MARSOL

Demonstrating Managed Aquifer Recharge as a Solution to Water Scarcity and Drought

Appropriate MAR methodology and tested *know-how* for the general rural development

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Author(s)	Enrique Fernández Escalante, Rodrigo Calero Gil, María Villanueva Lago (Tragsa) Jon San Sebastián Sauto, Óscar Martínez Tejero, Juan Antonio Valiente Blázquez (Tragsatec)
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1. EXECUTIVE SUMMARY

This report is part of the MARSOL (www.marsol.eu) FP7 founded EU project (Grant Agreement Number 619120).

The main objective of this deliverable is to provide a set of recommendations to apply Managed Aquifer Recharge (from now on, MAR) methods, as well as to present practical rules from general rural development from the experience obtained at Los Arenales aquifer and, partially, from the rest of the MAR-SOL project´s demo-sites.

It includes all the different techniques applied to solve the detected impacts affecting MAR facilities, from the initial stage until the monitoring phase, which aggregation constitutes a key element to combat groundwater over-exploitation.

The “improved MAR techniques” at Los Arenales have been achieved after a permanent study, monitoring and tracking along 15 years, providing a large amount of “technical solutions” willing to be extrapolated to parallel scenarios.

After the characterization of the three main operating facilities within the Arenales demo-site (Santiuste Basin, Carracillo Council and Alcazarén Area) and the large amount of problem-solution binomials exposed in the previous WP-5 deliverables (D5-1 and D5-2), there have been developed some important achievements presented in this report. These outcomes are not only related to the technical point of view but also to Public-Private Partnership (PPP) schemes, Decision Support Systems (DSS) and advices to end-users, always from a practical and applied perspective. Most of the aspects regarding solutions specifically associated to environmental elements will be deployed in the next deliverable (D5-4).

After this brief advance (Section 1) and the introductory paragraphs (Section 2), the Section 3 focusses on MAR technique improvements according to the general objective number 5 (DoW, pg. 22): optimization of ditches, canal slopes, infiltration ponds morphology; modifications in bottom designs; changes in the current designs; proposal for a suitable water pre-treatment standard, pre-treatment by different filters, etc. In order to maintain a certain parallelism with the previous reports, actions and findings will be presented in this order:

1- Physical assays, infiltration tests in the bottom of ponds and canals and variations with the presence of vegetation, furrows design recommendations, slopes stability and results from the experience. Apart from improved designs for MAR facilities, management and maintenance criteria are also considered.

2- Studies on clogging, identification and distribution of the main clogging processes and their combinations, distribution in the demo-site and factors conditioning their growth and development. Chemical analyses for water and clogging. Results from the studies for trapped air (gas clogging) obtained from the new sensors installed in Santiuste and Carracillo MAR Plants (ZNS stations, described in the deliverable 5-1.) have been exposed too. As this is a line of action permanently open, some later conclusions are procrastinated for the deliverable 5-4.

3- Soil and Aquifer Treatment Techniques (SATs) and SAT-MAR studies: Experimental tests on “treatment in itinere” of purified water along the canals (triplet schemes, see deliverable 5-1), purification along the conductions by means of filters (biofilms, geofabrics, gravel and sand filters, chemical additives (DBPs), solar exposure, etc. Also biological studies on clogging have been conducted to support practical recommendations regarding an appropriate quality standard for MAR, based on valid water pre-treatment and on the effect of the filters made of different materials such as gravel, sand-grit, geofabrics and organic reactive layers.

Lastly, Section 4 summarizes and collects the most important conclusive remarks regarding design and operation aspects obtained at Los Arenales demo-site [to be extended in the Technical Solutions (D13-3) report]; to finalise with references and a vast collection of annexes with most of the data-sets collected during the project.

2. INTRODUCTION

The MARSOL project aims at providing scientists, practitioners and end-users with an engineering-enabled set of technical solutions to improve Managed Aquifer Recharge (MAR) efficiency in areas where it is applied, and consequently, on general integrated water resources management and rural development.

This deliverable 5.3 intends to provide a set of methodological technical solutions to improve and enhance MAR activities at Los Arenales demo-site, the biggest living-lab in the project directly linked to irrigation purposes and agro-industry uses.

MARSOL keeps the usual bi-directional communication channel between the partners and end-users, who in general are farmers, associated in irrigation communities. This organizational structure enhances the social participation as a key source of inspiration to accomplish our envisaged tasks.

Regarding the demo-site, MAR activities began at Los Arenales aquifer in 2002 branded legally as “for National Common Good”. It was an initiative promoted by end-users through an appeal to Segovia province parliament member, which finally succeeded.

Building works were developed by the Ministry of Agriculture & Tragsa, as a pilot-scale experience under two premises (MAPA, 2005): avoiding pumping cost (passive system) and winter water surpluses use for MAR (intermittent system). After MAR activity started, the management and maintenance of the facilities were transferred to the irrigation communities, under two conditions: In the future, these farmer associations were obliged to maintain and clean the devices, and second, they should allow the Ministry of Agriculture and to their in-house service suppliers (such as Tragsa Group) to develop R&D activities to in order to test if the design might be extrapolated to analogous circumstances.

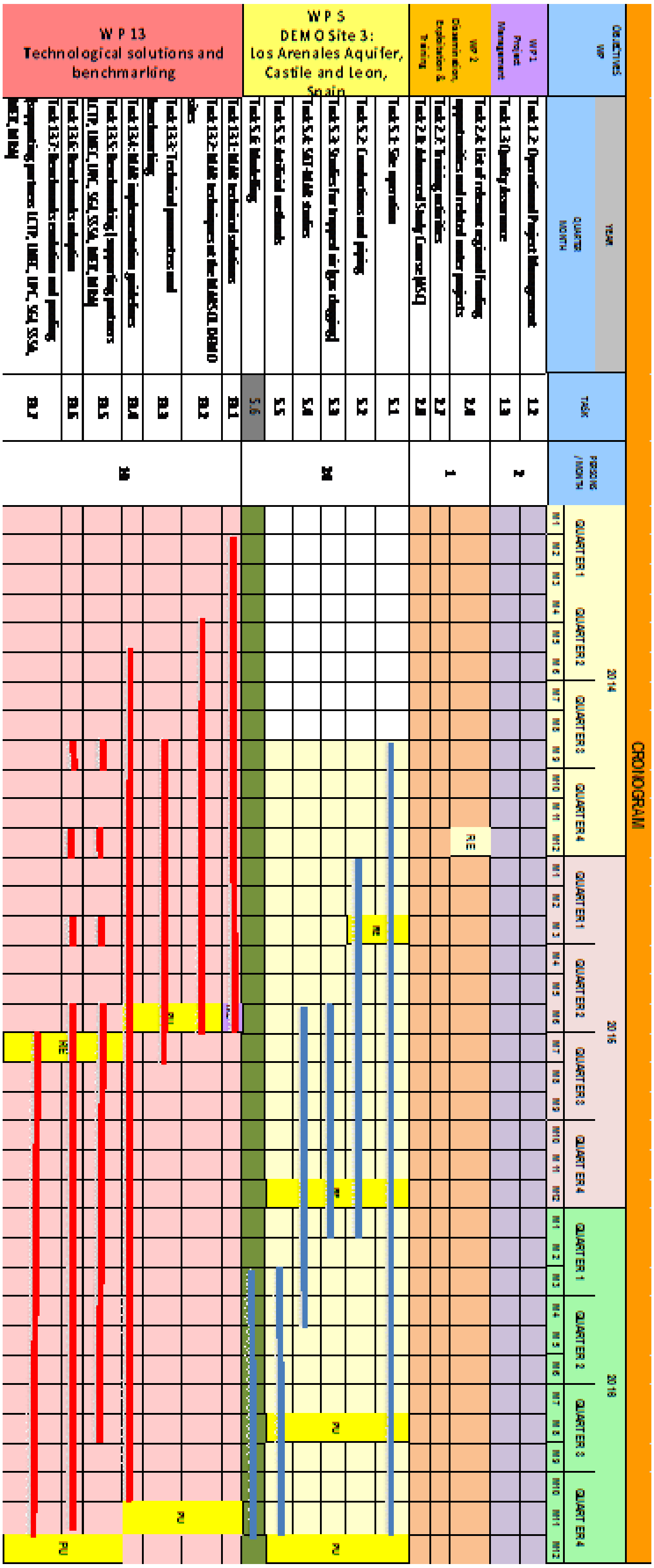
The present deliverable 5-3: “Appropriate MAR methodology and a tested know-how for general rural development”, according to the DoW, pg. 22-23, reports the base to develop further technical solutions related to design and operational advises (tested know-how). Most of the data-sets obtained along the project duration are enclosed in the final annexes in order to share this information with all the interested agents.

The exposition of the information and data sets relates, in special, to tasks 5.1 (site operation); task 5.2 (conductions and piping); task 5.3 (gas clogging) and task 5.4 (SAT-MAR studies).

The lines of action more related to the general rural development and artificial wetlands uses will be broadened in D5.4. Disinfection By Products (DBP) while clogging analyses are currently under development and data compilation and analysis are in progress yet. Specific rural development at Los Arenales demo-site directly linked to MAR applications since the activity began will be posted at deliverable 5.4 too.

The timetable keeps as programmed in the DoW, including the collaboration of Tragsatec staff, a branch of Tragsa Group whose official participation was requested in the first project amendment and finally approved. There are also important inputs from WP5 partners: LNEC and UPC.

Table 2-1: Proposed timetable for WP5 and other related WPs where Tragsa Group participates.



3. PRACTICAL IMPROVEMENTS FOR MAR TECHNIQUE ATTAINED AT LOS ARENALES DEMO SITE

Los Arenales demo-site is composed by three different MAR plants and each different task has been developed in the most appropriate.

Regarding studies on clogging (task 5-1 in DoW pg. 22) Santiuste basin has a broad scope of clogging processes, with the most complex distribution at Los Arenales, where the first study was conducted in 2009.

Physical assays have been developed in Santiuste Basin and Carracillo Council (task 5-1).

Talking about conductions and piping (task 5-2), the main tests have been carried out in Alcazarén Area, the most modern plant, where some little constructions proposed by MARSOL partners have been allowed by the local authorities and implemented.

The studies on trapped air (gas clogging, task 5-3) are conducted by means of the new ZNS (for Unsaturated Zone, "Zona No Saturada" in Spanish) stations, two of them are in Santiuste Basin and ZNS-3 in Carracillo S.E. (see MARSOL deliverable 5-1 to consult these stations´ designs).

Studies on SAT-MAR and artificial wetlands (tasks 5-4 and 5-5) are being performed in special in Santiuste and Carracillo.

This distribution has allowed choosing the best plant for each specific objective so that every task has its own site. There are also several conclusions obtained from the aggregation of the different results collected in separated areas.

