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Deliverable D9

Confidential

D2.6
Report on close loop recycling strategies and alternative water sources for the Steel

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1. - Glossary

CA	Consortium Agreement
DoW	Description of Work
EB	Executive Board
GA	General Assembly
IPR	Intellectual Property Rights
LCA	Life Cycle Analysis
QAP	Quality Assurance Plan
WP	Work Package
WPM	Work Package Meeting
WPC	Work Package Committee
WPL	Work Package Leader

2. - Contributions

The SPOTVIEW project participants are shown below. For this deliverable the contributors are ArcelorMittal (AMIII) and BFI.

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3. - Introduction

This deliverable is part of the WP 2. The objective of this work package is to select and assess existing or innovative technologies and process components that can achieve resource-efficient water management and improve process water and wastewater treatment practices in three water-intensive industrial sectors, namely dairy, paper, and steel. This report is focus on the work for the steel industry. Testing of the individual technologies or process components will be performed in realistic environment, under 'high-fidelity' laboratory set-ups and with real or closely simulated water and wastewater samples. The task related to the steel industry in this work packages are the following ones:

- Specification of water quality requirements and process water stream characterization.
- Closed-loop recycling practices for process, cooling or CIP water streams; as well as exploiting alternative water sources (i.e. treated effluents) through advanced wastewater treatment.

The specification of water quality requirements and process water stream characterization was previously reported in Deliverable 2.1 (M12).

3.1. - Objectives

The objective of this deliverable is to report the selection and testing in realistic environment of solid and salt removal technologies to reduce fresh water usage in steel making processes.

3.2. - Work progress and achievement

This report summarizes the work carried out in Task 2.3 for the steel sector. In this workpage, the tasks related to steel industry are T2.3.3 and T2.3.4. Those are explained below.

T2.3 Close loop recycling and alternative water sources (M6-M18) (CTP, VTT, VAL, SCA, CERTH, MEVGAL, BFI, AMIII).
The scope of this task is to examine opportunities for developing closed-loop recycling practices in industrial processes and the required technologies that should be employed to achieve sustainable water recycling. Furthermore, alternative water sources, including treated wastewater effluents will be assessed together with the requisite technologies for advanced wastewater treatment.
In the development of the following tasks as well as in the contribution of this deliverable BFI and AMIII are the contributors.

T2.3.3 Closed loop recycling strategies for the steel industry (BFI)
Capacity Deionization (CDI) technology will be evaluated as a key technology for the removal of ionic species from specific water streams of the steel industry that would facilitate establishment of closed loop recycling strategies. Laboratory tests with lab CDI (flow rate: 6 l/h) an operational waters after pretreatment to determination of optimal operating parameters (flow, voltage, cleaning interval) output, energy use, operational stability possible interactions between chemicals and CDI membrane or electrodes. Analysis of the water before / after capacitive deionization, gravity analysis of ions by ion chromatography (IC), hardness, conductivity. Description of the application area and process adequacy for pilot plant tests (WP4).

***T.2.3.4. Alternative water resources for the steel industry (AMIII)**,*

Alternative water sources as sea water, storm water and back flush water from sand filters of a hot rolling mill (direct cooling) will be evaluated in terms of treatments required to achieve the desired quality, considering the location of the majority of AMIII plants at cost lines. For sea water, reverse osmosis is addressed to remove dissolved salts. The assessment of membrane technology pretreatment required before reverse osmosis will be performed followed key parameters: turbidity and suspended solids. Once the pretreatment is defined, reverse osmosis will be tested to determine the design to achieve required quality in the permeate for usage as cooling water for direct cooling (hot rolling), gas washing (blast furnace, steel shop) or slag granulation. Storm water needs to be used as make-up water will be studied and quantified in terms of rainfall index.

This Task aims to achieve two milestone, M2.3 and M2.4 as can be seen in Table 1.

Table 1. Milestones for this task

M#	Milestone name	Related WP(s)	Due date	Means of verification
2.3	Close loop recycling strategies and alternative water sources selected and described in each sector	WP2 – T2.3	M18	Two strategies per sector
2.4	Technologies selected and described for each water management strategy	WP2 – T2.3	M18	List of technologies with specifications

4. - Water treatment technology assessment

For the case of sea water as alternative water resources for the steel industry, different trials and experiments were done with sea water samples, specifically jar tests with different concentration of coagulant, multimedia filtrations with different media and different velocities, ultrafiltration tests with different operational conditions and reverse osmosis experiment (T2.3.4). Further on, the desalting by capacitive deionization of back flushing water and river water was investigated.

4.1. - Capacitive deionization of back flushing water and river water

The analysed composition of the investigated waters:

- Back flushing water sand filter
- River water
- Sea water

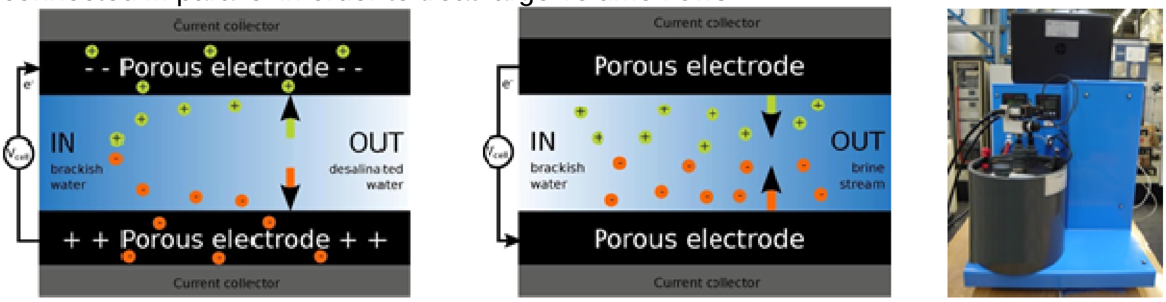
pointed out the need for different treatment techniques for desalting before use for e.g. cooling purposes according to the AM requirements regarding the water composition (conductivity < 200 µS/cm,. chloride content < 100 mg/L). Regarding the CDI, a treatment of river water and back flushing water is after the removal of suspended solids and oil/fat possible. An application for sea water is not possible because of its total dissolved solid content 10 times above the limiting value of the CDI manufacture. In any case, the removal of suspended solids is required before the desalting step.

Sample	Sea water	River water	Back flushing water	Limiting values according CDI manufacture	
				Permanent	short term
Conductivity [µS/cm]	52100	260 - 275	991	---	---
Cl [mg/L]	3870	37 - 38	200 - 248	---	---
SO_4 [mg/L]	1690	16	90 - 115	---	---
pH-value [-]	8.1	9.3 - 10.3	7.7 - 7.8	2 - 10	1 - 12
TOC [mg/L]	<5	<15	14 - 16	15	---
Solid content [mg/L]	n.m.	12	160 - 394	Prefiltration: < 1 µm	FNU (4/100)
Total Dissolved solids [mg/L]	40330	145 - 163	806 - 893	4.000	---
Hardness as $CaCO_3$ [mg/L]	10	30 - 60	300 - 500	1000	---
Ca [mg/L]	< 1	8 - 25	100 - 140	---	---
Mg [mg/L]	< 1	< 1 - 3	22 - 34	---	---
F [mg/L]	1.30	0.22	0.20 - 0.22	---	---
NO_2 [mg/L]	< 1	< 0.1 - 0.2	< 0.1	---	---
NO_3 [mg/L]	1390	9 - 11	< 0.1 - 3.3	**---**	**---**
Further requirement:	Temperature: 5 – 40°C, oil < 0.5 mg/L, COD: 50 mg/l permanent, 100 mg/l short term				

The different technologies investigated for the treatment of river and back flushing water respectively for sea water were described in chapter 6 and are related to the tasks T2.3.3 "Closed loop recycling strategies for the steel industry (BFI) – CDI treatment" and task T.2.3.4. "Alternative water resources for the steel industry (AMIII) - Chemical Preconditioning, multimedia filtration, ultrafiltration and reverse osmosis".

4.1.1. - Technology description and objectives

Capacitive deionization (CDI) is a novel method for the removal of ions from water by electrostatic adsorption on two oppositely charged electrodes by a low-voltage electromagnetic field (1.5 V in Voltea's design), Figure 1. In front of the porous electrodes, ion exchange membranes are installed to improve the removal efficiency of the process. After loading the electrodes with ions a cleaning cycle is performed by reversing the polarity of the electrodes and discharging the ions in a concentrate stream. A large number of cells can be connected in parallel in order to treat large volume flows.



Desalting | Cleaning by polarity reversal | Lab CDI

Figure 1. CDI. Principle and lab CDI

The CDI differs from electro deionization (EDI), which is used with much higher voltages for ultrapure water production. Furthermore, the energy consumption of the CDI differs from the treatment with RO and EDI depending on the water composition.
Objectives of the work were: Evaluation of Capacity Deionization (CDI) for the removal of ionic species from specific water streams of the steel industry.

4.1.2. - Technology trials

The trials were performed with a lab CDI with a capacity of 60 l/h - 210 l/h and river water and back flushing water samples. Aim was the reduction of the conductivity below 200 µS/cm and the chloride content below 100 mg/L according to the requirements of AM by adapting the parameter: pure time = desalting time, waste time – cleaning by polarity reversal, pre-pure time = rinsing time after polarity reversal as well as the flow rates for pure and waste and the current. Further on, possible interactions between cooling water treatment chemicals as flocculants and coagulants were investigated.
The trials with river water are explained in detail as an example for the performed CDI tests.
First step was the investigation of the process stability during operating the CDI, in the beginning 3.75 h and in the following for 24 h.
As shown in Figure 2, a stable state for the produced clean water regarding the parameter conductivity, Cl, SO_4 and hardness is reached after 0.5 h.

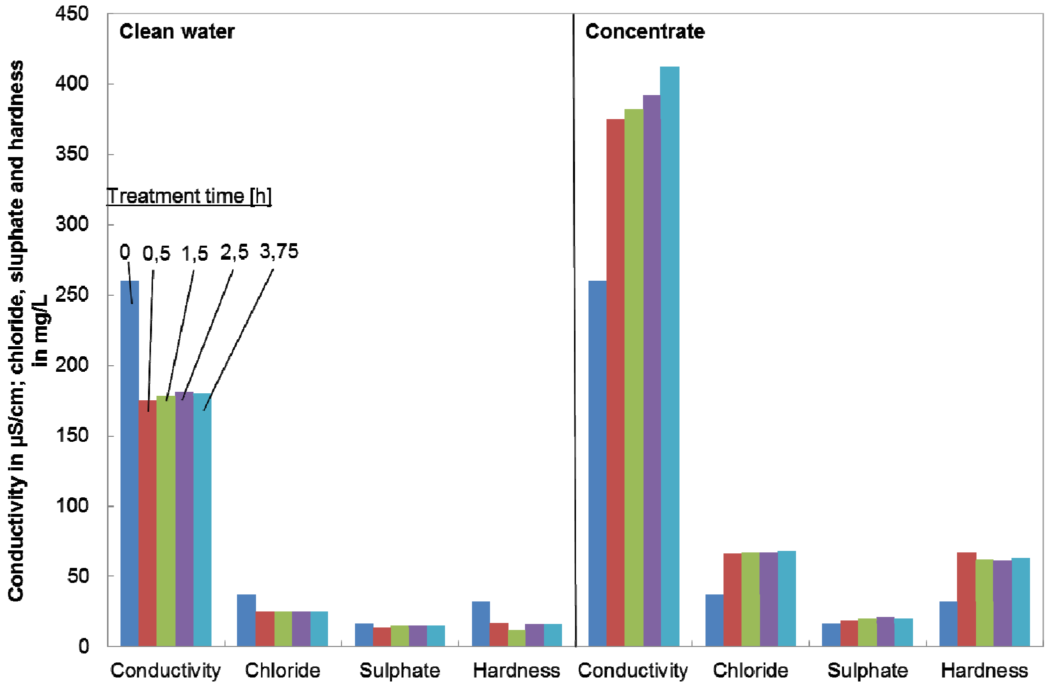


Figure 2. Comparison of clean water and concentrate composition over the trial duration

Second step was the optimization of the desalting (pure time), cleaning and rinsing time as well as the flow rate. Figure 3, shows the main results. The pure time could be doubled, leading to an increase of the water recovery from 73% to 79%. The requirements of AM regarding conductivity and chloride content were fulfilled. Further lead extended pure times to removal efficiencies over 80%, but even to a continuous increase of the conductivity in the clean water passing the requirement of 200 µS/cm with increasing operating times, Figure 3. The investigation of the maximum desalination with the lowest achievable conductivity led to following results: conductivity 46 µS/cm (removal efficiency: 81%) with a water recovery of 66% and an energy demand of 0.94 kW/m³ feed.

