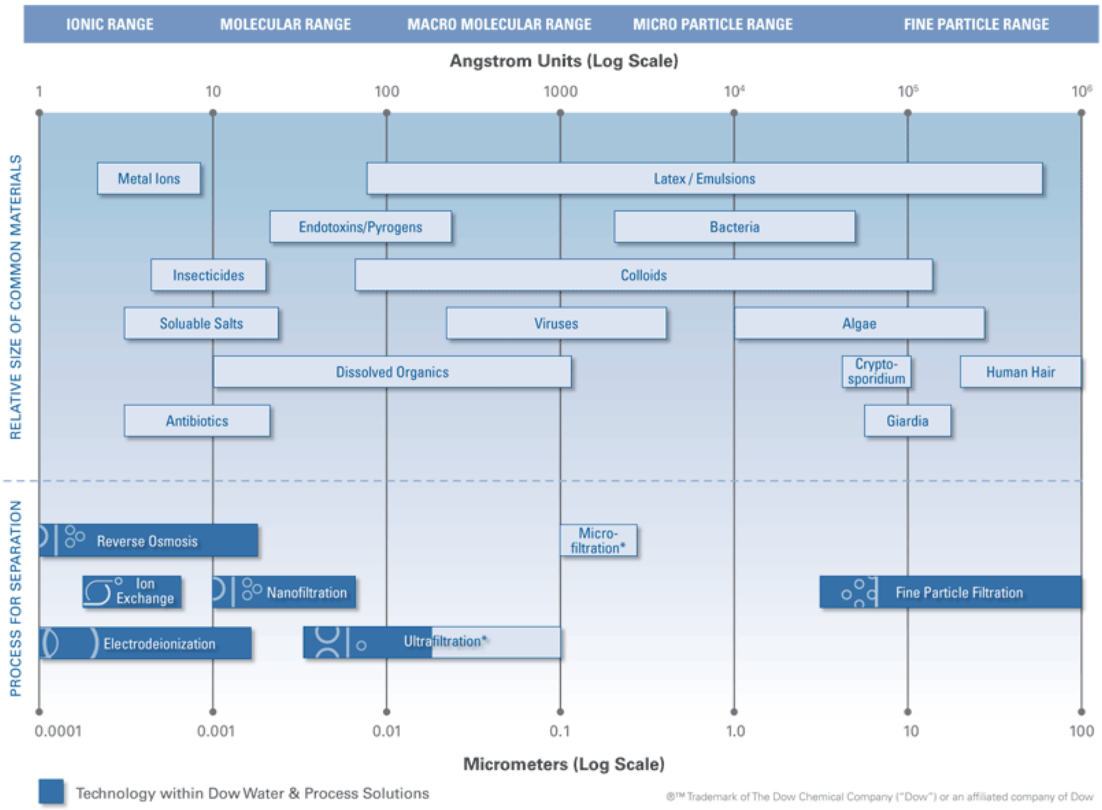

Figure 24. Ranges of membrane filtration processes (36).

Annex 19. Treatment processes and removal efficiencies

Table 13. Treatment processes and efficiencies to remove constituents of concern during water reclamation (17).