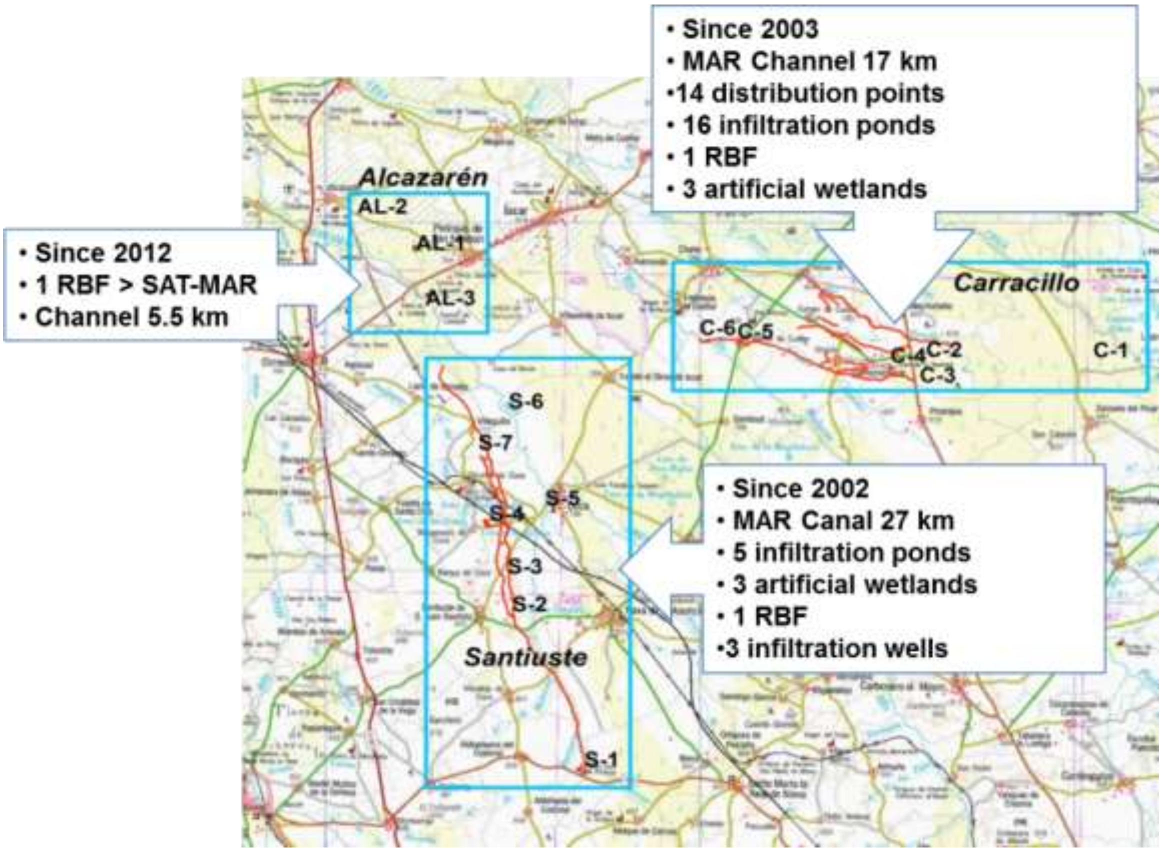


Figure 3-1: Los Arenales aquifer MAR systems position and devise of the facilities on the topographic map with a list of the main MAR components. Approximate scale: 1:150.000.

3.1 Physical analyses and assays

Most of the assays exposed in this paragraph are related to earth moving works, with especial attention paid to ditches and canals slopes, infiltration ponds morphology and all those parameters related to the design of MAR surface facilities.

Treatments applied to MAR receiving media in Santiuste Basin have included variations in the walls and bottom of the artificial recharge channels and ponds.

The actions carried out have mainly been by “trial and error” and have included changes of the morphology of the channel, by incorporating a small size “V”-shaped ditch in the centre of the bottom, or modifications of the slope of both sides of the channel.

This chapter explains the tests posed on, primarily, Santiuste Basin, regarding experiments ploughing the bottom of the infiltration pond with furrows separated at different distances and the results of the infiltration tests after some cycles of MAR.

A second test has been conducted in Carracillo regarding the differences at the bottom of an infiltration pond with and without vegetation.

Slopes stability has been studied, concluding in practical advises related to the most appropriate slopes for MAR canals and ponds, depending on their characteristics.

Finally, all these sections have been supplemented by actions in the bottom and walls of surface facilities so as to increase the infiltration rate and reduce clogging accumulation.

3.1.1 Furrows design recommendations at the bottom of the infiltration ponds

The morphology of the bottom of infiltration ponds is an important issue due to its significant direct effect on the infiltration rate. The main objective is to reduce clogging problems and try to maximize the seepage rate.

Previous studies (Peyton, 2002) affirm that furrows increase the infiltration rate when compared with flat-bottom basins, with higher values in the ridge of the mounds than at the bottom of them. Silts are deposited at the bottom of the furrows due to gravity while the ridges remaining higher up and relatively cleaned (Fernández & Martínez, 2012). Similarly, Dillon (2002) and Peyton (2002) claim that furrows can be used to minimize maintenance and enhance a permanent infiltration if this stroke is combined with wave action. Water levels may be varied to allow some portions of the ridges to dry periodically soany organic accumulation in the concave grooves can be eliminated.

PREVIOUS STAGES AND TESTS

At Los Arenales aquifer, the first infiltration tests were conducted during DINA-MAR research project, with a flat pond bed in 2007. The subsequent years’ tests (2008 and 2009) were conducted with furrows spacing distance of 60, 80 and 100 cm in different sectors. The range in furrow spacing was used to quantify the difference in the infiltration rate, allowing comparison also with non-ploughed pond bed. Double-ring infiltrometer observations were taken at the end of each following MAR cycle, showing that infiltration rates were generally higher on the furrow crests compared to the grooves and, in particular for furrows 80 cm spacing. More details from these studies in Fernández Escalante *et al.*, (2009).

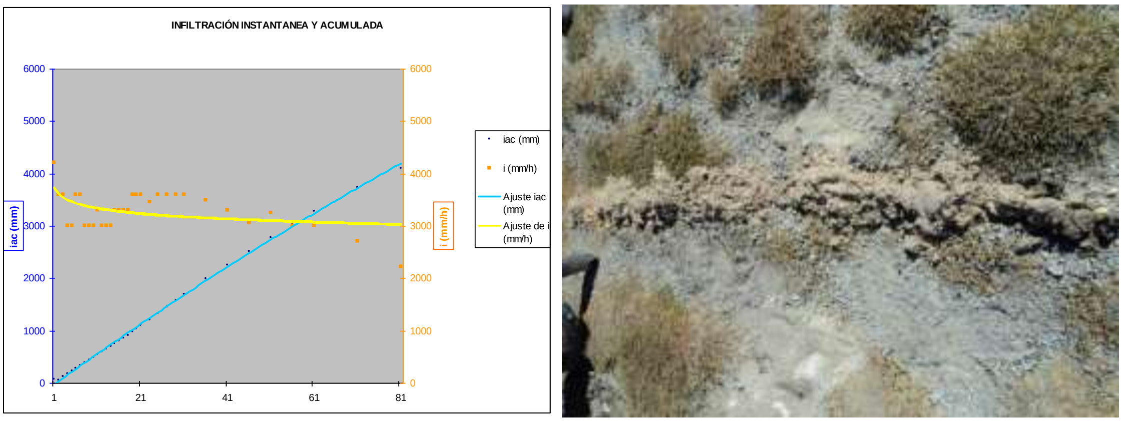
TESTS PERFORMED DURING MARSOL PROJECT

2014 CAMPAIGN

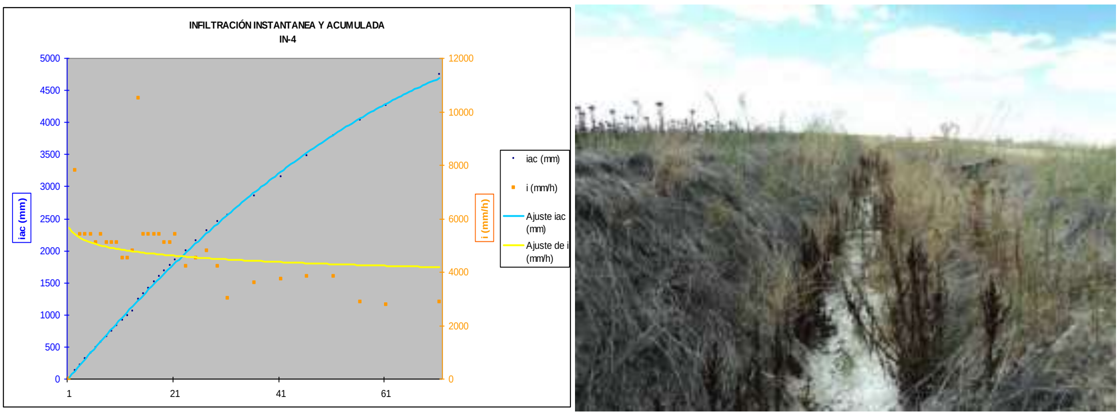
During MARSOL project, with the aim to continue this line of action, infiltration tests were performed from 2014 in two separate occasions. Firstly, new infiltration tests in ponds and canals were performed so as to determine the starting conditions to study the variations during the rest of the project. Secondly, new studies on infiltration ponds and canals morphology related to actions in their bottom (furrows design) were also done.

On 2014 September 10th, the infiltration devices conditions were tested. The results showed that compared to earlier 2009 campaign results, a general improvement or stabilization, at least in the infiltration rates, can be settled. The main cause is attributable to the Total Suspended Solids (TSS) reduction for the last 5 years.

The infiltration rates along time have scarcely varied, ranging around 3,000 mm/h in the pond and 2,500 in the canals, without any relevant clogging problems for this period. It could accordingly be concluded that maintaining current recharge conditions with the done degree of maintenance can guarantee long term infiltration capabilities.



Figures 3-2 a & b: Infiltration test chart for the pond analysis (a) and soil profile with the bottom at the left hand (b).



Figures 3-3 a & b: Infiltration rate test charting conducted at the MAR canal (a). Vegetated canal bed showing whitish crust (b).

In a second experience (2014 Sep. 29th) different furrows were practised in other sectors of the Santiuste Basin infiltration pond, preparing six allotments with a different furrow width (40, 60, 80, 100, 120 & 140 cm) apart from one plot of land ploughed with a “roman” ploughing tool. The furrows were wrought following the water stream direction. The distribution of these sectors appears in the scheme exposed in the figure 3-4. The highest infiltration rates were achieved in those furrows spaced 80 cm again.

Parcels with different furrows design
** cm: furrows width

Figure 3-4: Santiuste Basin´s head infiltration pond with seven parcels furrowed with a different width.

In 2015 the infiltration pond of Santiuste was ploughed with the same distribution than in 2014, in pursuance of preparing the surface for future tests.

2016 CAMPAIGN

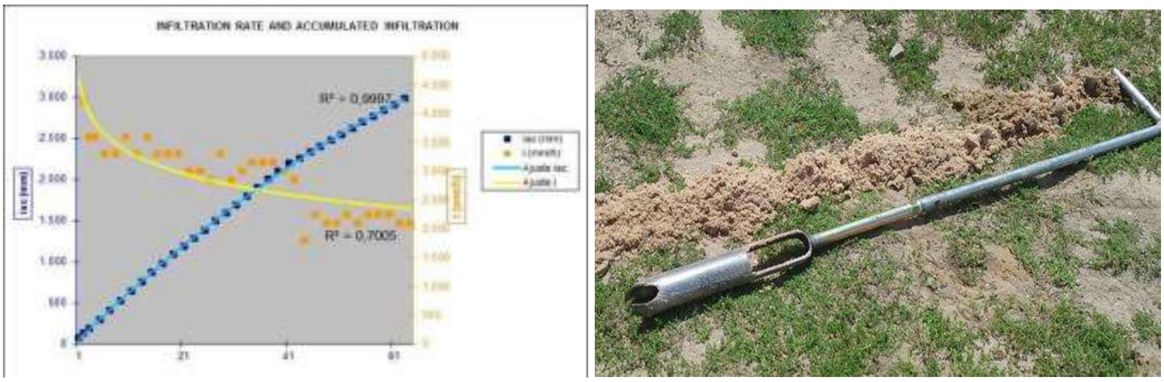
Infiltration tests were carried out again in July 2016, after the last recharge cycle finished. The aim was to confirm that furrows spaced at 80 cm provided the best results on seepage capacity. These physical analyses took place again in Santiuste at the head infiltration pond, in particular in the zone previously prepared in 2015.

After a thorough visual inspection, good conditions in the infiltration pond were observed. Despite some vegetal cover had grown on its bed, the pond still showed an evident sandy substrate compatible with a high infiltration rate. It should be noted that the pool was quite eroded, so that some furrows were less intense. Three ploughed areas were selected with furrow spacing at 40, 80 and 140 cm. In addition, a fourth test in a non-ploughed area was performed, in order to serve as a blank. After every test, a soil column was extracted using a hand drill to check the soil profile characteristics.