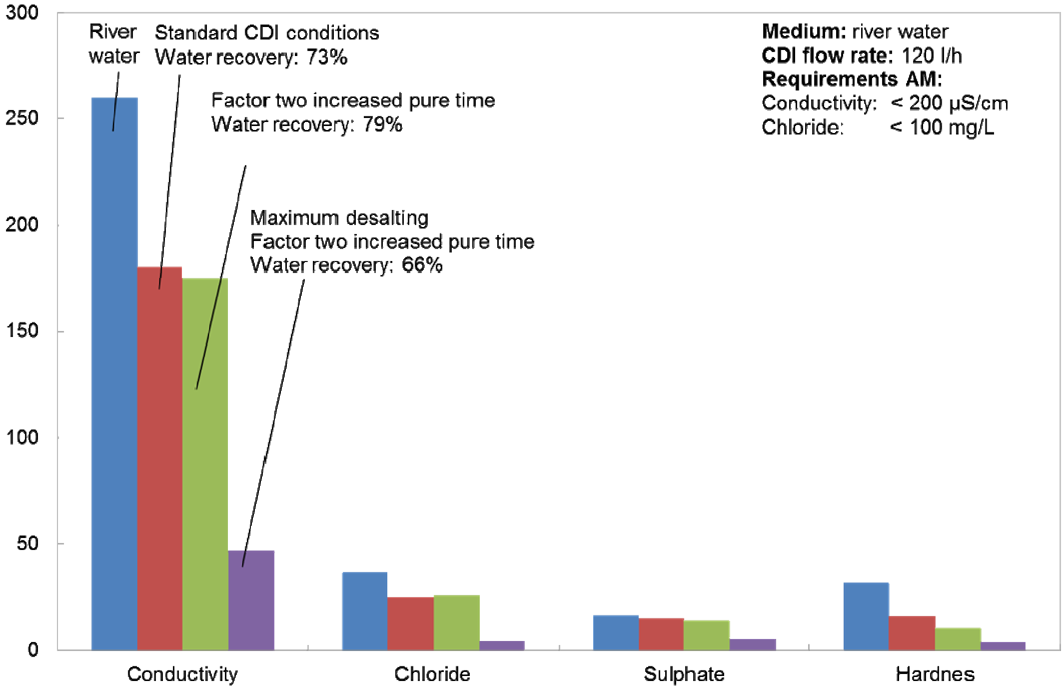


Figure 3. Influence of different CDI conditions to the clean water composition

In Figure 4, the trial results with the optimum CDI configuration for the treatment of back wash and river water were presented. In both cases, the AM requirements regarding conductivity and chloride were fulfilled.

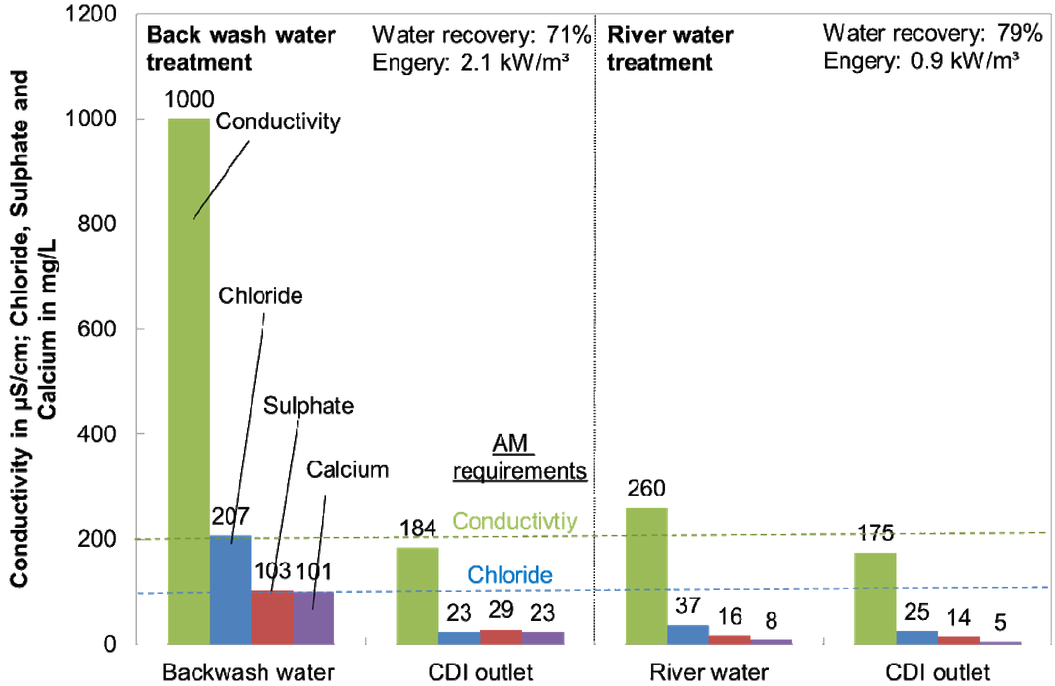


Figure 4. Comparison of trial results with optimum CDI configuration for back wash and river water

Basing on the detailed composition of the concentrates, Table 2 and Table 3, it can be determined that the concentrate fulfil in general the limiting values for discharge, also for compounds like F, NO_2 and NO_3. For a final evaluation, a comparison with the local discharge limits has to be performed considering further the metal and COD content.

Table 2. Comparison of clean water and concentrate composition (treatment of back washing water)

	Back wash water	Clean water	Concentrate	Removal Efficiency [%]
Conductivity [µS/cm]	**1000**	**184**	**836**	**82**
Cl [mg/L]	**207**	**23**	**123**	**89**
SO4 [mg/L]	**103**	**29**	**83**	**78**
pH-value [-]	7.3	6.5		
Total hardness [mmol/L]	3.43	0.58	2.95	83
DOC [mg/L]	11	9.5	2.5	
Ca [mg/L]	101	23	88	77
Mg [mg/L]	22	1	18	95
NO_2 [mg/L]	<0.5	<0.1	<0.05	
NO_3 [mg/L]	0.58	<0.1	10	
F [mg/L]	<0.5	<0.1	<0.5	

Table 3 Comparison of clean water and concentrate composition (treatment of river water)

	River water	Clean water	Concentrate	Removal Efficiency [%]
Conductivity [µS/cm]	**260**	**175**	**420**	**33**
Cl [mg/L]	**37**	**25**	**76**	**32**
SO4 [mg/L]	**16**	**14**	**22**	**12**
pH-value [-]	10.3	9.8	---	---
Total hardness [mmol/L]	0.32	0.17	0.68	47
Ca [mg/L]	8	5.2	19	37
Mg [mg/L]	2.7	1.1	5.3	59
NO_2 [mg/L]	0.22	0.16	0.74	27
NO_3 [mg/L]	9.4	3.9	16	59
F [mg/L]	0.22	0.17	0.32	23

In the third step, the investigation of the possible influence of cooling water treatment chemicals to the desalting by CDI was performed with operational flocculants and coagulant in the currently used dosage and a 5 times higher dosage for simulating an overdosing. The trials were performed with tap water and the addition of the treatment chemicals to exclude any other effect. To ensure a stable operation point of the CDI the trials were performed over a treatment time of 24 h.
The dosage of the Al-Cl based coagulant had no disturbing influence to the removal of chloride or SO_4, Figure 5. The conductivity and the removal efficiency of the clean water were nearly on the same level as for the treatment of tap water without chemical dosage. Same as the energy demand and the water recovery, but the hardness removal decreased from 95% to 72%, Figure 6. The dosage of coagulant showed no effect to the achieved removal efficiency compared to the trial with flocculant.

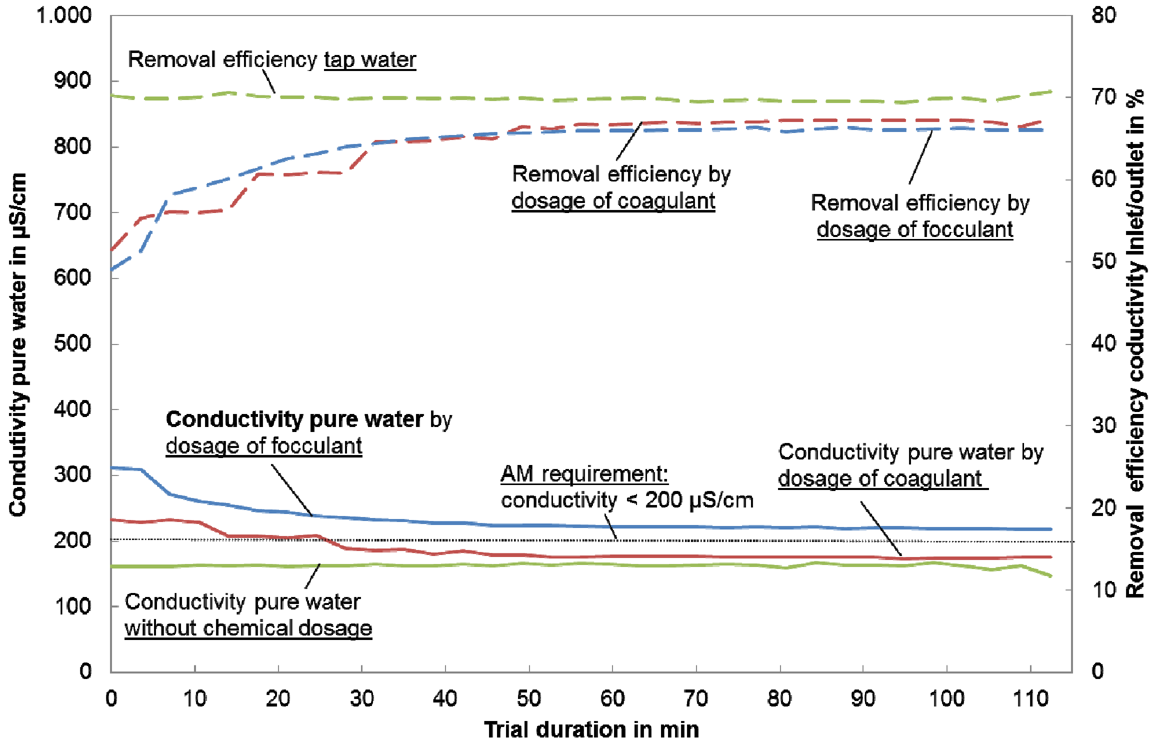


Figure 5. Comparison of the conductivity in the pure water after CDI and the removal efficiency related to the conductivity for tap water without any addition and addition of coagulant / flocculant.

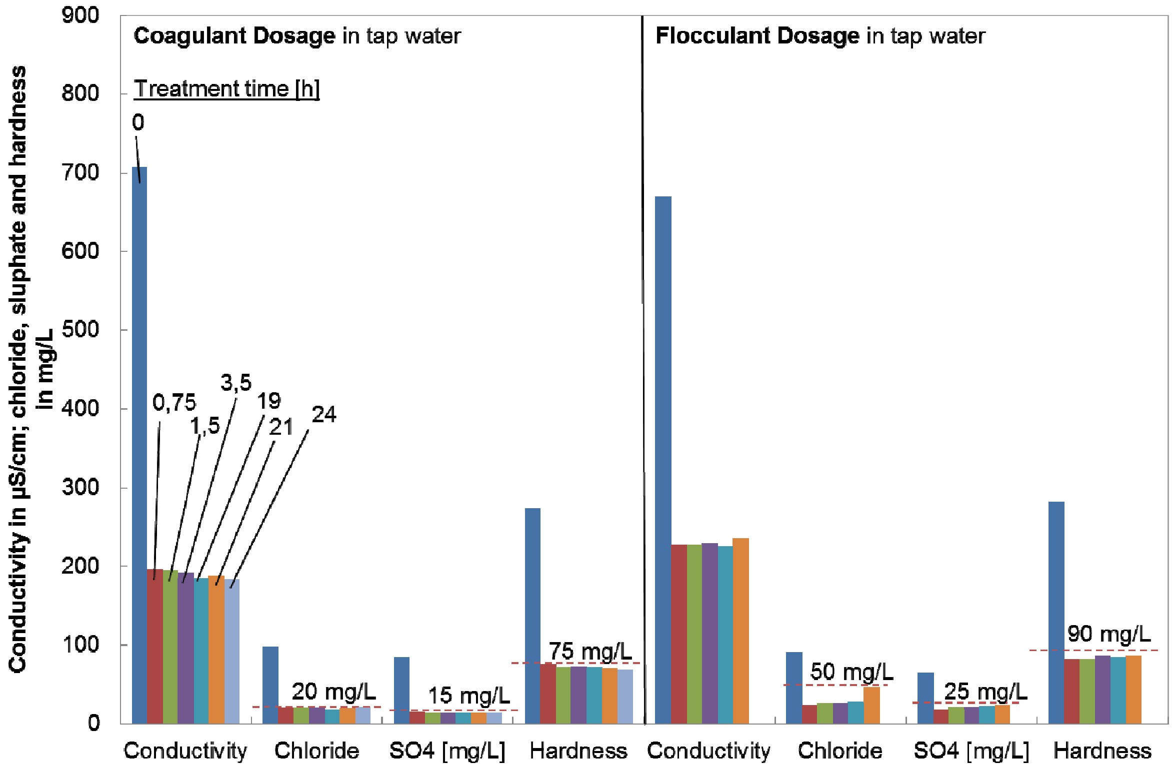


Figure 6. Effect of the cooling water chemicals to the composition of the CDI effluent (pure water)

Summarizing, the capacitive deionization (CDI) is a suitable technology for the desalting of river and back wash water after the removal of solids and in the case of back wash water of oil /grease**.** Water recovery rates of 71 to 79% were achieved. The achieved quality of the treated water fulfils the operational requirements of AM. Because of the high total dissolved solid content (40,000 mg/L), which is 10times higher than the recommended limit value of the CDI manufacture, the CDI is not suitable for sea water.

4.2. - Multimedia filtration

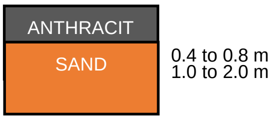
4.2.1. - Technology description and objectives

Seawater pretreatment is a key component for membrane desalination treatment. The main purpose of the pretreatment system is to remove particulate, colloidal, organic, mineral and microbiological contaminants contained in the source seawater and to prevent their accumulation on the downstream seawater reverse osmosis (RO) membranes. The content and nature of pollutants contained in the source seawater depend on the type and location of the desalination plant intake.

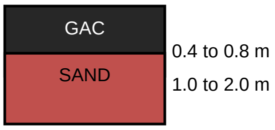
Seawater pollutants are removed by a series of source water conditioning processes (coagulation, flocculation and pH adjustment) followed by granular media (anthracite and sand) filtration. Over the past 10 years, advances in microfiltration (MF) and ultrafiltration (UF) membrane technologies, and their successful application for water and wastewater treatment have created an impetus for using membrane pretreatment in seawater desalination plants.