	Constituents of Concern													
	Pathogens									Trace Organics				
Process	Protozoa	Bacteria	Viruses	Nitrate	TDS	Boron	Bromate and Chorate	Metals	DBFs	Nonpolar	Polar	Energy Requirements	Residual Generation[a]	Cost
Engineered Systems: Physical														
Filtration	Moderate	Moderate	Low	None	None	None	None	Low	None	None	None	Low	Low	Low
PAC/GAC	Low	Low	Low	None	None	None	Low	Low	Moderate	High	Low	Low	Low	Moderate
MF/UF	High	Moderate	Low	None	None	None	Low	Low	Low	Low	None	Moderate	Low	Moderate
NF/RO	High	High	High	High	High	Moderate	High	High	Moderate	High	High	High	High	High
Engineered Systems: Chemical														
Chloramine	Low	Moderate	Low	None	None	None	None	None	None	None	None	Low	None	Low
Chlorine	Moderate	High	High	None	None	None	None	None	None	Low to moderate	Low to moderate	Low	None	Low
Ozone	Moderate	High	High	None	None	None	None	None	Low	High	High	High	None	High
UV	High	High	Moderate	None	None	None	None	None	None	None	None	Moderate	None	Low
UV/H_2O_2	High	High	High	None	None	None	None	None	Low	High	High	High	None	High
Engineered Systems: Biological														
BAC	Low	Low	Low	None to low	None	None	Low	Low	Low to moderate	Moderate	Moderate	Low	None to low	Low
Natural Systems														
SAT	High	High	Moderate	High	None	None	Low to moderate	High	High	High	Moderate to High	Low	None	Low
Riverbank Filtration	High	High	Moderate	High	None	None	Low to moderate	High	High	High	Moderate to High	Low	None	Low
Direct inj.	Moderate	Low	Low	Low	None	None	Low to moderate	High	Moderate	Low	None	Moderate	None	Low to moderate[b]
ASR	Moderate	Moderate	Moderate	Moderate	None	None	Low	High	Moderate	Moderate	Low to moderate	Low	None	Low
Wetlands	Low to moderate	Low to moderate	Low	Moderate	None	None	Low	Moderate to high	Low	Low to moderate	Low	Low	None	Low
Reservoirs	Low to moderate	Low	Low	Low to moderate	None	None	Low	Moderate to high	Low	Low	Low	Low	None	Low

NOTE: The qualitative values in the table represent the consensus best professional judgment of the committee.
[a]Low represents little generation of residuals, high represents significant amounts of residual generation; [b]High when required pretreatment is considered.

Annex 20. Cost of water reclamation

The cost of water reclamation can vary significantly depending on the quality of the water that needs to be achieved for its reuse, and thus, on the technology used.

Table 14 shows the estimations on the costs of several technologies used in water reclamation according to a study published at the Journal (Water Pollution Control Federation).

Table 14. Capital and operating costs for water reclamation technology($/1000 m^3) (39).

	Chemical Clarification	Lime Recovery	Ammonia Stripping	Recarbon-ation	Mixed Media Filtration	Activated Carbon Adsorptioı	Activated Carbon Regeneration	Chlorin-ation	Injection	Reverse Osmosis
Operations labor	1.57	3.68	0.44	2.27	0.72	0.99	3.49	1.49	0.86	5.18
Maintenance labor	0.66	2.78	0.66	0.66	0.66	2.00	2.01	1.13	2.77	Maintenance contract
Maintenance materials	0.67	3.34	0.67	0.67	0.67	2.37	2.37	1.26	3.33	35.08
Electricity	2.56	2.73	4.10[a]	3.08	0.68	3.03	1.01	0.97		72.91
Gas		5.74					2.45		2.24	
Chlorine				1.70[b]				6.22		0.13
Sulfuric acid										3.94
Lime	2.72									
SHMP										1.37
Polymer	0.60				0.07					
Standby acid				0.26						
Alum					0.06					
Carbon							—[c]			
TOTAL O&M	8.78	18.27	5.88	8.64	2.86	8.40	11.33	11.07	9.20	118.49
TOTAL CAPITAL	6.02	9.33	15.58	2.12	4.76	11.81	4.38	1.17	4.53	45.34
TOTAL COST	14.80	27.60[d]	21.46	10.76	7.62	20.21	15.71	12.24	13.73	163.83

[a] When ammonia stripping fans are operated, power costs are increased by $13.44.
[b] When breakpoint chlorination is included, chlorine cost increases by $16.64.
[c] If make-up carbon had been purchased, operating cost would be increased by $1.90.
[d] The total cost of recalcined CaO is $90.41/metric ton.

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