Figure 3-5: Location of Santiuste Basin head infiltration pond, where the infiltration tests have taken place.

The set of results have been enclosed as Annex III (Physical analyses. Infiltration test results). The main conclusions for the different spacing tests are described below:

Furrow width 40 cm



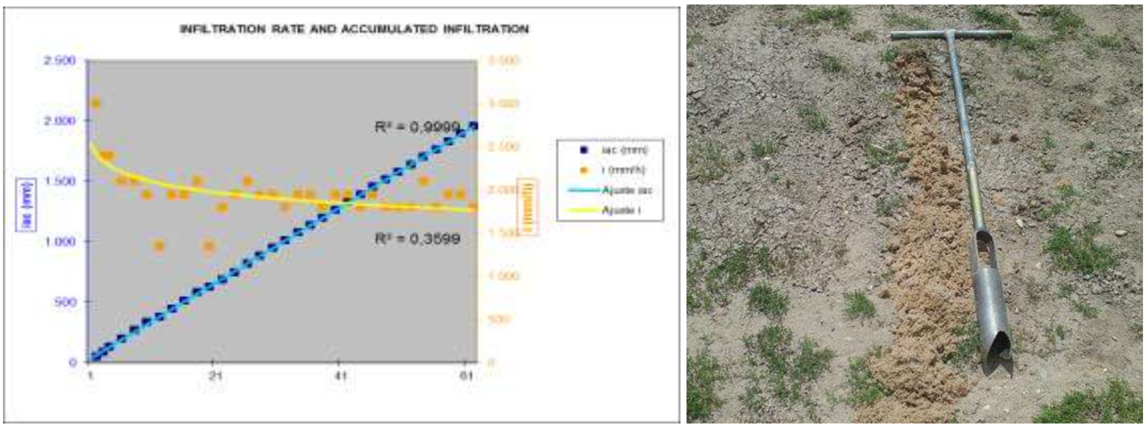
Figures 3-6 a & b: Infiltration test chart for the pond analysis furrowed 40 cm spacing (a) and soil profile with the bottom at the left hand (b).

As shown in the chart, infiltration rate gets steady and reaches the capillary infiltration level above 2,000 mm/h. After this assay, a column of a complete 1.5 m deep soil profile was obtained at the same spot (figure 3-6b).

From right to left, the superficial layer turns darker as it moistens as a result of its organic material composition. The rest of the sample remains as clean sand in regular conditions without clogging phenomena.

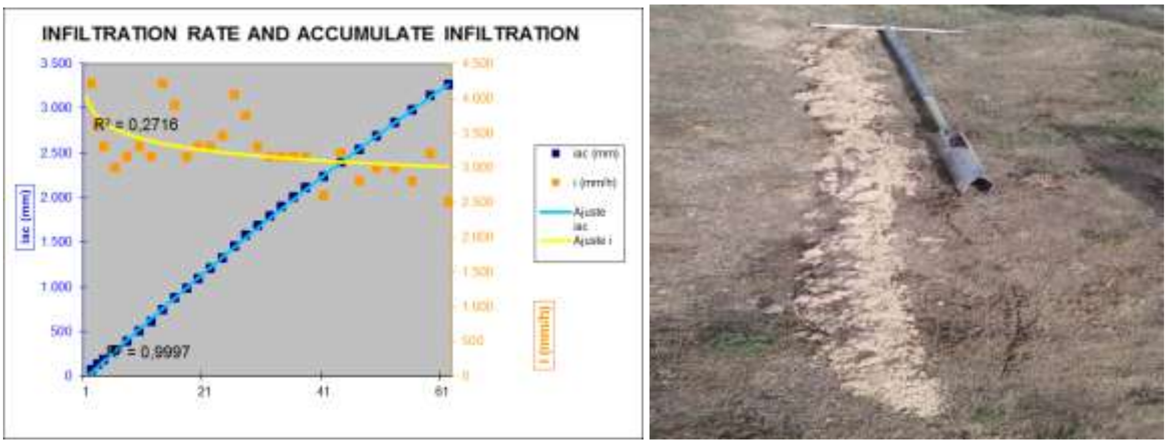
Furrow width 140 cm

This area has presented worse results; however its infiltration rate is perfectly compatible with sandy soils values and around 1,800 mm/h. It may be suggested that the distribution of sediments brought by MAR water may have been affected by the ploughing activity.



Figures 3-7 a & b: Infiltration test chart for the pond analysis furrowed 140 cm spacing (a) and soil profile with the top at the upper side (b).

Furrow width 80 cm



Figures 3-8 a & b: Infiltration test chart for the pond analysis furrowed 80 cm spacing (a) and soil profile with the top at the upper side (b).

Greater infiltration values were obtained in this area (over 2,500 mm/h). These results match with the previous experiments conducted in previous stages. The soil sample shows a steady column of sand with organic matter on the top of the soil, with clean sand 15 cm depth below.

Non-ploughed area

The last test performed in the pond revealed a lower infiltration rate value than ploughed areas (similar to the furrow of 140 cm). In general, capillary infiltration value was about 1,800 mm/h, a compatible result with the detected type of soil (sandy). Due to an electrical storm at the end of the assay, it was not possible to obtain a soil profile sample with a hand drill.

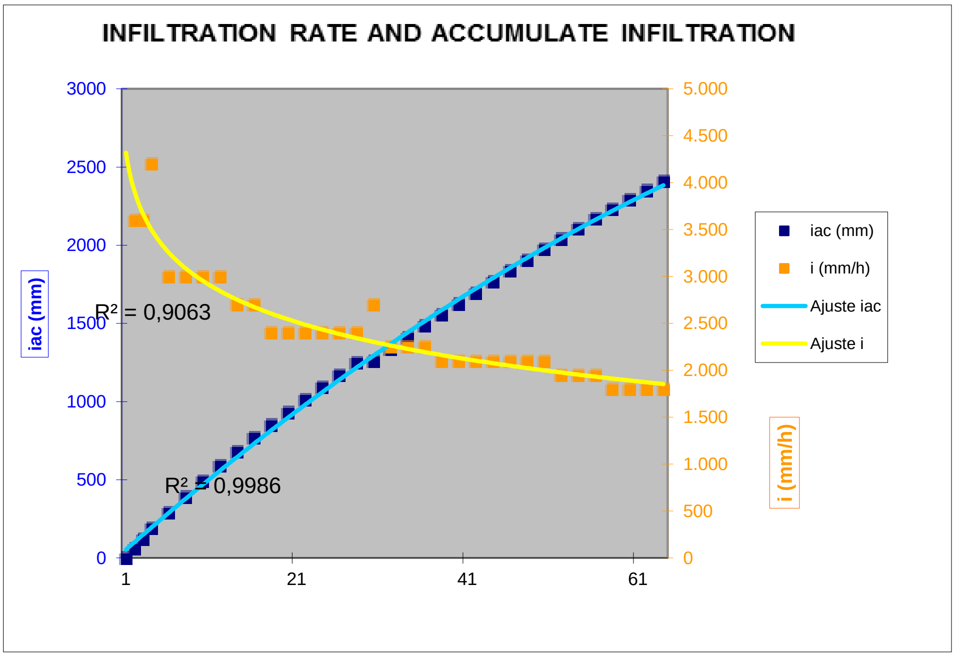


Figure 3-9: Infiltration test chart for the pond unaltered area.

CONCLUSIONS

The results of the infiltration tests carried out since 2008 have demonstrated that ploughing the bottom of these MAR ponds provide better infiltration rates values. The most appropriate furrow pattern was that for 80 cm spacing, repeated in three different occasions and always with the best results. These observations are consistent with the idea exposed by other authors in the first paragraph.

From a practical point of view, the disks ploughing tool is preferable to the mouldboard, due to the fact that the first one provokes a slighter pulverization rate in the superficial layer.

Figure 3-10: Tractor ploughing the surface of Santiuste Basin´s head infiltration pond.

3.1.2 Infiltration rate variations with the presence of vegetation in MAR structures

According to FAO (1975) sandy soils present a granular texture up to 50 cm deep and as a result, these soils retain few nutrients and have a low water retention capacity.

The influence of vegetation on water infiltration across a soil profile has largely been documented by several authors; for example, Dunne et al., (1991) noticed the effects of rainfall, vegetation and micro-topography on infiltration and runoff, and Jiménez et al. (2006) observed a relationship of dependency among them.

The presence of vegetation in the soil has a direct effect on the infiltration capacity in a vast variety of ways. The roots and their residues create macropores in the soil profile (Archer et al., 2002). Although water flows faster, the air trapped in the soil can easily go away (Jarrett and Hoover, 1985) favouring descending water circulation and drainage to lower horizons.

To some extent, the roots of trees and shrubs modify the topography of the medium, rising around the trunk and increasing cracks and other coarse pores in the receiving medium area. Under these conditions the trapped air can also escape easier to the atmosphere (Dixon and Peterson, 1971).

The elevation of the ground around the trees and the increase of coarser pores suggest an enormous influence of the micro-topography in the infiltration process (Dunne et al., 1991) as formerly discussed. For example, Johnson and Gordon (1988) indicate that the infiltration rate below bushes is greater than the measure with green cover or bare ground. This effect was also found in olive tree areas (Castro et al., 2006). In all cases, the area of influence is defined in terms of the canopy extent where trees and shrubs modify soil properties (Gile et al., 1998).

In order to evaluate the effect of the vegetation presence on the infiltration rate in the Los Arenales aquifer MAR plants, infiltration tests were done by means of a double-ring infiltrometer, controlling the initially added water volume and measuring the water layer evolution along the time until the infiltration rate was substantially constant.

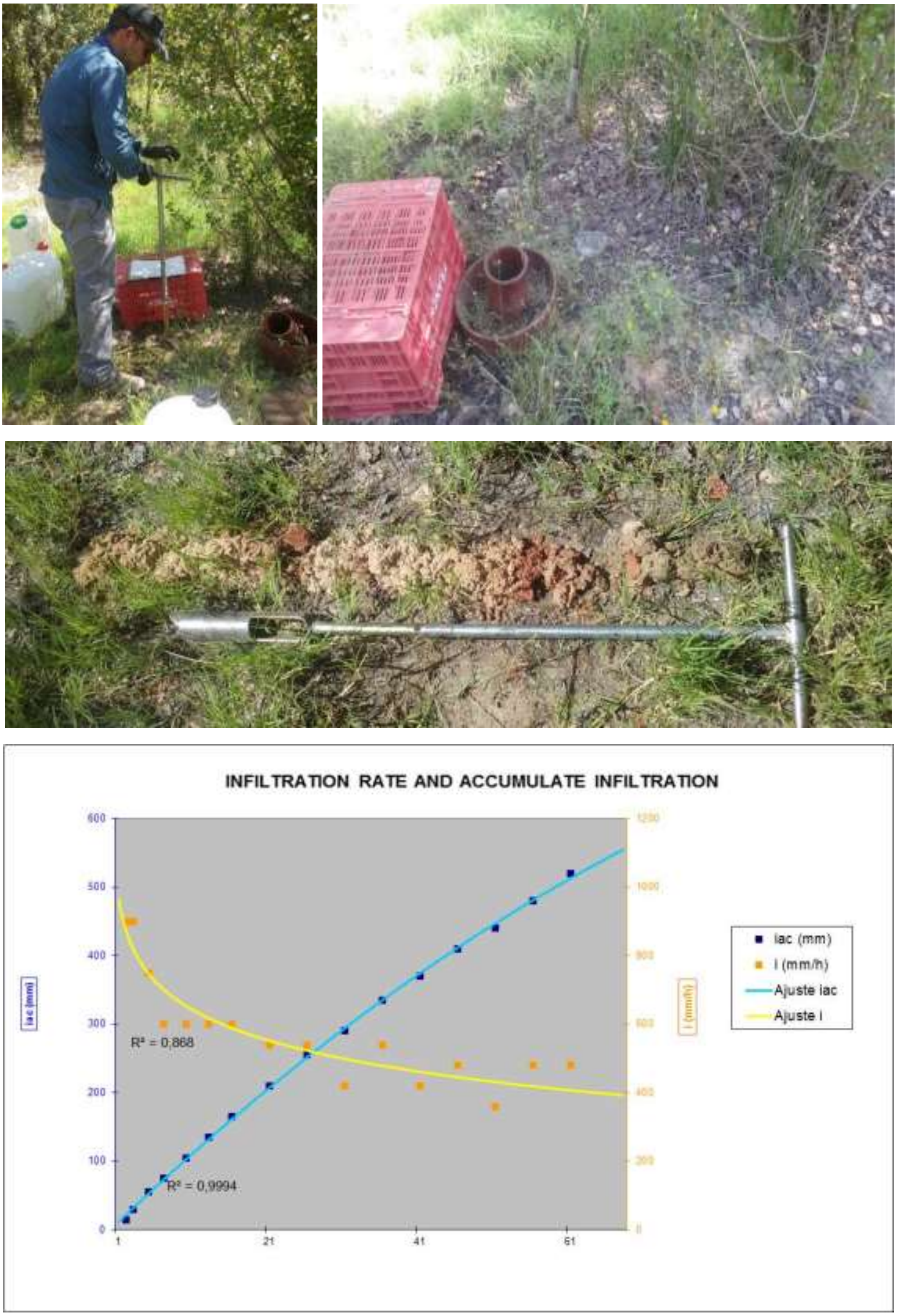
Figure 3-11: Location of Carracillo infiltration pond where the infiltration tests have taken place.