At present, granular media filtration is the most widely used seawater pretreatment technology. Depending on the driving force for seawater filtration, granular media filters are classified as gravity and pressure filters. The main differences between the two types of

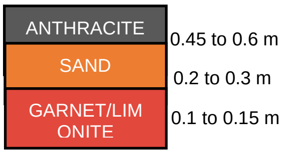
filters are the head required to convey the water through the media bed, the filtration rate, and the type of vessel used to contain the filter media.
Source seawater conditioning by coagulation and subsequent flocculation are necessary steps prior to granular media filtration. The optimum coagulant dosage is pH dependent and should be established based on an on-site jar or pilot testing for the site-specific conditions of a given application.



To achieve enhanced removal of soluble organics from seawater by biofiltration and/or to handle seawater with high pico-plankton content. In this case, the depth of the anthracite level is enhanced to between 1.5 and 1.8 m.



If the source seawater is relatively cold (i.e. average annual below 15ºC), and at the same time is of high organic content.
The depth of the GAC (granular activated carbon) media is estimated based on the average contact time in this media, which is recommended to be 10 to 15 min.



If the source seawater contains a large amount of fine silt or the seawater intake experiences algal blooms dominated by pico- plankton.

As it was mentioned before, depending on the driving force for seawater filtration, granular media filters are classified as gravity and pressure filters. Gravity pretreatment filters have found application for both small and large desalination plants worldwide. They are usually reinforced concrete structures that operate at water pressure drop through the media of between 1.5 and 2.5 m. Most large seawater desalination plants in operation today have deep open-ocean intakes and use single-stage/dual media gravity filters. Pressure filters have filter bed configuration similar to that of gravity filers, except that the filter media is contained in steel pressure vessel. They have found application mainly for small and medium size seawater desalination plants.
In most cases for relatively good source seawater quality (TOC < 1 mg/L, SDI < 5 and turbidity < 4 NTU) pressure filters are designed as single stage, dual media (anthracite and sand) units. Some plants with relatively poor water quality use two-stage pressure filtration systems. For small desalination plants, pressure filters are very cost-competitive, more space efficient and easier, and faster to install, and operate as compared to granular media gravity filters.
Gravity media filters have approximately two to three times larger volume of filtration media and retention time than pressure filters for the same water production capacity. Therefore, this type of filters can retain proportionally more solids and as a result, pretreatment filter performance is less sensitive to occasional source water turbidity spikes.
Pressure filters usually do not handle solids/turbidity spikes as well because of their smaller solids retention capacity. If source seawater is likely to experience occasional spikes of high turbidity will produce effluent with inferior effluent quality during such events. Therefore, the use of pressure filters would likely result in a more frequent SWRO membrane cleaning.
In order to handle solids/turbidity spikes pressure filters could be designed as two-stage pretreatment systems with two sets of pressure filters operating in series.

4.2.2. - Technology trials

Different trials and experiments have been done with two sea water samples in order to achieve the possible quality conditions for its use as make-up water.

The aim of this research is the evaluation of membrane technology pretreatment for sea water conditioning as make-up water. Performance of pilot plant trials with two samples (Sampling 1 and Sampling 2) was done to compare the results in terms of outlet water quality. Jar tests, multimedia filtration and ultrafiltration experiments were done, analyzing parameters before/after treatments in order to evaluate the effect on the reverse osmosis treatment.

Two sampling campaign of sea water were collected at the Gijon harbour. Sea water was collected in IBC containers and transported to the water laboratory to perform the corresponding experiments. First sampling campaign was done April and second in September.

Average values from the two different sampling campaigns had the characteristics shown below.

Table 4. Chemical characterization of sea water.

Parameter	Sampling 1	Sampling 2
Conductivity [µS/cm]	42001	46910
Cl [mg/L]	18360	20990
SO_4 [mg/L]	2616	1514
pH-value [-]	7.4	8.0
TOC [mg/L]	< 5	<10
Solid content [mg/L]	57	114
Turbidity (NTU)	11	8.3
Hardness as $CaCO_3$ [mg/L]	6110	8580
Calcium [mg/L]	414	476
Magnesium [mg/L]	1218	1623
NO_2 [mg/L]	< 1	<1
NO_3 [mg/L]	3	0.034

Multimedia filters needs a chemical conditioning with coagulant to form coagulant. To determine the optimum dosage jar tests are performed.

4.2.2.1. - Jar Tests

These trials have the aim of understanding processes of coagulation, flocculation and sedimentation, selecting types of coagulant and estimating the optimal dose needed in removing the charged particles that occurred in raw water.

In this case, the jar test device consisted of four batch beakers with a paddle mixer for each beaker. In each beaker, different concentration of coagulant ($FeCl_3$) was added in order to obtain the optimum dosage to remove turbidity from the sample. In addition, 0.5 mg/L of NaClO was added to oxidise organic matter, Figure 7.

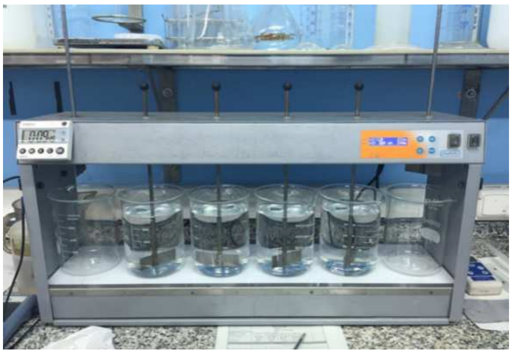


Figure 7. Jar test equipment.

Two different tests were carried out for both samplings (Test 1 and Test 2) in order to see the reproducibility of the results. These results are shown below.
With the first water campaign, the initial turbidity of the samples is very low (<5 NTU) and consequently the final turbidity is very low as the removal efficiency (%).
The maximum turbidity removal is reached with 0.5 ppm of coagulant. The final turbidity is < 0.4 NTU.
For the second water campaign, the initial characteristics of tested water were 24.3 NTU of turbidity and 57.1 mg/L of TSS.

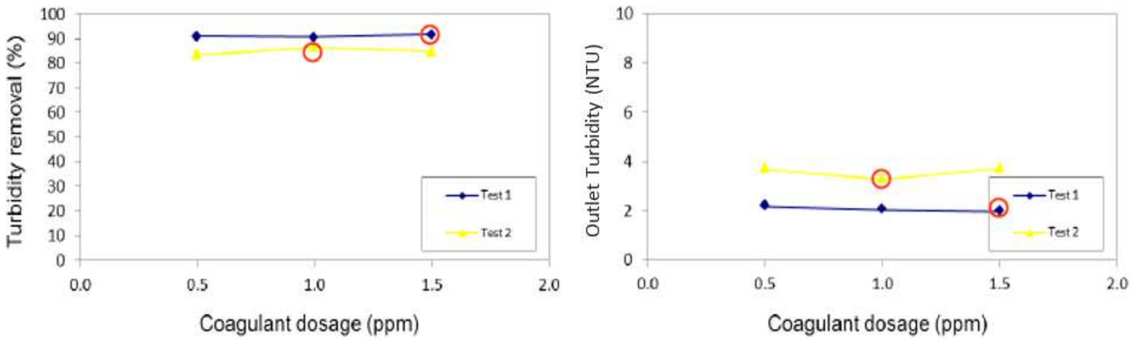


Figure 8. Jar test results for two different tests carried out in pilot plant for Sampling 2.

As it can be seen above, the maximum turbidity removal is reached with 1-1.5 ppm of coagulant. The final turbidity is < 4.14 NTU.
Taking into account all the results, some conclusions can be obtained. Both samplings reached a high turbidity removal, near 90%, but water form Sampling 1 needed less dosage of coagulant (0.5 ppm vs 1 ppm for Sampling 2). On the other hand, final turbidity is also different for both samplings. Water from Sampling 1 achieved lower outlet turbidity, < 0.4 NTU vs < 4.14 NTU from Sampling 2. For further experiments, 1 mg/L of coagulant was selected to assure good efficiency in case of worse water quality.

4.2.2.2. - Multimedia filtration

Sand filtration tests were done with different operational conditions in two columns with 16 cm of diameter.
The different test conditions were the medium (sand + anthracite, and sand + anthracite + garnet) and linear velocity (15 and 20 m/h).

Figure 9. Sand filtration system.

Different trials with two linear velocities were done for the two media used. Results are shown below for the first sampling campaign.

Table 5 shows the average removal efficiency for two types of media: sand + anthracite + garnet and sand + anthracite. Both types of media were tested at two linear velocities, 15 and 20 m/h.

Table 5. Turbidity Removal Efficiency (%).

Linear velocity	Sand+Anthractie	Sand+Anthracite+Garnet
15 m/h	69	58
20 m/h	49	71

As it was expected that lower velocity gave better efficiency removal. This was observed for sand+anthracite, although, it was not observed for the sand+anthracite+garnet. Thus, no clear correlation between linear velocity and quality outlet was noticed for 15 and 20 m/h. The highest turbidity efficiency was for the three layer filters at 20 m/h (71%).
The highest velocity, 20m/h, was chosen for the next experiments.
In the next figure, it can be seen the results in terms of turbidity removal and the outlet water quality for a velocity of 20 m/h for the two medium filtration.

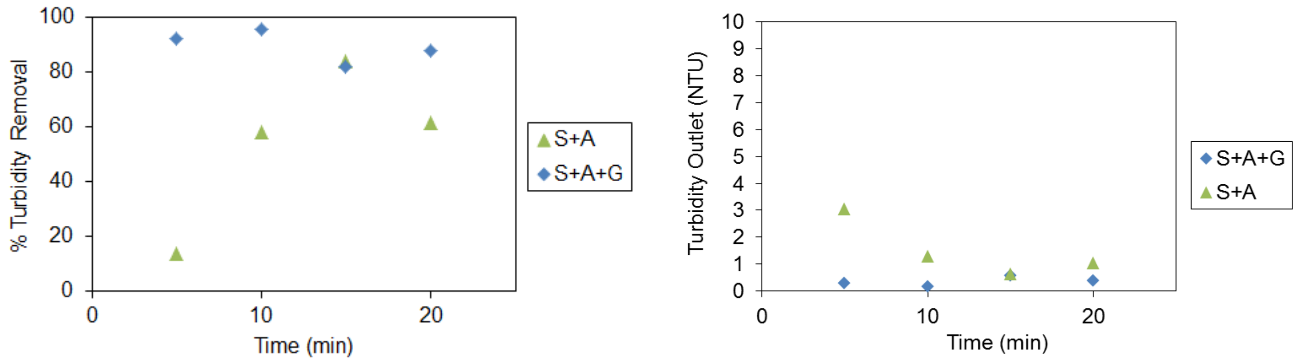


Figure 10. Plots of turbidity removal and turbidity outlet by effect of the media.

In the case of the three multimedia filters, the rejection of turbidity is above 80%. In the case of sand and anthracite, the rejection increases with time, the turbidity removal is around 50 and 70%, having an average rejection of 49%.
Graphs above show, in general, that Sand + Anthracite + Garnet (S+A+G) media is more efficient than Sand + Anthracite (S+A) media.

Table 6. Medium values of turbidity removal of multimedia filters tests (%)

v(m/h)	S+A	S+A+G
20	49	85

In terms of water quality at the outlet, the following results were obtained (See *Table 7*). For the filtration of S+A+G, turbidity is 0.7 ± 0.4 NTU and TSS is 13 ± 6 mg/L. For the S+A, the outlet turbidity is 1.5 ± 1.1 NTU and TSS is 17 ± 8 mg/L.
The requirement for feeding reverse osmosis is 1 NTU and below 10 mg/L for TSS, only the S+A+G achieves the requirement for the turbidity.

Table 7. Water Quality at the outlet

Medium	Outlet Turbidity (NTU)	Outlet Total Suspended Solids (mg/L)
S+A+G	0.7±0.4	13 ± 6
S+A	1.5±1.1	17 ± 8

As a summary for all trials some conclusions can be drawn:

- For the S+A, as expected the efficiency increases by decreasing the velocity.
- For the S+A+G, this effect was not observed, achieving higher rejection at higher velocity.
- The low turbidity removal is explained due to the low initial turbidity.
- No fouling of the media was observed for the experiments done.
- Best conditions: S+A+G at 20 m/h
- Sand + Anthracite + Garnet (S+A+G) gave better result than Sand+ Anthracite (S+A).
- S+A+G achieves, in most of the cases, the quality requirement for the inlet of a Reverse Osmosis (RO) in terms of turbidity, but not in the total suspended solids.

4.1. - Ultrafiltration of sea water

4.1.1. - Technology description and objectives

MF and UF membrane systems have been shown to be very efficient in removing turbidity and non-soluble and colloidal organics contained in the source seawater. Turbidity can be lowered consistently below 0.1 NTU and filter effluent SDI_{15} levels are usually below 3 over 90% of the time.

Depending on the type of the driving filtration force, membrane pretreatment filters are divided into two categories, pressure- and vacuum-driven. Pressure (UF and MF) systems consist of membrane elements installed in pressure vessels, which are grouped in racks, similar to these of SWRO systems. Vacuum-driven pretreatment systems include a series of filtration modules submerged in open tanks of size and configuration similar to that of gravity granular media filters.

The two most important parameters associated with the design of any membrane pretreatment system are the design flux and feed water recovery. Membrane flux determines the amount of total membrane area and modules/elements needed to produce certain volume of seawater and is defined as the ratio between the total filtration area and the volume of source water filters through the membranes. Feed water recovery indicates the fraction of the source seawater that is converted into filtrate suitable for seawater desalination. The recovery rate of membrane pretreatment systems is usually in a range of 88% to 94% and is typically lower than the recovery rate of granular media pretreatment filters for the same source water (95% to 98%).