Some infiltration tests were performed in the Eastern infiltration pond of Carracillo Council during 2016 July 5th with the purpose of determining the influence of root development in the infiltration rate under two different environmental conditions: the first test was conducted in an area with visible roots of a birch tree (*Betula pendula)* and a second one in another area with absence of woody vegetation.

At the end of each test, two soil samplings were collected by a hand drill in order to examine the continuity of the soil profile and to make comparisons.

TEST 1: INFILTRATION WITH THE PRESENCE OF VEGETATION

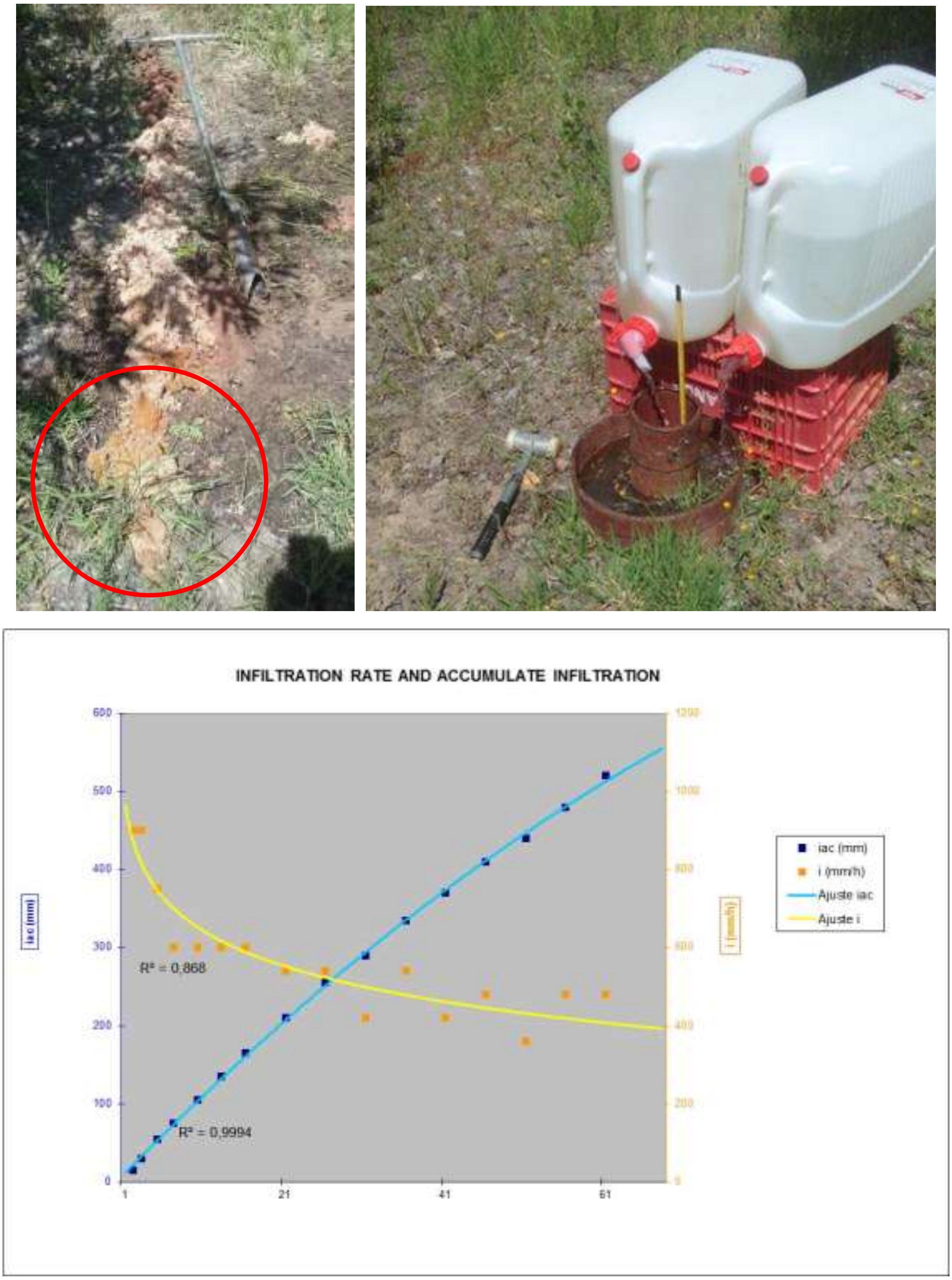
In this area a test was performed during 67 minutes (all the graphics from this paragraph are also in the Annex III to clarify the exposed information). As shown in the chart, infiltration rate gets steady and reaches the capillary infiltration level around 1,000 mm/h; results clearly greater than the ones in the area without vegetation. After this assay, a sample of a complete 1.5 m deep soil profile was obtained at the same spot by means of a hand drill. The soil sample presents a rich topsoil of organic matter. The presence of a woody species root system seems to affect positively the infiltration rate under equivalent types of soil.



Figures 3-12 a to d: Infiltration test (a-b), soil profile (top at the right side) (c), and result for the vegetated location (d).

TEST 2: INFILTRATION WITHOUT VEGETATION

In the second test was chosen an area without roots and away from the present trees canopy. The infiltration curve stabilized at values around 400 mm/h, which usually is reduced for sandy soils. In general, the presence of organic matter and detritus may be causing silting phenomena that affect infiltration negatively.



Figures 3-13 a to c: Infiltration test (a-b) and result for the non-vegetated location test (c).

The soil sample presented a surface horizon especially rich in organic matter and apparently affects the infiltration velocity adversely. In addition, a layer of construction works rubble was detected (red circle).

Infiltration tests results have been included in the Annex III b: Physical analyses. Carracillo Council. Changes in the infiltration rate in ponds with and without vegetation

CONCLUSIONS

According to the first results of this line of action, woody vegetation and the presence of roots improve soil infiltration capacity for the environmental conditions of the test performed at the Carracillo Eastern infiltration pond.

Concurring with the previously mentioned authors, the roots create macropores that favour the movement of water into deeper horizons, enhancing a greater infiltration rate.

These first tests open new activities and its further progress might be a key element in the operation and maintenance activities of any MAR scheme regarding to make decisions such as to leave or not to leave vegetation at the bottom of infiltration ponds, searching specific species which may have a high root development with low water consumption, specific cleaning periods, etc.

3.1.3 Slope stability tests in canals

The proper design for the infiltration channel slopes and its maintenance over time are vital issues for such devices´ efficiency. The uneven distribution of clogging processes along the channel slopes made necessary to modify the morphology of the canals, as well as design specific cleaning techniques adapted to the clogging usual distribution.

Hydrogeological references such as some of the Spanish Ministry of Agriculture recommend designs for MAR infiltration ponds in sandy aquifers with 1H:2V slopes and water layer thickness up to 2.5 m (MAPA, 1999b) and even up to 3 meters according to other sources (MIMAM, 2002). Nevertheless, no mentions have been found for the best infiltration canal slopes or designs in other sort of aquifers.

At Los Arenales aquifer, initially 1:1 slopes were selected for fine sands expecting a great durability and avoiding a tight clogging sedimentation due to their steeper angle. However, channel walls suffered some slumps (Figures 3-14) and this early design had to be modified to more stable patterns.

Figures 3-14: a & b. 1H/1V slope in MAR canals with potential slices due to desiccation processes (a); example for landslides impact in Santiuste MAR canal curves (b).

Channel slopes were modified to 2H:3V and after 3H:2V. The gentler slopes have increased the infiltration rate across the walls but also their clogging development, with eventual precipitation of carbonate lenses.

Slighter slopes designs are providing more stable results, with ultimate detachments by raindrop impact and erosion in high curvature external areas in the MAR channels. This fact drove to soft outlines in the path of the canals design.

It is worth noting that the channels of smaller width (2.8 m) have more landslides from both slopes than those ones with a greater width.

Figures 3-15 a & b: 2H/3V design (a); 3H/2V as the most common slope in the channels and ponds borders for Los Arenales environmental conditions (b).

The Irrigation Community of Santiuste Basin constructed a new canal in 2015. For the purpose of testing the stability of the channel slopes during MARSOL, the tests were carried out in this structure in the northern area where different slopes and widths could be tested.

Figures 3-16 a & b: New combined canal-pond construction where slope stability tests were done.

The materials (gabions, rip-rap…) were installed with a geotechnical containment function. Other types of activities experienced in this new in-channel modification were slope retention and correction of the acidity in the recharge water for water quality purposes.

Slope reinforcement activities in areas with higher risk of landslides present some pros and cons:

ADVANTAGES	DISADVANTAGES
Low cost materials	Structural breaks
Great drainage capacity	Wire nets can be corroded
Low maintenance requirements	Relatively large-size blocks or stones
Easy design and fast construction works	
Local materials can be used	
Ground adaptation capacity	

Materials often used in the reinforcement works are limestone, granite, quartzite or products from demolitions such as brick or concrete.

It is recommended adding a layer of filter material (thinner than 15 cm) in areas reinforced with gabions in order to improve drainage capacity through the holes between the blocks.

Figures 3-17 a to c. Mudstone gravel filter to induct pH corrections in MAR water as well as provide stability to some MAR facilities such as ponds (Santiuste, Los Arenales aquifer) (a & b). Protection gabions in the bottle neck between the MAR canal and a stopping device (c).

Bioengineering solutions become smart tools to apply in the fight against collapses. Some examples include replanting of gabions or of specific plantations with shrubs whose roots anchor the soil and have a containment effect.

3.1.4 Actions in the pond and pool walls to minimise clogging and to increase the seepage rate

Clogging management, and its consequent reduction in infiltration rates, is considered a severe impact and one of the most significant challenges in the operation of MAR plants. In general, a clogging layer is developed in the upper 0-15 centimetres of the infiltration surface (Platzer and Mauch, 1997), though this depends on the receiving medium and the quality of the recharge water.

Prevention is the best, and also the most cost effective way, to fight against clogging, because it will appear with complete security during the operational life of any MAR facility. There are various remediation and management technical solutions available for a smart sustainable operation of these schemes (see Martin, 2013).