Another important consideration is the operating pressure/vacuum of the pretreatment systems. Usually the vacuum-driven systems operate in a range of 0.1 to 0.8 bar and pressure-driven systems typically run at pressures of 1.0 to 2.5 bar (comparable to these of pressure-driven granular media filters).

Operating pressure may have a measurable impact on the rate of biofouling on the downstream SWRO membranes, if the source seawater is exposed to frequent algal blooms. In the case of algal blooms occurrence, both pressure and vacuum-driven membrane systems would typically operate at pressures higher than the threshold at which many algal cells break and release easily biodegradable organics in the filtered seawater. The cell rupture caused by the membrane pretreatment system would accelerate SWRO membrane fouling.

The pretreatment efficiency of the conventional media filtration technologies is very dependent on how robust the chemical coagulation and flocculation of the source seawater are ahead of the filtration process.

SWRO desalination plants equipped with vacuum-driven membrane pretreatment systems are typically designed to operate without coagulant addition or at coagulant dosages which are several times smaller than these needed for granular media pretreatment. Usually,

pressure-driven pretreatment systems, however, always require source water coagulation prior to filtration. In this case the coagulation dosages are also smaller than these needed for source water conditioning for granular media pretreatment of the same water.
UF membranes have found wider application for seawater pretreatment than MF membranes mainly because they usually provide better removal of suspended organics, silt and pathogens from seawater.
Vacuum-driven membrane pretreatment systems are usually more advantageous for treating seawater of variable quality in terms of turbidity. Pressure-driven membranes systems have limited capacity to retain solids due to the fact that the individual membrane elements are located in a tight membrane vessel of a very small retention volume.
Since vacuum-driven systems usually operate at lower transmembrane pressure, their rate of membrane fouling is lower and they have more stable operation during transient solids load conditions. Pressure-driven membrane pretreatment systems, however, are often more suitable and cost-competitive for cold source seawater or low turbidity and low organic, and algal content. Vacuum-driven system productivity is more sensitive to source water temperature/viscosity. This makes pressure-driven systems often the membrane pretreatment of choice for desalination plants with deep off-shore open ocean intakes.

4.1.2. - Technology trials

Two different types of ultrafiltration membranes were tested: one ceramic membrane and one polymeric membrane. These trials were based on different UF equipment for each water samples tested in the pilot plant.
The first experiments were done with a tubular ceramic membrane of 500 kDa of 19 channels from Likuid Manufacturer under operational conditions of 2 m/s of linear velocity, Transmembrane Pressure (TMP) of 2-4 bar and Volume Concentration Ratio (VCR) of 1-4.

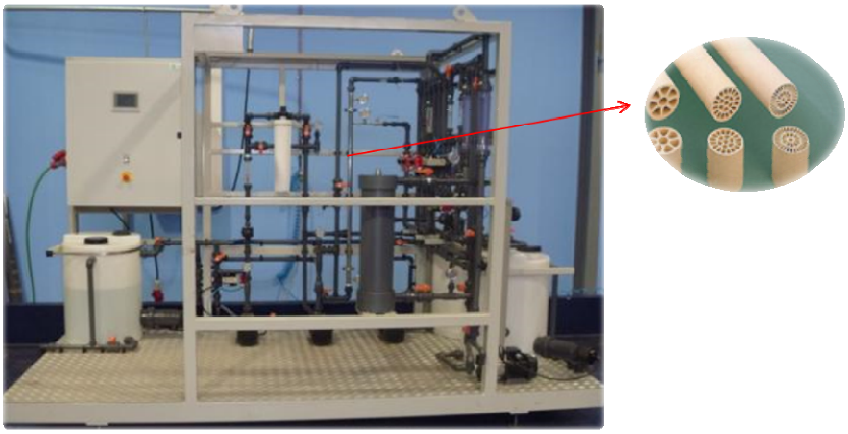


Figure 11. Ultrafiltration (UF) device and tubular ceramic membrane used for trials (Sampling 1).

Several tests were done with different TMPs and VCRs in order to obtain a general behavior for the treated water. Results obtained under these conditions are shown below, with an initial permeability of 155 L/hm^{2}bar. This value is according to the bibliography for this type of membranes Zebić Avdičević, M., Košutić, K., & Dobrović, S. (2017).

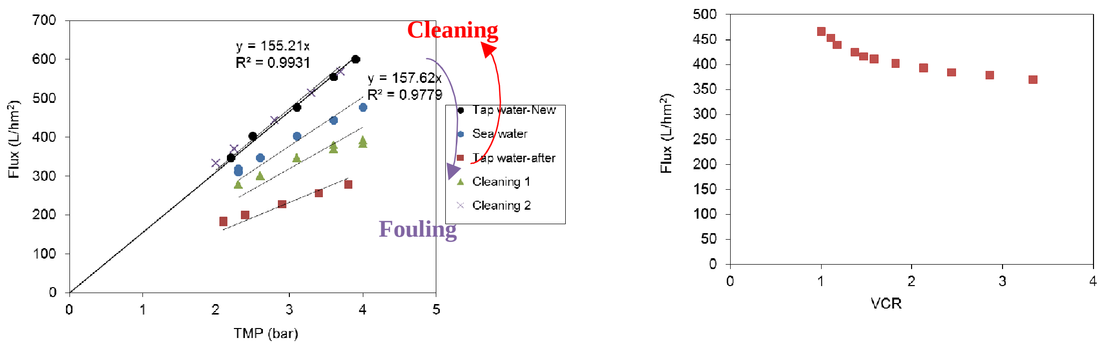


Figure 12. Graphs of Permeate Flux vs TMP and Permeate Flux vs VCR

The flux increases lineally with pressure and slightly decreases as the concentration increases. On the other hand, rejection increases with pressure. There is no effect of the concentration on the rejection as it can be seen below.

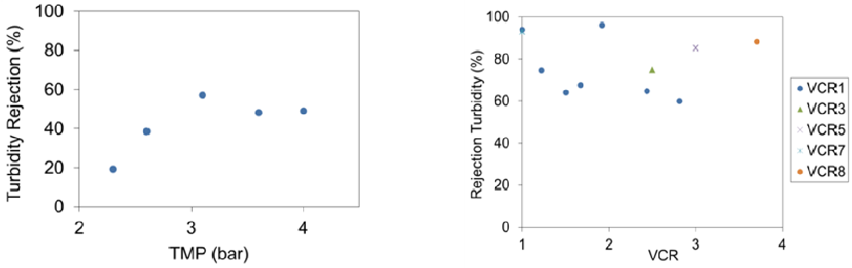


Figure 13. Graphs of Rejection Turbidity vs TMP and Rejection Turbidity vs VCR.

One important aspect is that after 1423 L/m², that is each 4 hours, the system need to be cleaned to recover the initial flux (flux decreases 15%).

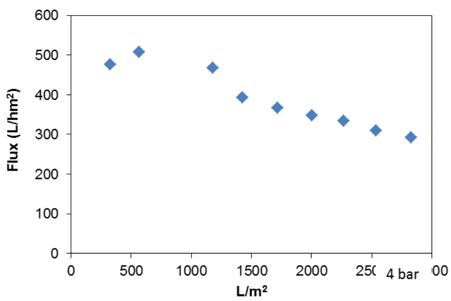


Figure 14. Reduction of permeate flux due to fouling for Sampling 1.

This flux reduction was caused by fouling, which was reversible, so total permeability was recovered after the application of the cleaning protocol.
Talking about outlet quality in terms of turbidity, values were mainly under 1 NTU in pressure and concentration experiments, as it can be observed below.

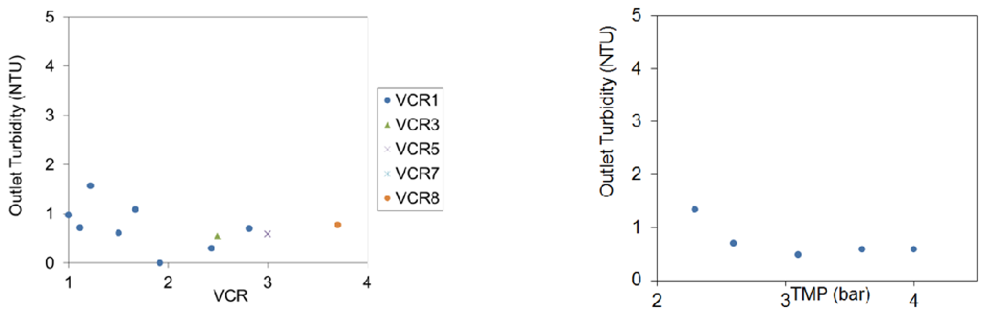


Figure 15. Graphs of outlet turbidity in pressure and concentration experiments for Sampling 1.

In general, as a summary, some conclusions can be drawn for the ceramic membrane:

- Ultrafiltration performs well, giving a constant outlet quality.
- Productivity increases with pressure.
- Rejection efficiency increases with pressure and concentration.
- Concentration experiments had better efficiency in terms of turbidity removal.

Table 8. Efficiencies for both Pressure and Concentration experiments.

Experiment	Efficiency Removal (%)
Pressure	42
Concentration	74

- Reversible fouling of the membrane was detected.
- Best conditions: 2 m/s at 4 bar, flux of 126 L/hm^{2}bar (74% turbidity removal).

The UF method based on a hollow fiber ultrafiltration module with 33 m^2 of polymeric membrane, model DOW SFP-2660 and a pore size of 0.03 µm was used for the second experimental campaign.

Figure 16. Ultrafiltration (UF) device and hollow fibre polymeric membrane used for trials (Sampling 2).

Several tests were done in order to obtain the removal for turbidity and total suspended solids. Results are shown below.

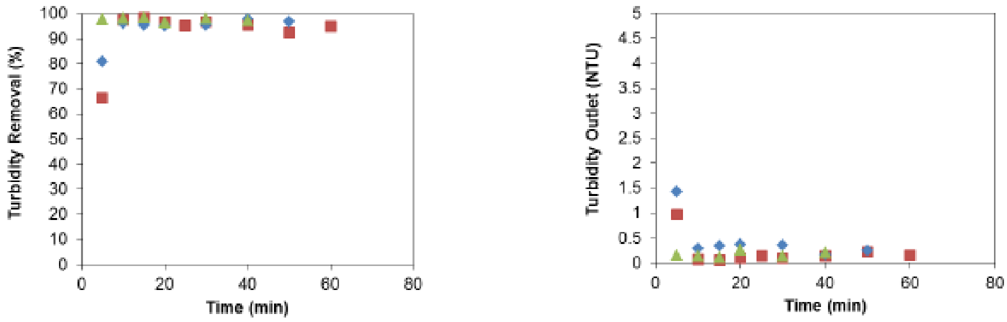


Figure 17. Turbidity Removal (%) vs Time and Turbidity Outlet (NTU) vs Time .

The initial filtered water is slightly worse, but after this brief period the turbidity removal is more constant and above 90%. After the stabilization period, the turbidity outlet is under 1 NTU.
The average value for the TSS is 7.8 ± 0.6 mg/L and for the turbidity is 0.3 ± 0.1 NTU.
In comparison with multimedia filters, the water quality obtained is higher and more constant in the case of ultrafiltration.

4.2. - Reverse Osmosis for desalting sea water

The water pretreated with mulitmedia and ultrafiltration was fed to the reverse osmosis pilot plant to asses if there is an effect on this depending on the pretreatment. Furthermore, activated carbon, metabilsulfite for chlorine removal and 3 mg/L of a scale inhibitor were added.
The RO was a polyamide thin-film composite spiral-wound membrane, model SW30-4040. Its characteristics are maximum flowrate of 3.6 m^3/h, maximum operation temperature of 45 ºC, maximum operation pressure of 69 bar and pH range of 2-11, among others.

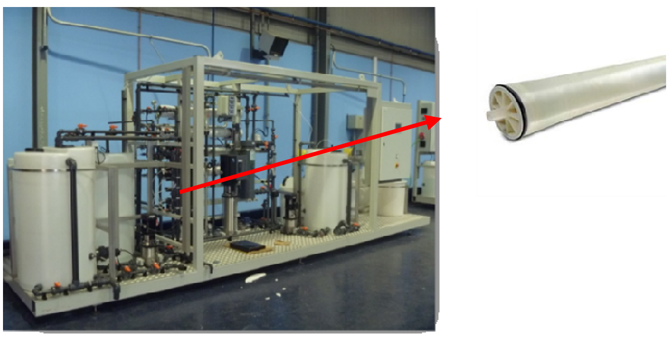


Figure 18. Membrane of reverse osmosis (RO) used in the trial.

Figure 19 showed the effect of the pressure on the flux and on the rejection for pressure closed to the osmotic one. The flux obtained with tap water at initial conditions is a characteristic of the membrane and the slope of the line in a diagram flux versus TMP is the permeability. The membrane permeability was 2.7 L/hm^{2}bar. In the case of sea water, there is a minimum pressure needed to obtain the first flux. This minimum pressure is the osmotic pressure that can be experimentally obtain from the intersection of the flux-TMP line with the x-axis. In this case the osmotic pressure was almost 20 bar. The plot of the right shows the effect of pressure on the salt rejection. It is observed that the salt rejection increases with pressure. The lower rejection is explained by the diffusion transport that is very significant at pressure close to the osmotic pressure.