The infiltration basins hydraulic capacity is primarily a function of the vertical hydraulic conductivity of the soils and the clogging layer development rate. Therefore, understanding clogging behaviour could lead to a better seepage rates and greater efficiency for any MAR scheme. To this end, this chapter studies new lines of action in the study of clogging processes, suggests a set of different actions to minimize clogging and enlarge infiltration rate in MAR surface facilities (ponds and channels).

WATER DEPTH

Bouwer and Rice (1984) already analysed the effect of water depth in groundwater recharge infiltration basins. It was found that increasing water layer thickness results in compression of the sediments and organic matter that cause clogging. Initially, increasing the water depth results in a temporary increase in infiltration rates very often; however it is followed by a reduction to rates lower than previously observed after compression succeeds. Conversely, shallow depths do not induce the necessary pressure to enhance the infiltration by the simple weight of the water layer.

Water depth also has a direct relation and impact on algal blooms so that they can greatly intensify clogging problems and provide another reason to maintain lower water depths. Solar incidence is the primary factor that limits algal growth. With greater water depth, exponential growing can occur and an algal bloom can be the primary reason for clogging.

During photosynthesis, the assimilation of carbon dioxide by algae raises the pH of the water. When algal mats are located on the basin surface, localized pH elevations can result in an additional calcium carbonate precipitation in the clogging layer.

Figures 3-18 a & b: Dark organic patches (a) and whitish crust on infiltration surface (b) at Santiuste MAR canal.

The most suitable level of the infiltration ponds water layer varies according to authors, e.g. lesser than 1.40 m (Custodio and Llamas, 1983), although depths lesser than 0.5 m (Bouwer, 2002) are not recommended. In Los Arenales aquifer water depth is maintained between 80 and 140 cm in the ponds and channels. The higher infiltration rates have occurred with depths of water near 80 cm in canals and 140 in ponds, and these have been adopted as a customary practice.

WET-DRY CYCLES

Wetting and drying cycles are an integral part of the operation of recharge basins. Drying cycles are necessary to stop the accumulation of clogging materials at the soil/water interface. During these cycles, the accumulated organic material tends to desiccate, shrink in size and separate from soil particles. In addition, the introduction of air provides aeration and the organic material may be biodegraded more effectively during the drying cycle. Dry organic material has a very low density and may also be dissipated by wind action. Long drying periods are necessary to drain the basins effectively and eliminate adverse impacts on the adjacent basins. In addition, drying cycles are valuable at aerating the soil and stimulating aerobic degradation of residual oxygen demanding materials.

Furthermore, wetting and drying cycles can result in cyclic anoxic/aerobic conditions in the vadose zone where nitrogen transformations and other redox-dependent microbial reactions occur.

The wetting-dry cycles slots vary depending on management factors. For example, in Tucson (Arizona) is often determined by the algal growth stages. When operators notice that the basins are turning green, flow directed at the basins is terminated and the basins are drained and dried before an algal bloom progresses.

At Los Arenales, in the specific case of Carracillo and Santiuste, the length of these cycles is conditioned by the River Basin Authority (CHD), that establishes a technical condition based on a minimum downstream E-flow to permit water diversion from Voltoya and Cega Rivers (respectively) during the wet season.

Figures 3-19 a & b: Biofilter in Carracillo Council´s "*triplet*" scheme.

SCRAPING

As clogging materials accumulate over time at the bottom and banks of infiltration basins, infiltration rates get reduced and the use of drying cycles alone is not sufficient to maintain those rates over long operational periods. Scraping off the clogging layer and removing the materials are being the most successful methods to extract clogging from surface. Depending on the amount of suspended solids, the cleaning and maintenance frequency must be increased or decreased.

When recharge water is used with a moderate suspended solids load (less than 10 mg/L), clogging materials must be removed over a 12 to 24 months operating period.

Devices used in the scraping of MAR facilities include front-end loaders, tractors with adapted accessories, etc.

At Los Arenales aquifer this activities are carried out in order to remove the surface layer or cake, which is replaced by clean sand. As a general rule, the frequency is yearly.

A study was conducted in the Republic of India at three artificial recharge sites in order to evaluate the infiltration rate improvement degree by scraping the upper soil materials (Sayed-Farjad & Rezai, 1999). Authors concluded that scraping the top sediment layer and 15 cm of topsoil could restore 68.3% of the initial infiltration capacity. It has been reaffirmed that cleaning is a very efficient activity to recover infiltration rates close to initial stages; however, this operative activity involves economic costs, so that it is necessary to ensure the economic viability of the scraping and a positive cost-benefit rate.

Figures 3-20 a & b: Cleaning and maintenance operations in ponds and canals by means of excavators (clogged sand is replaced by clean sand (a), and scarification by means of excavators with specifically adapted accessories (b).

OTHER ACTIONS

Other actions to avoid clogging and maximizing the seepage rate are the installation of geofabrics in the channel so as to trap the finest particles. This activity usually delays clogging problems at the bottom of the MAR canals and is considered in the design for Clogging Specific Control Protocols based on monitoring simple parameters.

CONCLUSIONS

Broad conclusions and lessons learnt about the three previous sections of physical analyses can be drawn. In the first section, an action that minimises clogging and increases the seepage rate is ploughing furrows at the bottom of the infiltration pond. These furrows also allow the deposit of silt in the grooves bottom by simple gravity, while remaining relatively clean along the crests.

In the second section, the influence of vegetation is discussed. The preliminary conclusion is that the presence of vegetation and the growth of roots within the filter helps to decompose organic matter and prevents clogging in vertical flow systems. At the same time, it helps increasing infiltration rates. The existence of deep larger diameter roots in shrub areas creates large open canaliculi at deeper soil depths, facilitating deep-water percolation (Archer et al., 2002). Allowing the growth of vegetation action in areas where roots perforate and break the clogging crust usually facilitates the deeper passage of water, reducing the amount of soil nutrients. This stroke could be carried out after each recharge cycle. The expense of water in vegetal growth seems to be affordable in comparison to the benefits of induced soil permeability.

The slope stability is treated in the third section. According to FAO (1975) sandy soils are often unstable and consequently they require moderate slopes in canals and ditches: 1:2 or 1:3, and low flow velocities. At Los Arenales aquifer, channel slopes were modified from 1:1 to 2V:3H and after to 3H:2V. Gabions reinforcements were applied in those areas with a high landslide risk.

3.2 Studies on clogging

Clogging is considered one of the major negative environmental impacts caused and affecting the 'artificial recharge' devices. Consequently, several experiments aimed at the study of clogging have been accomplished in Los Arenales demo-site.

Since 2010, research is specially being conducted on the detection and distribution of physical, chemical and biological clogging processes and their synergistic combinations by means of sampling in 34 stations and other direct operations already described in the methodology paragraph. These activities have led to a classification of these complex clogging processes:

On the one hand, clogging has been characterized as a complex process and five main types of clogging have been individualized in the MAR canals and ponds: Areas with physical clogging processes, biological and biophysical, chemical, physical-biological and mixed plus synergistic mixtures. There are many different combinations of all those previous ones as well.

On the other hand, Santiuste basin started its MAR activity in 2002, when the Spanish Ministry of Agriculture (MAPA) set up a groundwater quality monitoring network. Groundwater iso-contents cartographies have eventually been done and were available to conduct this line of action.

This chapter presents a brief exposition of the main clogging types detected and their distribution, as well as the relations between groundwater quality and clogging processes, looking for coherence in their spatial distribution by means of two different methods: iso-contents cartographies and multivariable statistical analyses.

3.2.1 Objectives

The chapter aims several goals, such as:

- To perform a new characterization of clogging processes at Los Arenales aquifer, in concrete at Santiuste basin, where MAR activities have been performed since 2002 and where the process has become very complex after 14 years of activity. It implies the elaboration of a specific map attending the generated physical, chemical and biological clogging vectors, plus their multiple combinations.
- To suggests a methodological proposal to correlate clogging and groundwater quality, based on two different approaches: the comparison between the clogging distribution and the groundwater quality cartographies (made from monitoring campaigns datasets collected in the area’s network); and also the study of correlations by means of multivariable geostatistical analyses and calculations.
- To convert the findings into practical conclusions in order to provide some specific guidelines to face the clogging impact in this aquifer and in analogous scenarios, with special dedication to pursue practical interventions *ad hoc* in order to reduce the clogging genesis. They include air entrainment, to increase the effectiveness of the facilities, and also recommendations for cleaning and maintenance operations up.

3.2.2 Demo-site background

Los Arenales groundwater body has an area of 2,400 km^2, with 96 villages in the provinces of Valladolid, Segovia and Ávila, with 46,000 inhabitants. MAR activities started in 2002, with a special development in three areas: Santiuste Basin, Carracillo Council and Alcazarén Area, with smaller isolated developments.

Santiuste basin's MAR activity started in 2002, as a response to the provisional declaration of over-exploitation of Los Arenales aquifer (Segovia, Spain). The Spanish Ministry of Agriculture (MAPA) reacted performing different MAR facilities and also setting up a groundwater quality monitoring network, whose results have allowed the mapping of several groundwater iso-contents cartographies.

The demo-site has become a living-lab for MARSOL project by means of the partner Tragsa, and new activities are constantly tested, especially at Santiuste basin, which has been considered the most suitable area at Los Arenales to perform this study, thanks to the vast variety of clogging types affecting canals and other MAR facilities. The topologic scheme for Santiuste with the main water resources management components and structure is displayed in the figure 3-21.

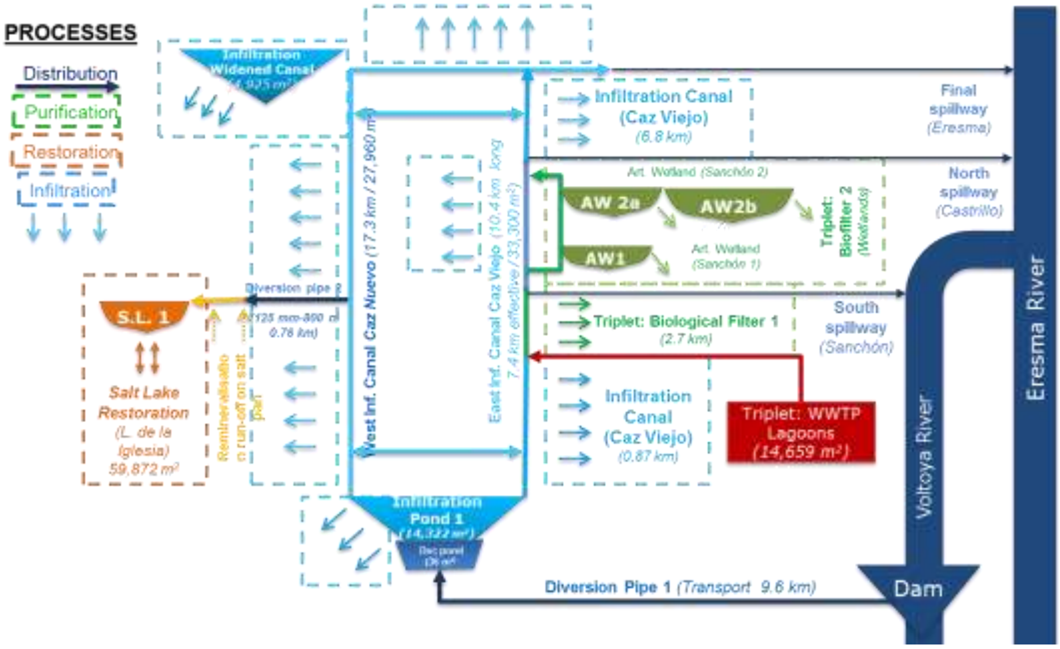


Figure 3-21: Operational sketch of Santiuste basin, the pioneer MAR plant at Los Arenales aquifer.

A detailed description of Santiuste basin can be found in deliverable 5-1 (MARSOL 2015a) as well as in the IAH MAR Commission "Clogging monograph" [Fernández-Escalante, 2013, in Martin R. (coordinator)].

3.2.3 Identification and distribution of the main clogging processes and their combinations

Identification of the dominant clogging mechanism affecting the MAR facility has been done through the characterization of physical, chemical and biological clogging processes and their synergistic combinations along Santiuste basin. The procedure consisted on the direct sampling in 34 stations combined with field work activities, such as visual inspection using magnifier and/or microscope, reaction to acid tests, bio-chemical analyses, radiometric images, photographs on-site and unstable physical parameters determinations, in special the Total Dissolved Oxygen (TDO). These data were determined by means of a pH meter (Hanna Instruments HI 9018) and a multiparametric meter with pH/ORP/EC/DO sensors (HI 9828) and through field titration.

According to the spatial distribution of key processes and combinations thereof, an initial mapping from the field work and the results of the 34 clogging sampling stations has been done, overlapping the clogging processes over the MAR facilities cartography (figure 3-23). There have been differentiated five main clogging processes varieties:

1. Areas with physical clogging processes
2. Biological and biophysics clogging processes
3. Chemical clogging processes
4. Physical-biological clogging processes
5. Mixed clogging processes

Figures 3-22 a to e: Physical clogging processes (a); biological and biophysics (b); chemical processes (carbonates) (c); vegetated canal bed showing whitish crust (d); physical-biological (e) and biological (filamentous algae colonies) (f) observed at Santiuste basin MAR ponds and canals.

Additionally, thermographic camera imagery has been implemented since 2010 for the detection and characterization of clogging processes. The Therma-Cam E2 (Flir systems) was employed to study the clogging distribution through temperature differences between clogged and non-clogged zones. These sectors show different thermal profiles when visualized. Background information is presented in Fernández and Prieto (2013) where is also displayed an initial clogging characterization cartography for the 2010 situation.

The next cartography displays some variations over time, also including series of photos and clogging profiles. The visual inspection has been a key to define the main processes affecting the infiltration capacity at the bottom of the MAR structures.

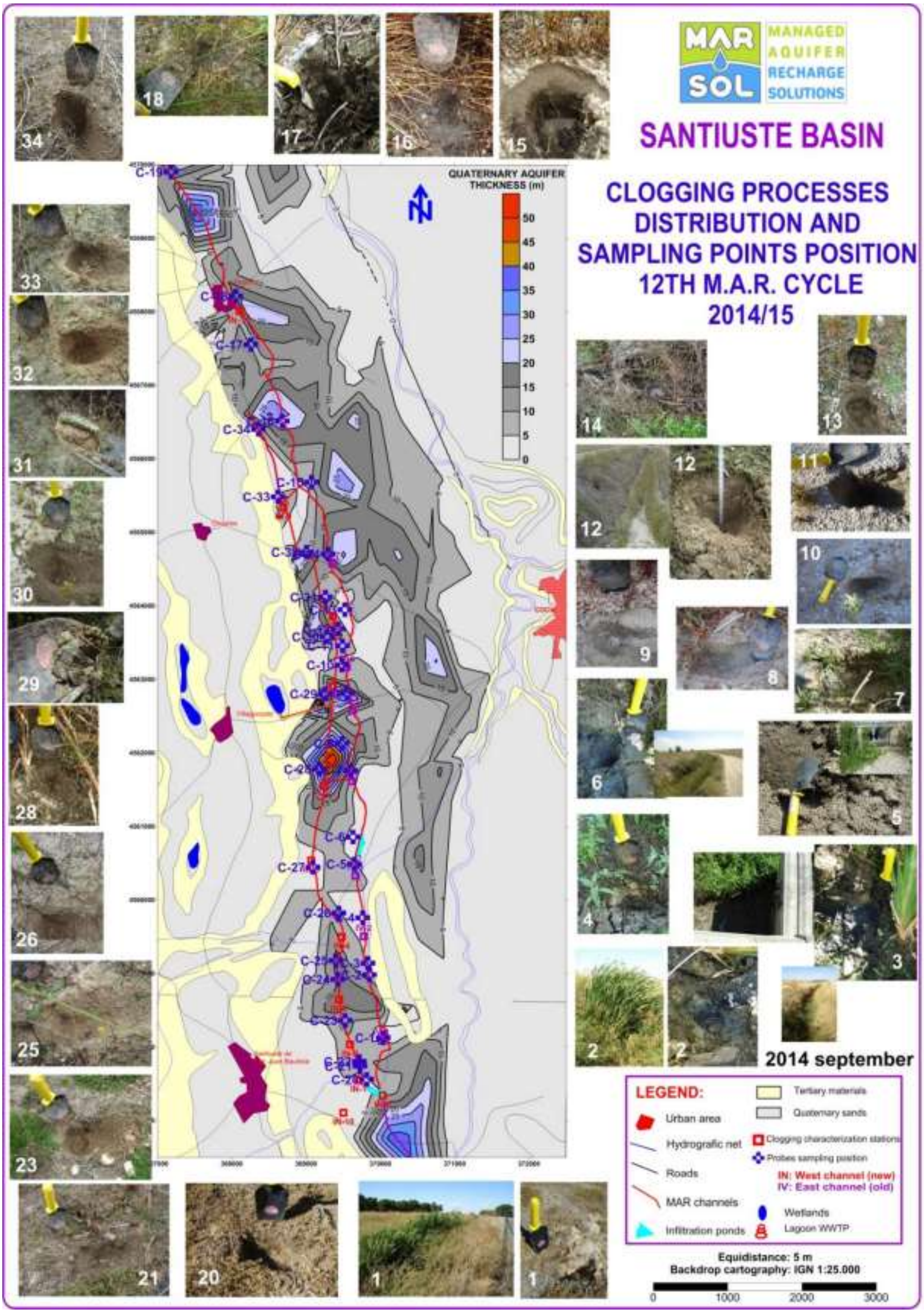


Figure 3-23: Network to study the clogging processes at Santiuste basin MAR system, and sampling/data collection for the situation of 2014 September.

3.2.4 Studies for trapped air (gas clogging)

Gas entrainment caused through cascading and turbulence can cause severe clogging through generating hyper-oxidizing conditions, and a significant blockage of the pores of the aquifer, triggering the "Lisse effect" (Krul and Liefrinck, 1946, Bouwer, 1999 and 2002). This effect is produced by the pressure of air entering the pores of the aquifer, so that trapped "bubbles" reach hydrostatic pressure exerting a centrifugal force contrary to the recharging path direction.

Unsaturated zone processes were monitored by means of remote sensing DINA-MAR ZNS stations; a combination of sensors built into telemonitoring stations installed next to MAR channels, wells and ponds recording changes for the unsaturated zone parameters (water table, humidity, temperature and capillary tension – connected to data-loggers). These stations provide accurate natural infiltration data to be complemented with water balance calculations. Sensors are placed crosswise to the artificial recharge channels. These methods allow the investigation of gas clogging "indirectly", allowing estimations rather than direct determinations and inviting to formulate their complex relations.

Air held in ground pores has been estimated through two different approaches:

- Studies on dissolved oxygen changes between MAR water and groundwater in sealed observation wells (with monitored seepage capacity evolution). In these cases Total Dissolved Oxygen (TDO) data were determined periodically with sensors mentioned in the previous paragraph.
- Studies on the evolution of the capillary tension in tensiometers installed in specific areas with known problems of gas clogging. The monitoring of the air inflow into the aquifer around the MAR infiltration channels and basins is accomplished with humidimeters, termometers y tensiometers at MARSOL ZNS stations (described in full detail in deliverable 5-1). The comparison of capillary tension values and changes of infiltration rate have led to valuable insights.

There is a third approach, that is the evolution of air trapped in the aquifer using the techniques of Blaxejewski (1979), with sequential infiltration testing during a complete MAR cycle utilising a specifically designed bench-ditch [(this task has been performed in previous stages and is described in the clogging monograph (Martin et al., 2013) and in MARSOL 2015a, deliverable 5-1, pg. 54)]. Not repeated in order to avoid redundancies.

DISSOLVED OXYGEN CONCENTRATION CHANGES BETWEEN MAR WATER AND GROUNDWATER IN CLOSED OBSERVATION WELLS

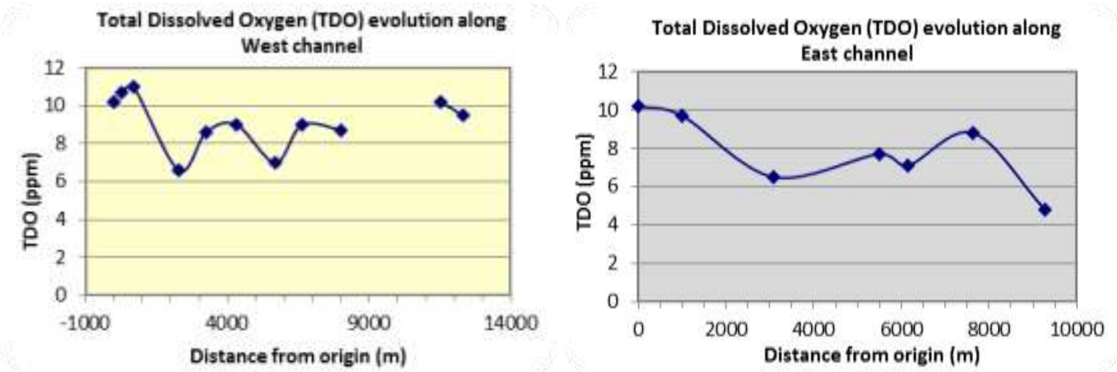
Measurements of the evolution of variable parameters along the infiltration channels have been conducted. Several parameters were controlled, paying especial attention on Total Dissolved Oxygen (TDO), with determinations shown in Tables 3-1. Sampling points are projected on Figure 3-29.

Tables 3-1 a) and b): TDO determined in observation wells close and hydraulically connected to Santiuste MAR canal stations. Last column shows the well-canal distances (m).

Station	X	Y	TDO (ppm)	Date
EA-0b	369833	4557404	10.5	22/01/2015
EA-2	369563	4558102	10.9	22/01/2015
EA-3b	369152	4560188	7.7	22/01/2015
EA-4b	369095	4560809	8.5	22/01/2015
EV-3b	369698	4560204	6.4	22/01/2015
EV-7b	368838	4565954	4.9	22/01/2015

RCH WELL	X	Y	Z	TOD (ppm)	date	Est. Well Dist. (m)
RCH 08-42	369776	4557346	801.5	5.4	01/03/2015	81
RCH 03-17	369370	4558001	806.0	3.63	01/03/2015	218
RCH 03-21	369113	4560186	794.0	3.70	01/03/2015	39
RCH 03-13	368889	4560820	790.4	4.25	01/03/2015	206
RCH 03-22	369855	4560210	793.6	4.38	01/03/2015	157
RCH 03-5	368902	4565953	776.6	3.33	01/03/2015	64

Figures 3-24 show the evolution of these parameters along the various infiltration channels.



Figures 3-24 a & b: TDO evolution representation along the MAR channels West (a) and East (b).

The dissolved oxygen content fluctuates between 6 to 11 ppm along the channel path. The oscillations accurately record changes in environmental conditions and external inputs. pH values fluctuate in the range of 6.8 to 7.5 (nearly neutral values).