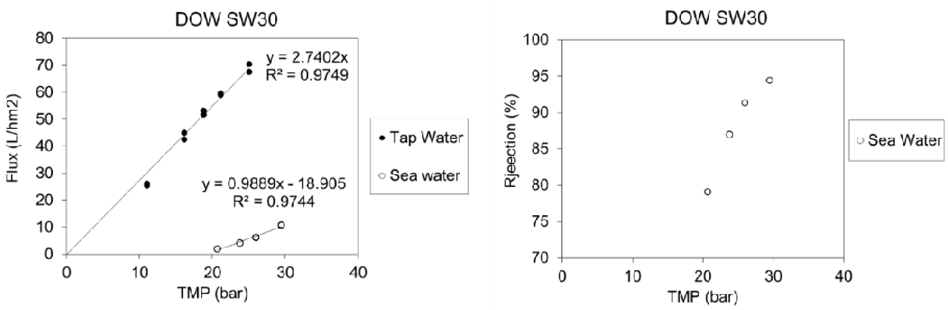


Figure 19. Graphs of Permeate flux vs TMP and %Rejection vs TMP for Sampling 1.

On the other hand, experiments at higher pressure need to be performed to compensate diffusional effect and to properly evaluate the concentration effect.

4.2.1. - Sea water pretreated with multimedia filters

First case of study corresponds to the RO after multimedia filters. The pretreated water was done with three layers of filtration material: sand, anthracite and garnet at 20 m/h.

Figure 20 showed the effect of the pressure on the flux for tap water and three for the pretreated water. The three experiments showed similar values. The lower flux compared to the tap water is due to the higher concentration of the water that makes more difficult to pass the membrane.

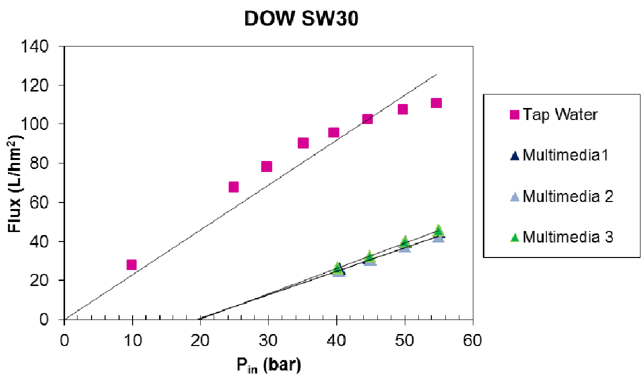


Figure 20. Effect of the pressure on the flux at 25ºC.

After each experiment the membrane was checked for fouling. No fouling was detected during all the experimental phase.

The effect of concentration was tested by continuously removing the permeate during batch experiments. Three experiments are reported in Figure 21.

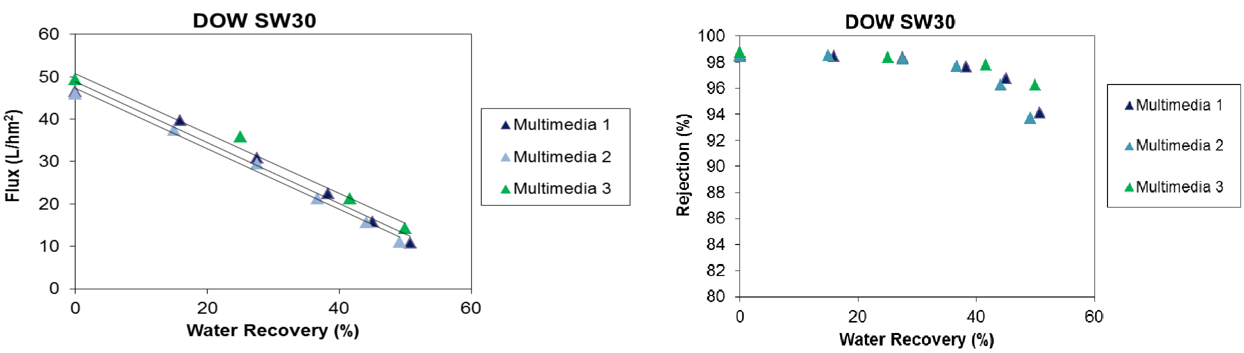


Figure 21. Effect of water recovery on the flux and on rejection at 25ºC and 55 bar.

The flux decreases as the water recovery increases. The initial flux was 50 L/hm². For a 40% water recovery, the flux declined was above 50%. This decline is also observed in the rejection with a high decline after 40% water recovery. This limited the possibilities in water recovery to values closed to 40%.

4.2.2. - Seawater pretreated with ultrafiltration

The second case of study, as it was mentioned before, corresponds to the RO after UF pretreatment.
Figure 22 showed the effect of pressure on the flux for three experiments with pretreated water with ultrafiltration and one for tap water as reference. The flux linearly increases with pressure. The results for the sea water are very similar between them and slightly higher flux is obtained compared to multimedia pretreatment. The osmotic pressure is between 14-16 bar, lower than for multimedia filters pretreated.

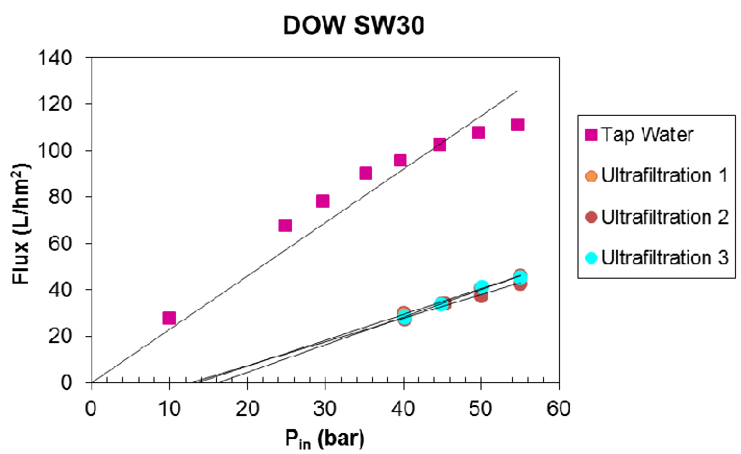


Figure 22. Effect of pressure on the flux at 25ºC.

The effect of the water recovery on the flux and on the rejection was also studied. Three experiments were carried out. And after each experiment, the system was checked to determine if fouling took place. No fouling was observed during all the experimental phase.
The effect of the water recovery on the flux is observed in Figure 23. The system was set to the maximum water recovery that can be achieved that was closed to 70%. It can be seen that for water recovery of 70% the flux is close to zero. In the case of the rejection, the rejection importantly decreases after water recovery higher than 40%.

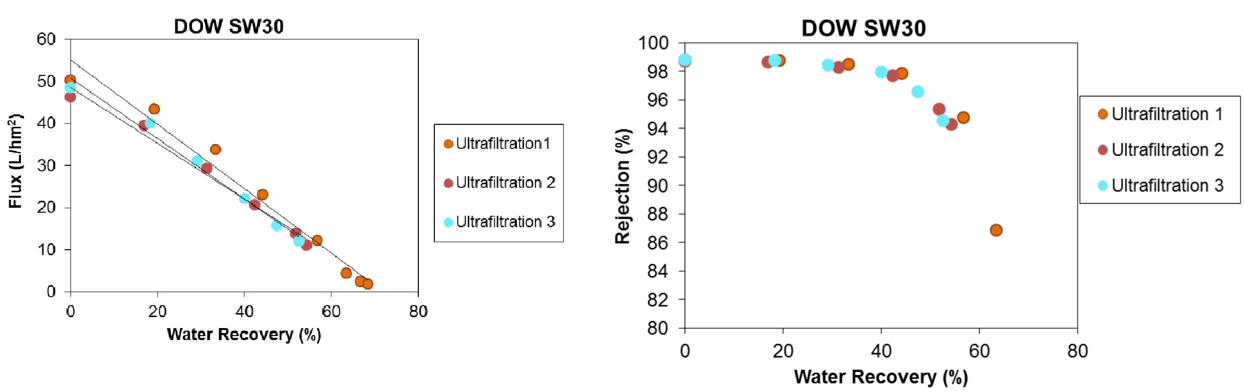


Figure 23. Effect of the water recovery on the flux at 55 bar and 25ºC.

One important aspect is the different Osmotic Pressure for both cases. Those 5 bar of difference mean that more pressure (+ 5 bar) are needed to be applied for the pretreated water based on multimedia filter.

The requirements to achieve industrial water quality are conductivity lower than 200 µS/cm and chlorides lower than 100 mg/L. As the sea water has a high conductivity, even with a rejection higher than 99% is not achieved the inlet requirements in one pass (Chlorides = 1200 mg/L and conductivity = 1500 µS/cm). The solution is to filtrate the permeate again through a second pass of reverse osmosis. In this second pass, the desired concentration can be easily obtained.

5. - Rainwater harvesting

Rainwater in terms of industrial harvesting is about rainfall directly stored in storage tanks or in other devices surrounding roofs or other buildings.
Quantity and characteristics of the materials will be function of the area topography, water storage and harvesting facilities and rainfall characteristics, such as pH, rainfall event duration and water chemical constituents.
Water quantity and quality must be the main objective to set the most appropriate management strategy, which must include a well-defined pollution prevention plan and correct storage, treatment and monitoring facilities. A Stormwater Pollution Prevention Plan (SWPPP) must include data of:

- A map of the industrial area where rainwater and stormwater collection are detailed.
- Industrial and non-industrial activities in those areas.
- Identification of potential pollutants focuses.
- A list of outdoor materials.
- An estimation of quantity of pollutants that could be incorporated to runoff.
- Historical data of leaks and outflows of toxic and dangerous materials in rainfall areas in the last 3 years.

An effective and well-designed stormwater management plan for industrial harvesting must contain three main points:

- A prevention plan for pollutants.
- A segregation of rainwater and stormwater sources.
- A catchment and a treatment of these waters.

The segregation of rainwater and stormwater sources has the main objective of separate the "clean" focus and the "dirt" focus. In this way, it can be possible to achieve good catchment and treatments systems according to the water pollution level. In this point, it is important to have historical data of structural characteristics, pollutants and regular events of rain and storms in terms of quantity. This point is especially relevant for the later water treatment because in an area with pollutants, the less quantity of precipitation in which pollutants can be incorporated, the more concentrated they will be. Therefore, sources segregation is essential to choose the correct treatment systems. Thus, oil skimmers or settlers are more efficient working with water with more concentrated pollutants.
The catchment and treatment of stormwater and rainwater are conditioned by grade of pollution. A well-designed management plan and correct sources segregation will allow the use of not too much expensive systems of catchment, storage, treatment and use or discharge of these waters.
Taking into account all the previous aspects, the main target and the greatest achievement of a correct rainwater and stormwater management is the reduction of pollutants in their origin source, because this will be the main point that will determine all the next stages.
The treatment systems design for rainwater and stormwater is based in both quantity and quality of rainfall.
The basic hydrology must determine the amount of water that circulates on the surface (runoff) in order to design the collection and treatment systems correctly. This aspect is mainly conditioned by topography of the area.
The rainfall of a specific area can be quantified in different ways. There are databases that collect information about rainfall and storm events in different periods of time, as well as statistical methods of calculation based of these databases. It is necessary to take into account, especially in certain areas, the precipitations that fall as snow and its subsequent melting.
The runoff estimation is one of the basic aspects that will condition the different facilities design. There are several methods to estimate the quantity of water in a runoff. Two examples of them are: the rational method and the hydrographic method.

The rational method is based on the balance of flows and has a more theoretical and ideal analysis. It has an effective application for small areas and facilities and it is more ineffective for larger areas (> 0.5 km^2).
The hydrographic method is based on the geography and the meteorological conditions of the area, having a much more extensive application. This method includes the combined effect of climate, hydrological losses (for example evaporation, infiltration, etc.), surface runoff, surface water and groundwater. With these considerations, a continuous graph can be done where instantaneous discharge of water versus time can be represented. The peak of the graph represents the maximum flow during a storm event and the area under the curve represents the amount of water discharged during that event. This method provides the necessary information to size rainwater and stormwater collection and detention systems, as well as other treatment systems.
In order to design the different facilities, there must be data of rainfall in the area of a large period of time, normally the last 25 years with 24-hour records.

5.1. - Rainfall data in Spain

In the database of AEMET that is the Spanish National Agency for Meteorology (Agencia Estatal de Meteorología) there is information about meteorological data from different stations throughout the national territory and collected over a long period of time (more than 100 years in some cases). With this information, data of historical temperature, sun hours or, as the case that interests us, rainfall.
There are different ways to group such rainfall data: hourly, monthly, annual, comparison between cities, etc. Figure 24 shows the quantity of rain per square meter for different cities of Spain. In Spain, a special focus will be done in the north of Spain where the Global Asturias R&D centre is sited and that is the part of the country that receives more rainfall. The main cities of this region are Oviedo and Gijón.
It can be observed that the climatic behaviour of Oviedo and Gijón, and by extension the northern side of Spain, is quite different from other cities of the centre and south of the country, where there is much less average rainfall.

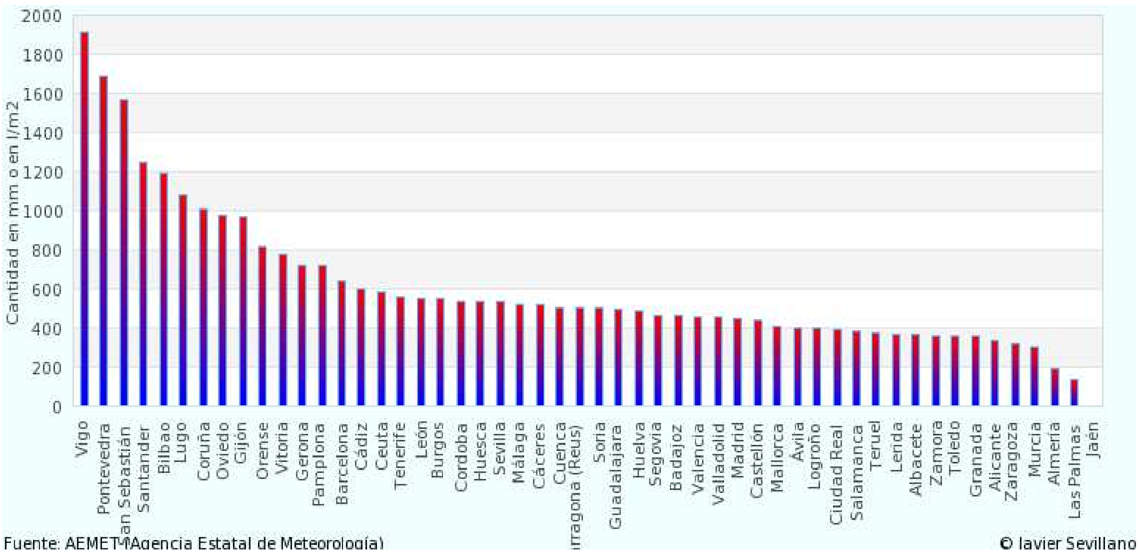


Figure 24. Average of total rainfall for different cities of Spain.