The TDO decreases from 10.2 to 6.5 ppm at a distance of about 3 km from the inlet and then begins to rise to 7.7 at station EV-4. From station EV-4 to EV-5 there is a marked reducing environment and thus, another TDO reduction occurs. In EV-6 station TDO increases again (7.6) associated with runoff entering the channel, and at distance of about 9 km from the inlet, and oxygen concentration decreases to 4.8 ppm. The graphical representation of these values (figures 3-24) has allowed an equation of gas clogging deairation for the specific conditions of this area:

	Equation of the interpolated curve	R^2 value	∆ / D mean
O_2	$y = 0.0002\,x^2 - 0.0368\,x + 4.9704$	0.0866	42 µgr/l /m

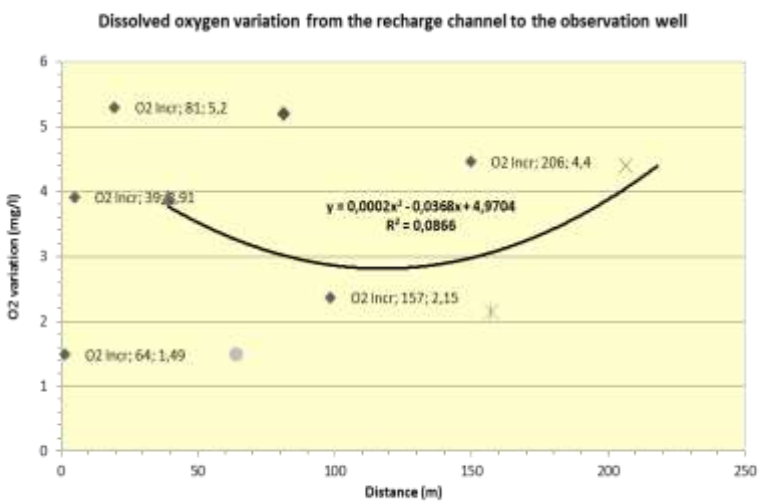


Figure 3-25: Representation of the Total Dissolved Oxygen (TDO) variation along the circuit between the recharge canal and the related observation wells.

STUDIES ON THE EVOLUTION OF THE CAPILLARY TENSION IN ZNS STATIONS´ TENSIOMETERS

The installation of tensiometers in the specifically designed data-collection stations close to MAR canals has been used as an indirect method to estimate the Lisse effect by means of the over pressure caused by the air trapped in the aquifer pores during its movement.

The collection of capillary tension data-sets has been complemented with simultaneous registers of soil moisture and temperature, in order to obtain the necessary data to check the degree of fitness of some conventional equations for the flow in the unsaturated zone under "hypercontroled" situations.

The data collection started in 2008 in a previous project called DINA-MAR. Since then, there has been a vast amount of information pointing out the strong relation between gas clogging and capillary tension in both, the unsaturated and the saturated zones.

The evolution of datasets in the different tensiometers and their relation with humidity and temperature has been represented in the set of graphics attached in Annex II. The main finding and conclusions are presented separately:

SANTIUSTE BASIN (ZNS 1 and 2 stations).

ZNS-1. Tensiometer 1.20 m.

Capillary stress presents trends posing a clear proportional relation with the increase of the soil moisture, attributable to the humidification bulb lateral expansion during the early stages of each recharge cycle. This proportionality is essentially patent with the growing trend for the second week of December, when the bulb reaches the deepest humidimeter-thermometer sensor, saturating it. During the previous days strong variations in humidity were registered which match the tension in an inverse proportional relation.

When the 2 m deep sensor enters saturation, the tensiometer displays an upward trend in about two units. Since then, there is a not very clear correlation with humidity registered at 0.5 m (upper-humidimeter-thermometer), while strong oscillations are recorded about the third month since each recharge cycle began, with maximum values close to 5 units above average (see figure 3-26 and annex II). The correlation with the temperature seems to be, generally, reverse.

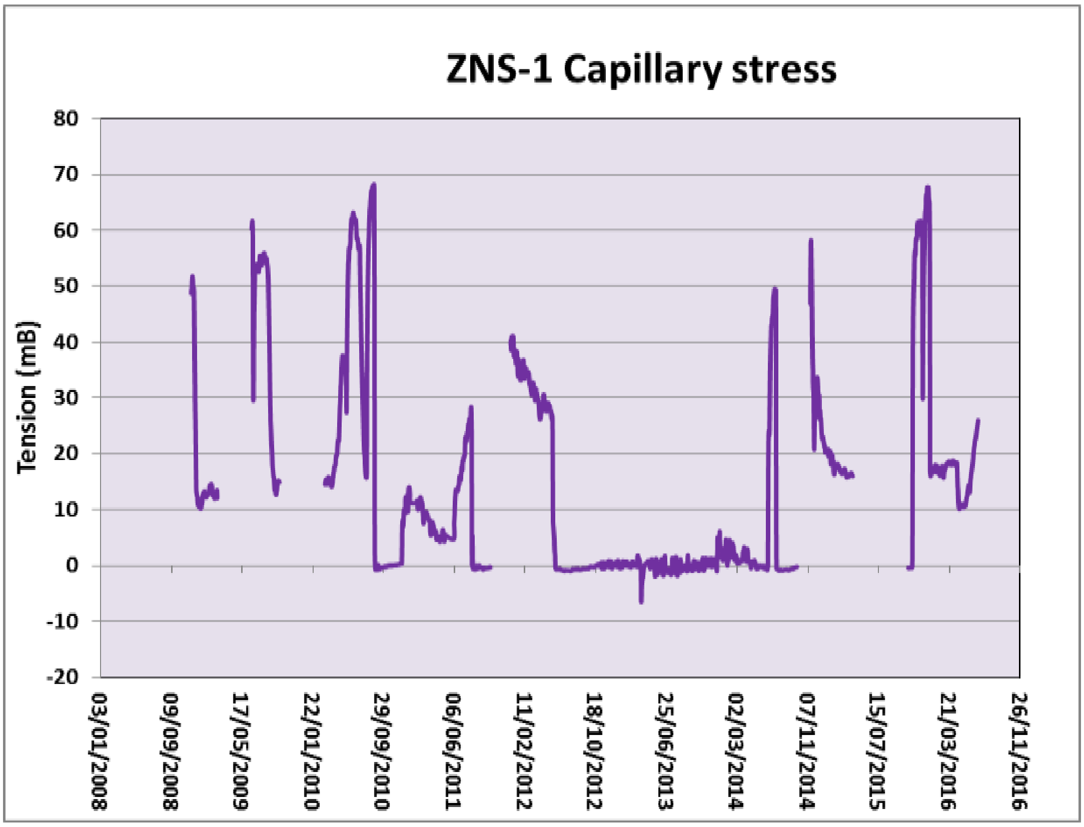


Figure 3-26: Capillary tension chart showing the evolution registered at MARSOL ZNS 1 Station between 2008 November and 2016 June. Sensor installed 1.2 m depth.

ZNS-2. Tensiometer 1.20 m.

Capillary stress presents trends that keep some proportionality with both, upper and lower humidimeters, although this relationship is not as clear as in the previous station (this station is next to the confluence of two infiltration canals, thus their environmental conditions are different).

The upper humidimeter-thermometer sensor was installed 1.1 m deep and has not entered into saturation, according to water level measures taken in an adjacent well used as a piezometer and located 5 m aside. In mid-December humidification bulb seems to rub the sensor and the channel seems to be entering in lateral control (there is a distance of about 10 meters between the channel and the deepest sensor and 12 m to the most shallow). The water level in the well has ranged around 1.15 m with respect to the mean ground level, and the resulting hydraulic gradient is 6%. Since then, tension tends to increase, with some oscillations related to groundwater level evolution.

Minimum values, registered almost at the end of the semester of each recharge cycle, present a direct proportional relationship with moisture, with clear trade-off values coinciding with periods without rainfall.

The advance of the humidification bulb has a horizontal expansion speed between 4 and 5 m/day in this sector, and the resulting calculated transmissivity is around the range 1,200-1,400 m^2/ day. Repeating the calculations between the channel and the well No. 49, the parameters are closer to the upper limit of this range.

Capillary stress presents downward trend coinciding with rainfall at the beginning of each recharge cycle (November-December). Then and for about three weeks (second fortnight of December and first week of January) capillary tension presents a valley.

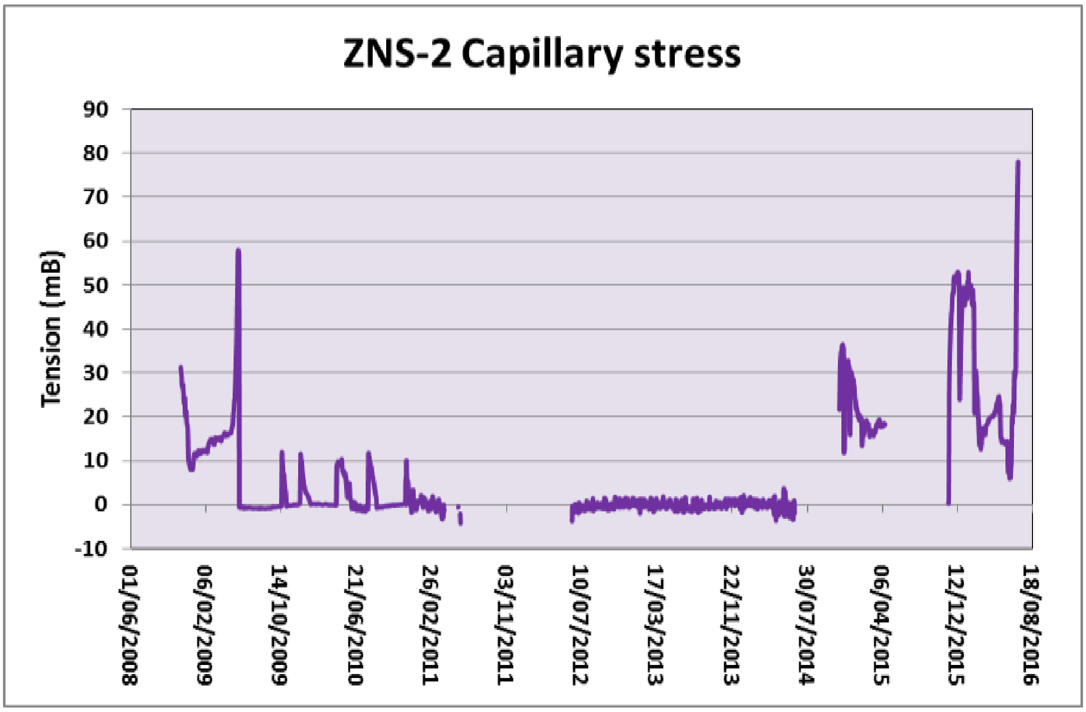


Figure 3-27: Capillary tension chart showing the evolution registered at MARSOL ZNS 2 Station between 2008 November and 2016 June. Sensor installed at 1.2 m depth.

The turning point comes to coincide with two days prior to the deepest humidimeter (2.0 m) is saturated. Before registering this water level increase, capillary tension poses high values, which could be attributable to the fact that the humidification bulb had reached the oscillation area (between 2.0 and 2.4 meters depth). In this case the water level rise does not cause a parallel rise in tension, but rather a capital letter "M" trend shape for a period of five to seven days. Since then the tendency grows up closely related to rain rebounds. Generally it is appreciated a descent drift in the capillary tension around two days after each rainfall episode occurs.

Capillary tension log is descending in those periods in which the generated humidification bulb reaches the lower sensor (humidimeter -thermometer 2,0 m deep). As the water level approaches the tensiometer, capillary stress proffers, in general, an upward trend which comes down suddenly. This fact leads to interpret a first approximation in which the arrival of the humidification bulb instigates an initial compression of the air trapped in the unsaturated area, followed by a strife (see figure 3-27 and annex II).

CARRACILLO COUNCIL (ZNS 3 Station) (1.10 m).

The capillary tension of the tensiometer located 1.10 m deep presents trends that keep a certain proportionality with both humidimeters, although this relationship is not as sharp as in the previous season.