Both Oviedo and Gijón have similar graphics and complementary tendency in terms of rainfall and temperatures, so it can be extrapolated to the rest of Asturias and much of northern Spain, except territories of Galicia, which are considerably more humid.

Based on their average data (973 mm/m^{2}year of rainfall and 13 ºC for Oviedo, 971 mm/m^{2}year and 14 ºC for Gijón), both cites can be climatically classified according to Köppen Index as Cfb, that is, mild temperature oceanic climate with mild summer, characterized by average maximum temperatures that do not exceed 22 ºC.
The average data with relevance for both cities can be seen below in form of a climograph, where rainfall and average temperatures are monthly represented.

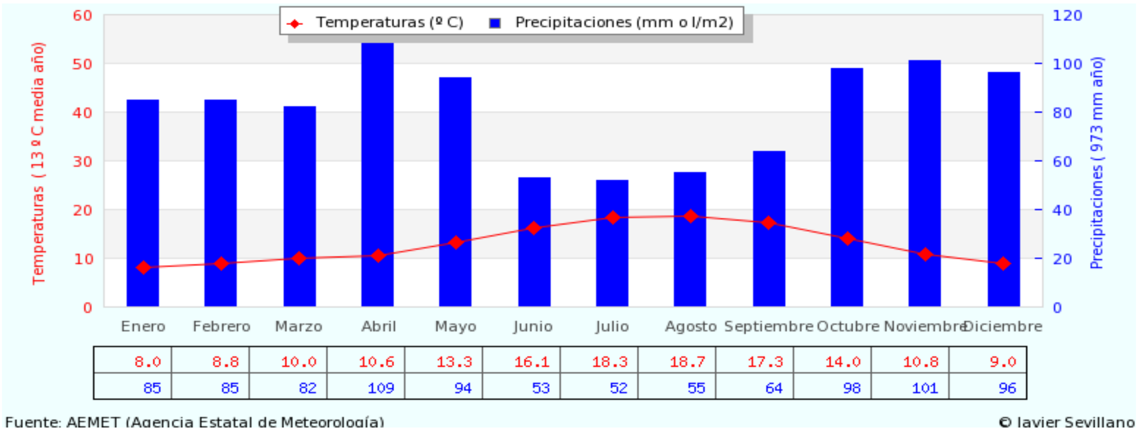


Figure 25. Climograph of Oviedo.

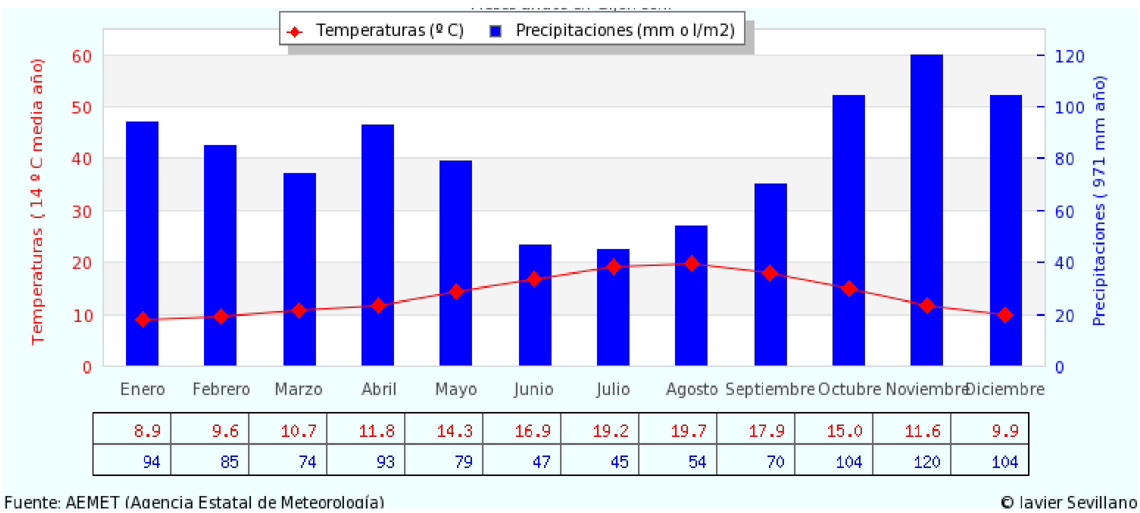


Figure 26. Climograph of Gijón.

Climographs give information about arid months, which would be those in which the T curve is above the rainfall graph (Gaussen index criterion). For the cases of Oviedo and Gijón this does not happen even in the driest month, July. It can also be seen that both cities have the same tendency of temperatures and rainfall, which are more abundant in April and November.

Other types of graphs that give relevant information about rainfall for both cities are shown below. They are especially useful graphs to find the years with extreme volumes of rainfall. With this information, general tendency, anomalies or other kind of analysis can be done. They represent the cumulative total annual rainfall for each monitored year.
Graphs of the cities of Oviedo and Gijón are shown below.

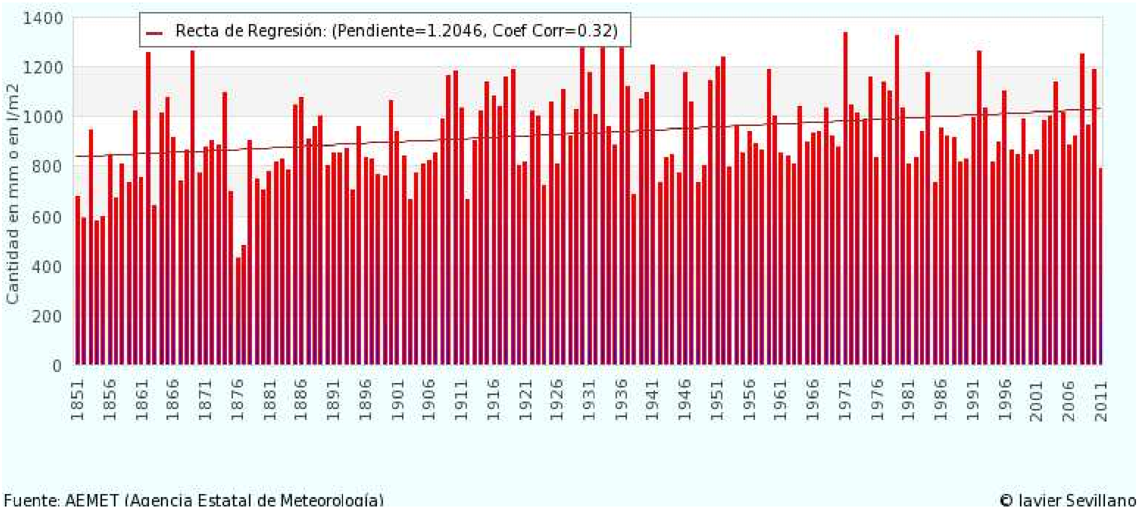


Figure 27. Total annual rainfall of Oviedo over the years.

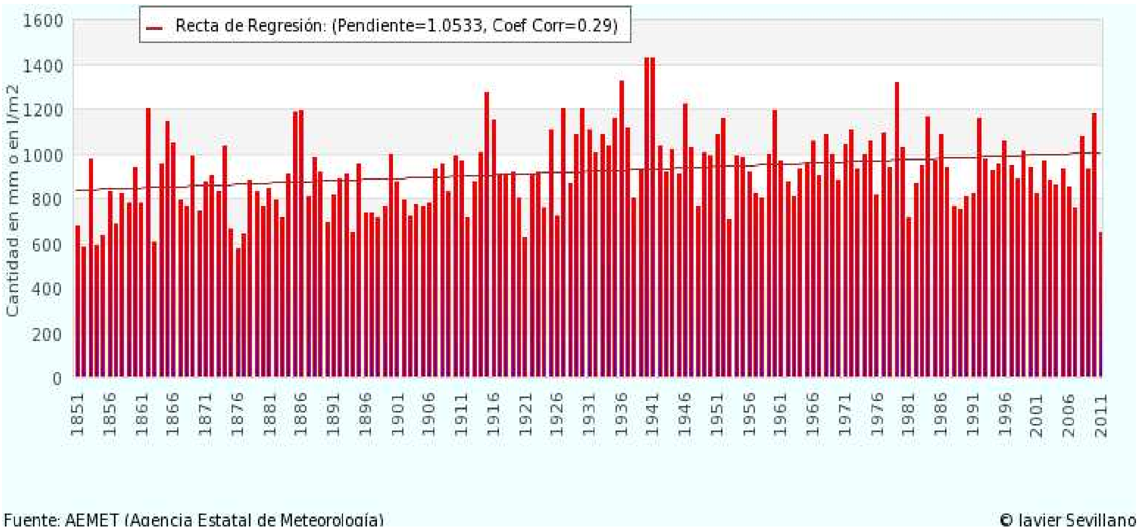


Figure 28. Total annual rainfall of Gijón over the years.

It can be seen that both graphs have a similar tendency. For both cities there are relatively few years exceeding 1000 mm/m^{2}year (more cases for Oviedo) and few years below 700 mm/m^{2}year, so it could be considered a stable behaviour during the years. In addition, both cities coincide in the driest year with records, 1876, with just over 400 mm/m^{2}year in the case of Oviedo and slightly less than 600 mm/m^{2}year in the case of Gijón, so this year could be considered an exception to the general behaviour.

As it was mentioned before, information recorded in weather databases allows us to group and analyze it in different ways, from long periods of time (series of consecutive years) to monthly or daily data, as well as comparisons between the same months, days, etc. of different years, among others.

Some useful examples for the city of Oviedo can be seen below. The analysis can be extrapolated to the case of Gijón or Asturias in general.

First of all, the cumulative rainfall data of the driest month of Oviedo, July, are shown below.

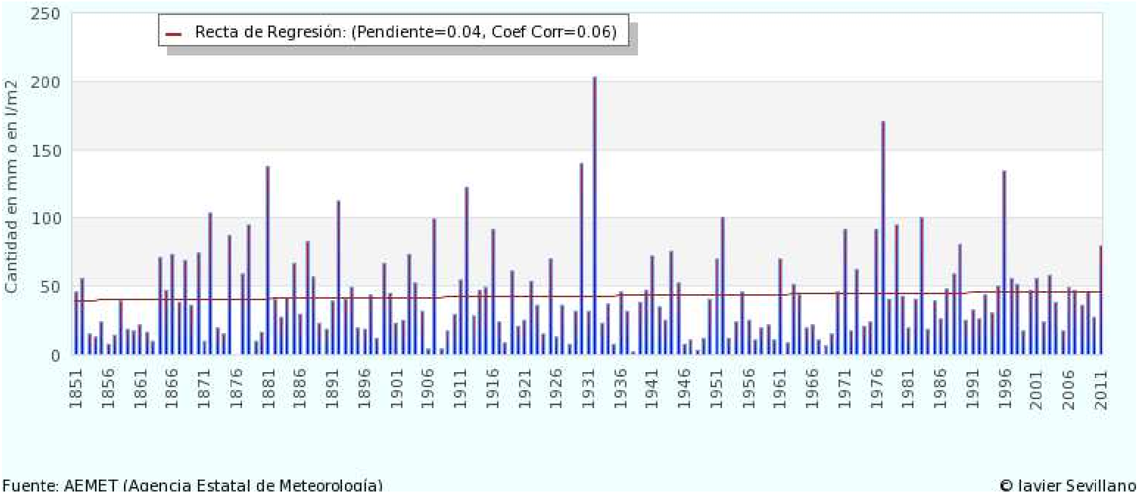


Figure 29. Accumulated rainfall of July over the years in Oviedo.

It can be observed that is very rare to exceed 100 mm/m^{2}month, being these cases probably due to heavy storm events. Thus, the most usual rainfall is around 50 mm/m^{2}month.
On the other hand, the accumulated rainfall within that dry month of a particular year per day can be represented. In the following case, the month of July 2015.

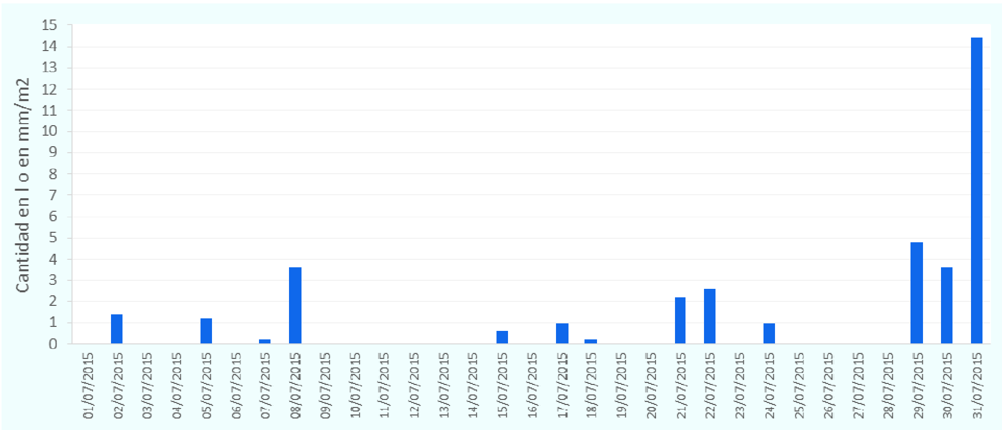


Figure 30. Accumulated rainfall in a dry month in Oviedo (July 2015).

It can be seen that the month of July is very dry indeed, with few events of rainfall and little of volume in each one, not exceeding a maximum of 15 mm/m^{2}day. The total accumulated rainfall in that month is 37.4 mm/m^{2}month.
The rainfall of the dry season can also be found, considering for example June, July, August and September. The resulting graph is shown below.

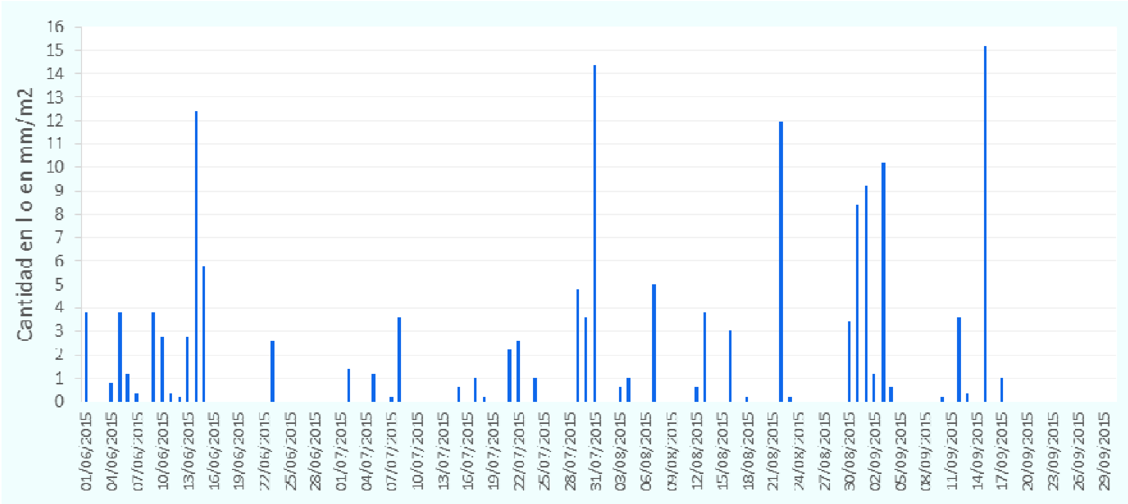


Figure 31. Accumulated rainfall during dry season in Oviedo (June, July, August and September of 2015).

It can be seen that the dry season is scarce in rainfall, in general, with very few events exceeding for example 5 mm/m^{2}day. The maximum is reached in September (15 mm/m^2), probably a storm event, and the average rainfall for this quarter is 1.3 mm/m^2. The total accumulated volume for the chosen period of time is 157.8 mm/m^2.

The rainiest month for Oviedo and Gijón has been historically November, with April also being a month with important rainfall. The accumulated rainfall in November in Oviedo over the years is shown below.

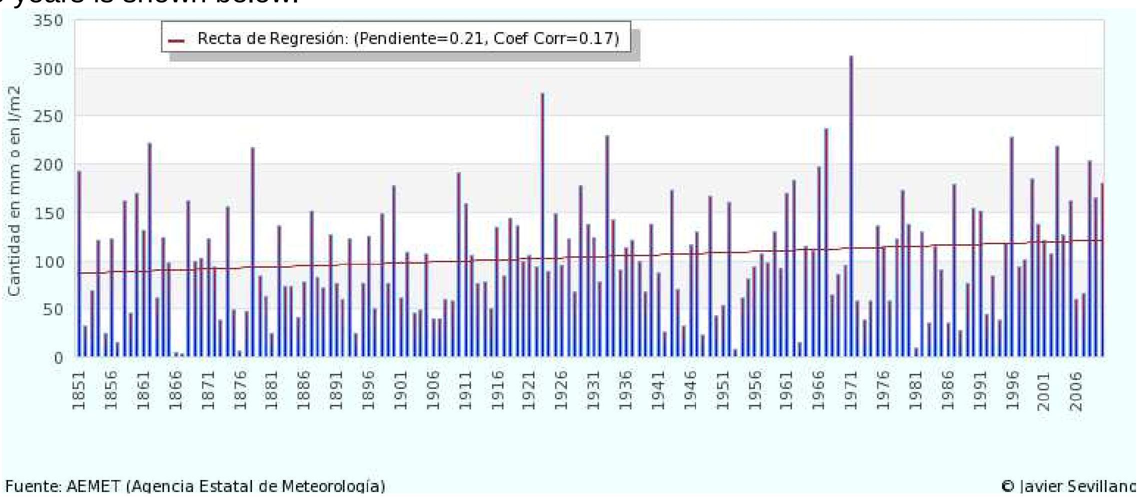


Figure 32. Accumulated rainfall in November over the years in Oviedo.

Volumes of rainfall are quite abundant and there are several times over 100 mm/m^{2}month. Some years have exceeded 200 mm/m^{2}month and even 300 mm/m^{2}month.

On the other hand, the accumulated rainfall can be represented within the month of November of a particular year. The following case represents November 2015.

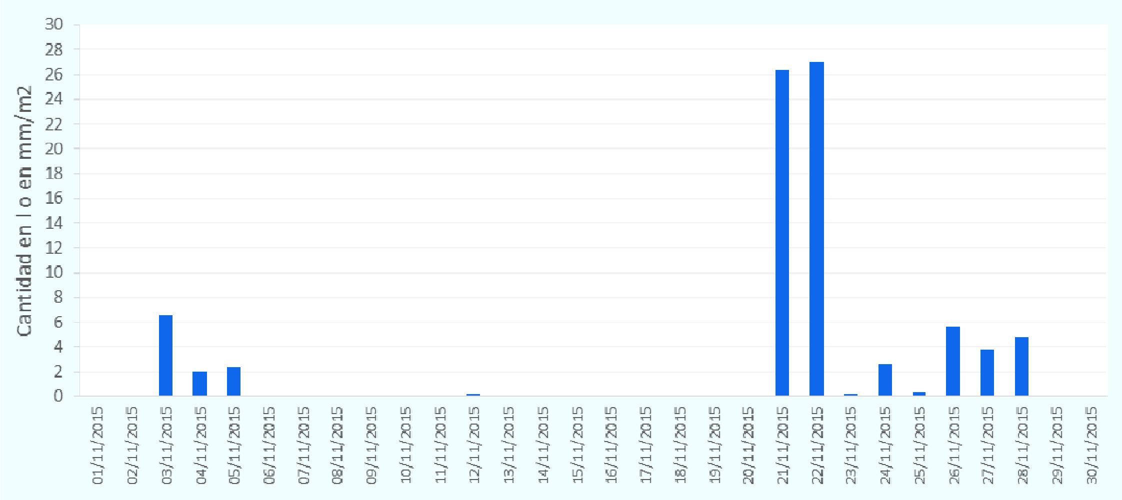


Figure 33. Accumulated rainfall in a rainy month in Oviedo (November 2015).

It can be seen that the month of November is quite rainy, with many events of rainfall (12 mm/m^{2}day, like the month of July previously analyzed) but there is abundant volume of rainfall in each of them.

In addition, the days of rainfall are consecutive and mark the maximum of the month in some cases. In this example, the two maximums, more than 26 mm/m^{2}day, are two consecutive days. The maximum daily rainfall was 27 mm/m^{2}day and the total accumulated rainfall for that month of November was 82 mm/m^{2}month, values that practically double those referred to the dry month of July.

As it was done for the dry season, the rainfall corresponding to the rainy months of 2015 can be found, considering for example October, November, December and January of 2016.

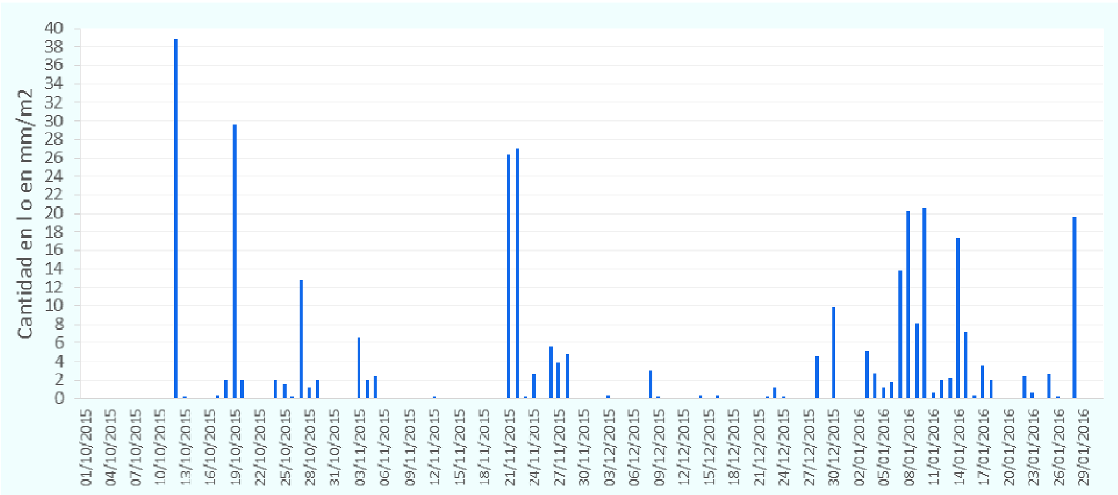


Figure 34. Accumulated rainfall in the rainy season in Oviedo (October, November and December 2015, January 2016).

The rainy season is quite abundant in rainfall, having several events that exceed 15 mm/m^{2}day. The maximum rainfall is reached in October, with 38 mm/m^2, a single day of rainfall, so it could be a stormy day. The average rainfall is 3 mm/m^2 and the total accumulated volume is 329.8 mm/m^2.

In general, for the chosen periods, the rainfall values in “rainy season” exceed twice the values corresponding to the “dry season”. This behaviour could be extrapolated as a general

behaviour because, as it was said before, the climate in Asturias is not characterized by abrupt or unexpected changes in the general tendency within the seasons in the year.
These meteorological representations are a useful tool to compare behaviours and tendencies of different cities, both in the same geographical area and similar climate and areas with different climatology. Two examples of this are shown below.

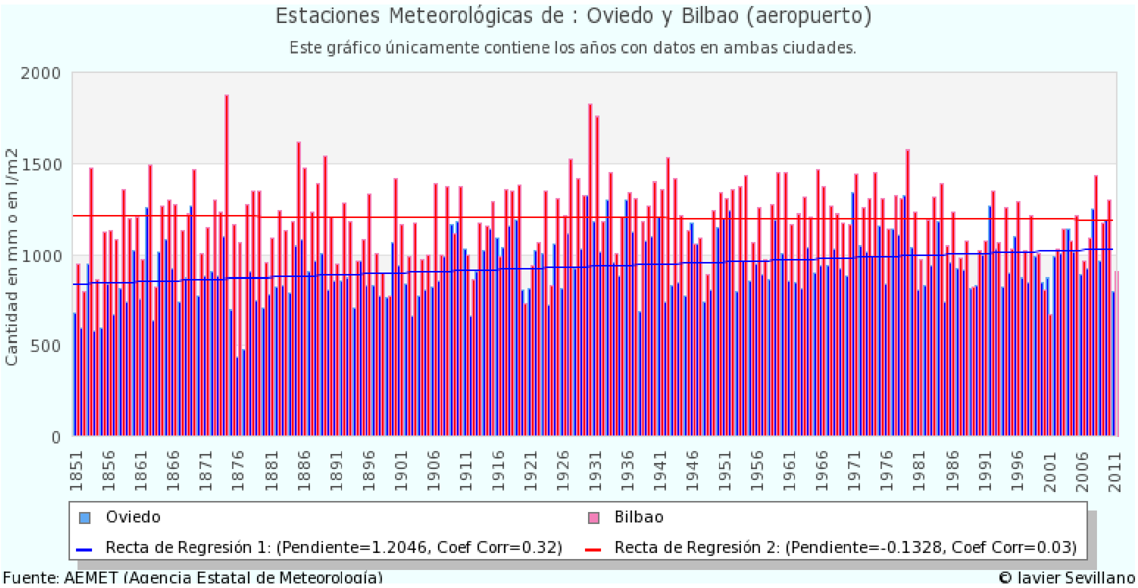


Figure 35. Total annual rainfall of Oviedo vs Total annual rainfall of Bilbao.

The graph above compares rainfall of the cities of Oviedo and Bilbao, both from the north of Spain but from different regions. Rainfall volume and tendency are similar, although Bilbao collects more annual rainfall (1197 mm/m^{2}year compared to 973 mm/m^{2}year of Oviedo).

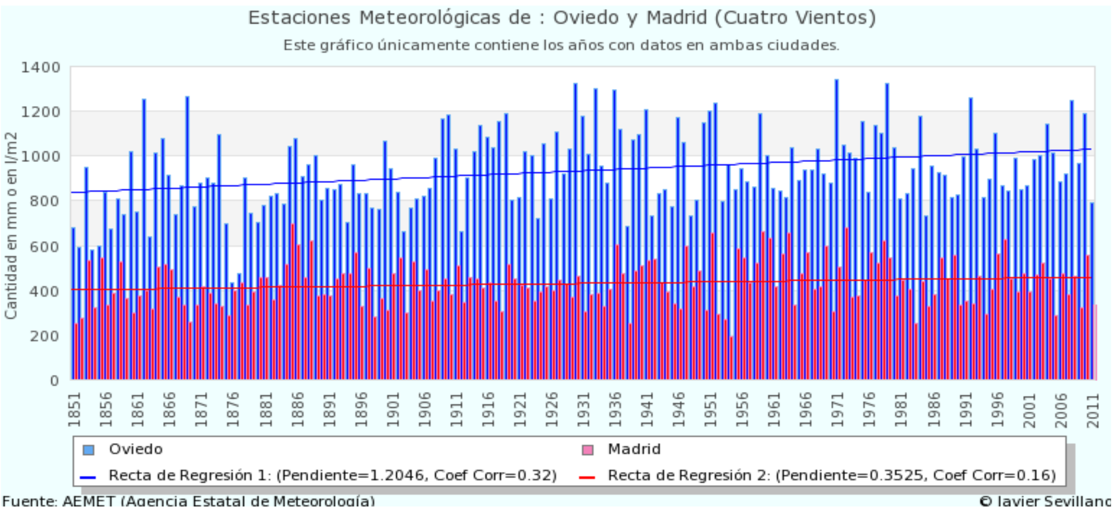


Figure 36. Total annual rainfall of Oviedo vs Total annual rainfall of Madrid.

The graph above compares rainfall of two cities located geographically distant and with different climates within Spain, Oviedo and Madrid. As it was previously mentioned, Oviedo has a mild temperature oceanic climate with mild summer (Köppen Index Cfb), while Madrid has a cold semi-arid climate (Köppen Index BSk) with Mediterranean climate characteristics (Köppen Index Csa), which translates into higher thermal amplitudes and a considerably lower volume of rainfall than in a more rainy climatic areas.

Once climate data previously collected is viewed and analysed in a general way, a series of ideas can be extracted as preliminary and general conclusions.
The official climate data for a specific city or region are a reliable and indispensable source to design a rainwater and stormwater management system.
Regions of northern Spain, with climates of the Cfb type (mild temperature oceanic climate with mild summer), have a considerable rainfall that can be harvested, especially in the rainy season. On the other hand, the summer season has also an appreciable volume of rainfall, much more than regions of southern Spain, with Mediterranean and semi-arid climates. In addition, the climatic behaviour in general is stable, with few storm events with little volumes.
Even though there are few storms and not very volumetric, the designed system must take into account the possibility of an abrupt storm event, as it has been seen in some of the previous graphs. In contrast, the design must also consider the possibility of particularly dry years, as it has also been proved. Despite being a rainy, mild and relatively stable climatic zone, the climate can be somehow unpredictable. Therefore, the rainwater management design must be flexible enough to cushion the climate discrepancies with respect to the expected general behaviour.
For a potential surface area of 500 000 m^2 with oceanic climate and average rainfall of 970 mm/m^2year the potential quantity of water harvested per month is shown in the next table.

Table 9. Potential rainwater harvesting per month.

	mm/m^2month	**Footprint (m^2)**	**m^3/month**
Jan	85	500000	42500
Feb	85	500000	42500
March	82	500000	41000
April	109	500000	54500
May	94	500000	47000
June	53	500000	26500
July	52	500000	26000
Augoust	55	500000	27500
September	64	500000	32000
October	98	500000	49000
November	101	500000	50500
December	96	500000	48000

A collection system design

The classic design for a stormwater and rainwater collection system for industrial purposes includes roof drains, water collection basins, stormwater drains, open pipelines and pumping stations. Peaks of maximum water flow are used to size the water collection, transport and pumping systems. These systems must be clean and easily accessible for periodic sampling and measurement campaigns.

Retention/Detention systems design.

In general, the retention systems refer to lagoons or wet wells that always contain an amount of water, whereas the detention systems refer to concrete, steel or earthen basins that remain dry once are drained. They can be located on the ground level or underground, and their dimensions are conditioned by the study of rainfall events, as previously mentioned.
Usually, for industrial facilities outside the urban area, earthen retention/detention systems are usually used due to costs, whereas in an urban area, where the available space is much more limited, systems made of concrete or other material are more common.

These system designs can be approached in a similar way to an equalization tank, once the rainfall characteristics are completely known.
On the other hand, due to the "unstable" or even "unpredictable" nature of precipitation phenomena in general and storms in particular, systems must be designed to manage events of overflow or periodic failure. These systems must receive the same maintenance and cleaning routines as usual systems.
If stormwater or rainwater is going to be used in the industrial complex as process water, the treatment and considerations could be very different from those used for wastewater. For example, a storage area for this water is considered necessary.
The most common and developed uses in industry are:

- Cooling towers. It is the most common use.
- Dust and suspensions control within the industrial area and surroundings.
- Washing water in the process.
- Irrigation of gardens and green areas.
- Non potable water for baths and toilets.
- Potable water, if a high quality has been reached.

6. - Water recycling strategies - Alternative water resources for the steel industry

In this deliverable, alternative water resources were evaluated in terms of pre-treatment, treatment and quantity index for rain water to be industrial make-up water. The following points were evaluated here:

- Backwash water and river water was desalted to be used as industrial make-up water
- Evaluation of pre-treatment for sea water conditioning as make-up water and further effect on reverse osmosis.
- Rainwater was evaluated in terms of quantity.

Regarding technologies several technologies were tested at laboratory and pilot plant to achieve the requirements of the above points. The technologies tested were the following ones:

- Capacitive deionization
- Hollow fibre ultrafiltration membranes
- Ceramic ultrafiltration membranes
- Multimedia filters with different filtration media
- Spiral wound reverse osmosis

Considering the results of the performed investigations, an overview of the different treatment technologies depending on the water source and required water quality are shown for different water recycling strategies in steel industry, Figure 37.

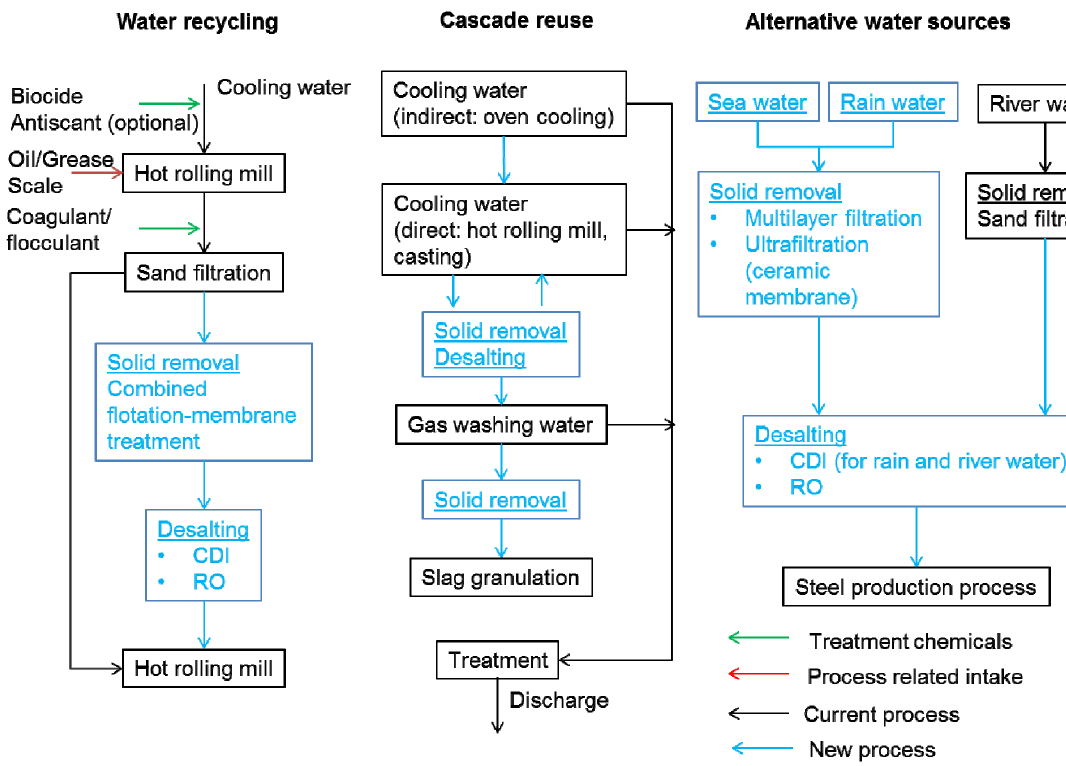


Figure 37. Water recycling strategies based on trial results

The CDI treated river and back wash water can be used for the applications shown in Figure 18: All requirements regarding conductivity, Cl, SO_4, Ca, Mg and total hardness are fulfilled for all application. Only in the case of the Indirect closed cooling at the Electric Arc Furnace a total hardness < 10 mg $CaCO_3$/L is required, while the values in the clean water of the treated river water and back wash water are 17 respectably 58 mg $CaCO_3$/L.

Table 10. Suitable applications for reuse of CDI treated river and back washing water

		Back wash	River water
Hot Rolling Mill	Reheat furnaces		x
	Equipment cooling	x	x
	Direct cooling		x
Continuous Casting Circuits	Mould cooling		x
	Contact cooling		x
Electric Arc Furnace	Indirect closed cooling	Further softening required (total hardness, Ca < 10 mg/L required)	
	Open cooling	x	x
Converter Circuits	Indirect cooling	x	x
	BOF gas cleaning		x
Blast Furnace Circuits	Indirect cooling	x	x
	Gas cleaning		x
	Slag granulation		x

Limiting factor is the pH- value of the pure water, which is in the treated back washing water 6.5. The requirement is regarding BREF “Iron and Steelmaking” minimum 7.0 (marked value) or according plant suppliers preferable above 7.5 (marked green). As conclusion, a pH adjustment would be necessary before reuse (marked orange), Table 10. The pH value of the river water was in the investigated samples about 9.5, while long term sampling of AM showed a pH range of 7.0 – 7.8. Considering experience with CDI, the pH change by CDI treatment was always in a range of +/- 0.25.

For the case of sea water, a focus on the pre-treatment was done. Multimedia filters based on three layer obtained results that were suitable for reverse osmosis is most of the cases, being some values above the specifications.
Between ceramic and polymer ultrafiltration membrane, polymeric membrane gave more stable results and no fouling on it was obtained.
On the reverse osmosis, a gain in the pressure needed for the separation is obtained with the ultrafiltration pre-treatment. Ultrafiltration pre-treated water gave lower osmotic pressure, that is was translate in a 10% less energy for the same productivity.
To achieve an industrial water quality (Conductivity <200 µS/cm and Chlorides < 100 mg/L), it is needed that the permeate of the first RO is filtered through a second pass of RO.
The possible of rainwater harvesting was investigated and a case of study in Spain was considered.

7. - Conclusions and Prospects

In the Table 9, a summary is included of the types of water and the technologies reported in this deliverable.

Table 11. Type of water and technologies tested in this report.

Type of water	Technologies
Backwash	CDI
River water	
Sea water	Ultrafiltration
	Multimedia
	Reverse Osmosis
Stormwater	None. Quantification based on historical data

In the case of different technologies tested for the same water sources, the technologies selected in terms of water quality requirements are for the sea water the ultrafiltration and reverse osmosis.

Chapter 6 includes the strategies and points of applications for the steel industry.

The technical conclusions for the different technologies are the following ones.
For capacitive deionization:

- Capacitive deionization is a suitable technology for the desalting of river and back wash water after the removal of solids and in the case of back wash water of oil /grease**.** Water recovery rates of 71 to 79% were achieved. The achieved quality of the treated water fulfils the operational requirements of AM. Because of the high total dissolved solid content (40 000 mg/L), which is 10 times higher than the recommended limit value of the CDI manufacture, the CDI is not suitable for sea water.

For multimedia filters:

- For the S+A, as expected the efficiency increases by decreasing the velocity.
- For the S+A+G, this effect was not observed, achieving higher rejection at higher velocity.

- The low turbidity removal is explained due to the low initial turbidity.
- No fouling of the media was observed for the experiments done.
- Best conditions: S+A+G at 20 m/h
- Sand + Anthracite + Garnet (S+A+G) gave better result than Sand+ Anthracite (S+A).
- S+A+G achieves, in most of the cases, the quality requirement for the inlet of a Reverse Osmosis (RO) in terms of turbidity, but not in the total suspended solids.

For ceramic ultrafiltration:

- Ultrafiltration performs well, giving a constant outlet quality.
- Productivity increases with pressure.
- Rejection efficiency increases with pressure and concentration experiments.
- Concentration experiments had better efficiency in terms of turbidity removal.

Table 12. Efficiencies for both Pressure and Concentration experiments.

Experiment	Efficiency Removal (%)
Pressure	42
Concentration	74

- Reversible fouling of the membrane was detected.
- Best conditions: 2 m/s at 4 bar, flux of 126 L/hm^2bar (74% turbidity removal).

For polymeric ultrafiltration:

- The initial filtered water is slightly worse, but after a brief period the turbidity removal is constant and above 90%. After this stabilization period, the turbidity outlet is under 1 NTU.
- The average value for the TSS is 7.8 ± 0.6 mg/L and for the turbidity is 0.3 ± 0.1 NTU.

For reverse Osmosis

- One important aspect is the different Osmotic Pressure for both cases. Those 5 bar of difference mean that more pressure (+ 5 bar) are needed to be applied for the pretreated water based on multimedia filter.
- The requirements to achieve industrial water quality are conductivity lower than 200 µS/cm and chlorides lower than 100 mg/L. As the sea water has a high conductivity, even with a rejection higher than 99% is not achieved the inlet requirements in one pass (Chlorides = 1200 mg/L and conductivity = 1500 µS/cm). The solution is to filtrate the permeate again through a second pass of reverse osmosis. In this second pass, the desired concentration can be easily obtained.

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