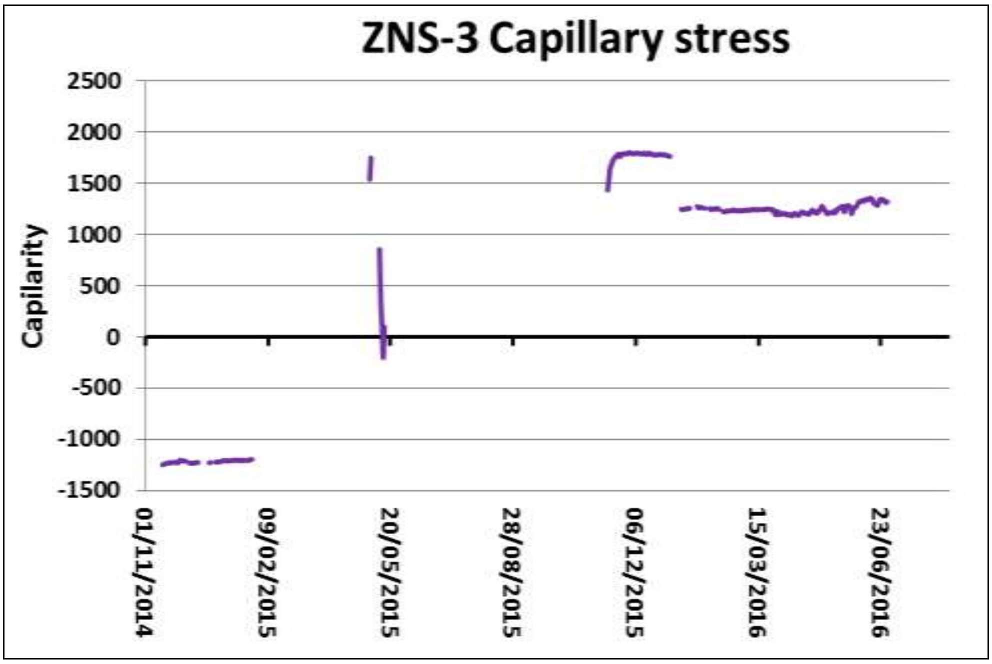


Figure 3-28: Capillary tension chart showing the evolution registered at MARSOL ZNS 3 Station between 2008 November and 2016 June. Sensor installed 1.5 m depth.

This sensor has not been entered in saturation at any moment to date. Piezometric levels sets collected in a nearby well (8 m) confirm it. From mid-December the humidification bulb seemed to touch the sensor, given that apparently the MAR canal had entered into lateral control (there is a distance of 10 metres between the channel and the deepest sensor and 12 m to the most shallow). In this period the water level in the observation well has ranged around 1.15 m with respect to the ground level and the resulting hydraulic gradient between the canal water sheet and the sensor is 6%.

Capillary tension registered at 1.0 m depth ceramic capsule presents downward trend, coinciding with the precipitation (in the shape of snow in this period). Then and for about three weeks (second fortnight of December and first week of January) the trend presented a concave trend. The turning point came to coincide with two days before the 2,0 m deep sensor entered into saturation. Before registering this increase, tension displayed a maximum value, attributable to the fact that humidification bulb had reached the area of oscillation (between 2.0 and 2.4 m deep), nevertheless the elevation of the groundwater level did not cause a rise in tension, but a capital letter "M" in the graph for five days. Since then the leaning is increased without rebounds.

The whole charting for the different data-sets collected in all the stations have been enclosed as Annex II: *(Datasets collection from ZNS stations*).

Once the relationship between the movement of the groundwater induced by managed aquifer recharge and the capillary tension has been granted, the intention of searching a mathematical relationship between the evolution of the humidification bulb and the capillary tension remains. According to the available results, each trend appears to be specific for each concrete case, and it does not seem easy to establish a general relation with the data-sets now available. In this way, it is necessary to complement observations with other related techniques, such as gas chambers sampling, probes, etc. maintaining active this line of action.

From the data obtained in these "hyper-controlled" situations, it is possible to adjust the previous hydrogeological parameters interval in these areas. It has been precised that the hydraulic gradient values ranges from 1 to 6%, permeability from1 to 4 m/day and transmissivity from 1,200 to 1,400 m^2/day.

The available data-sets have allowed conducting an additional experience, which has been to introduce the input data in the theoretical equations of Ernst and Kraijenhoff van de Leur (in Martinez, 1996; Fernandez & Senent, 2011).

$$h = s\frac{D_v}{K_l} + \frac{sL^2}{8KD} + sLW_r$$

Where:

- h: Input flow from the recharge canal to the unsaturated zone.
- s: specific discharge.
- Dv / D: thickness of the area with minor/major permeability values.
- K_{ll} / K: hydraulic conductivity of the extreme permeable layers.
- L: distance for the horizontal flow.
- W_r: radial resistance

The result of applying both equations for station ZNS-1 presents some divergence with on-site measures. In the case of Ernst, radial resistance obtained in the Ernst abacus is next to 5.50 d/m. If we consider Wr unknown, its magnitude can be estimated by clearing it in the equation and giving a directly measured value to h parameter. The final value obtained for this case has been 5.33 m/d. The vertical flow retrieved of applying the Kraijenhoff van of Leur equation is about 9.56 m/d, which is about the double of the horizontal permeability. Therefore, we can infer an "imprecise" setting of the theoretical equations of Ernst and Kraijenhoff van de Leur for these environmental conditions.

Regarding the estimation of air trapped in the aquifer and the Lisse effect, there have been observed small moisture declines prior to reach saturation in the humidimeters, with simultaneous ascents of capillary tension in the sensors located around 80 cm above in the vertical. This fact has been interpreted as the "drag" of air bubbles on the front of the humidification bulb.

After realizing that the humidification bulb profiles are oblique, it seems appropriate the drilling of deairation bores with an inclination parallel to the front of the moisture bulb (6%), although this test has not been tested to date, being delayed for latter phases.

3.2.5 Factors determining clogging growth and development. Geo-statistical analysis

The main procedure to check the relationship between clogging and groundwater quality has been the application of a multivariable geo-statistical analyses. The study of the variability has been done by a Probability Density Function (PDF) due to the fact that the system is considered to be variable rather than constant, and a sensitivity analysis to rank the possible effect of the different groundwater components in the different sorts of clogging.

PROBABILITY DENSITY FUNCTION (PDF)

When describing a P.D.F. (=PDF), the variable may take one of a range of values, each with a known probability of occurrence. Between the different methods available to fit a distribution to data, it has been applied the maximum likelihood estimation (Frey and Burmaster, 1999), method most widely used even in the present work. Moreover, this is the method used in the mathematical package @Risk™ (Palisade Corporation, Newfield, NY) for fitting distributions. Maximum likelihood estimation is used to find the parameter values for a distribution that maximize the probability of obtaining a particular set of data. In this case, the most abundant component relates with the different appearance of clogging processes. If several distributions are tested, the one with the highest likelihood will accordingly have the best fit (Westrell, 2004). The PDFs adjustment for component concentrations has been done by means of a log-normal distribution, according to several author´s recommendations (NHMRC–NRMMC, 2011; Petterson et al., 2006; Westrell, 2004). However, for some components and for the used data-sets, other distributions can be fitted adjusting to the given data better.

When using Probability Density Functions (PDFs) to describe the inputs, the final result (clogging process) will also be a PDF, and is calculated using a Monte Carlo simulation (Petterson et al., 2006). In Monte Carlo simulations one value is selected at random for every input PDF, thus creating one possible scenario. This is repeated 10,000 times and gives an output PDF.

Prior to any statistical analysis, it is necessary to examine the data in order to investigate their quality and to look for possible structures or patterns without performing any mathematical development about the structure of the observations.

When datasets fit a normal distribution, it is possible to use of methods based on either parametric confidence intervals or graphics methods.

The graphics are an essential tool to explore and to understand patterns in any data-set. The graphic representation of them provides additional information about their degree of adjustment to any formal statistical trend adjusted to a normal distribution (Singh and Nocerino, 2002). The development of graphics of normal probability and histograms allow information concerning the distribution of the data and their adjustment as a previous stage to accept a hypothesis of normality: accused bias, bimodality, isolated extreme values detection, etc. (Grima, 2016).

Many of the input variables have large statistical variability and uncertainties, thus, a sensitivity analysis provides hints on the effects of the input variables on the output assessed results (Frey and Patil, 2002; Zwietering and van Gerwen, 2000). It can therefore be a valuable tool to evaluate the events/phenomena guiding the clogging distribution; to assess the variables (groundwater components) that mainly determine the inaccuracy (or spread) in the effect estimation, and to identify uncertainties in which to pay a biggest effort in later studies.

The sensitivity analysis procedures used were based on methods described by van Gerwen (2000). The final component result for each clogging type and scenario needs to be initially calculated performing Monte Carlo simulations. Then, for the sensitivity analysis, the input parameters are assessed one by one by their interest held at its modal (or median for uniform PDFs) or at zero values, while leaving all other transformation process model and dose-response function parameters unchanged.

In order to evaluate the change in the risk output, the result obtained removing the factor/treatment, holding it at its modal, has been compared with the result obtained in the initial risk characterization. This comparison is performed by means of calculating the factor sensitivity (FS) for each component, using the worst-case sensitivity calculation (Zwietering and van Gerwen, 2000), dividing the new median (50th percentile) risk estimate by the initial median risk estimate with a log10 transformation:

$$FS = log10\ (new\ median\ risk\ /\ initial\ median\ risk)$$

High FS values indicate high sensitivity to variations, and show that changes of factors in process steps have profound effects on the final result. For a first analysis, every effect smaller than a factor of 10 (FS = 1) has been neglected, according to Zwietering and van Gerwen, 2000, in order to search for those factors mainly influencing the clogging distribution.

RESULTS AND DISCUSSION

Multi-variate statistics for macro-constituent hydrochemical analysis of groundwater sampled at control points along the MAR system network are presented as Table 1. They represent groundwater chemistry at less than 50 m depth (below ground level).

According to the methods explained in the previous paragraph, 34 detailed studies have been conducted in determined stations, providing an initial classification for the most often clogging process affecting each stretch of the MAR canals and infiltration ponds in Santiuste basin´s facilities. Five kinds of clogging have been established, in order to improve the existing range of clogging types mentioned in previous references (Fernández and Prieto, 2013). Those areas presenting a remarkable combination of processes of different origin have been included in the 5th class (mixed clogging processes), in order to simplify the calculations. The results of the clogging processes field campaigns (figures 3-23 and 3-29) are portrayed in the tables 3-2 for groundwater and 3-3.

Table 3-2: Groundwater analyses for the wells in the monitoring network which can be correlated with clogging types by their proximity. Preoperational stage. Position, depth of each well, clogging type: Areas with physical clogging processes (1); biological and biophysics clogging processes (2); chemical clogging processes (3); physical-biological clogging processes (4) leaving the mixed clogging processes. Values expressed in meq/l (r). Notice: Cationic Index (C.I.); Anionic Index (A.I.) and Bases Interchange Index (B.I.I.). Out of bounds (OOB). Position of the points in the map 3-29.

RCH	X	Y	Depth (m)	Clog type	EC (µS/cm)	pH	r Na	r K	r Ca	r Mg	r Cl	r HCO_3	r SO_4	r NO_3	r Na+K	r Ca+Mg	C.I.	A.I.	B.I.I.
rch-1	366002	4571760	7	OOB	975	7.20	1.96	0.18	2.89	4.69	1.21	5.77	2.17	1.42	2.14	7.58	0.282	0.586	6.762
rch-2	366758	4569620	9.1	OOB	748	8.00	0.70	0.20	2.59	4.03	1.47	3.28	1.29	1.61	0.90	6.63	0.136	0.841	5.329
rch-3	367488	4568356	30	3	1310	7.90	2.26	0.13	4.94	7.40	2.62	5.77	3.33	2.89	2.39	12.34	0.194	1.032	8.726
rch-4	369959	4567090	37	OOB	1396	8.00	1.57	0.15	9.08	4.94	2.82	5.39	2.46	3.68	1.72	14.02	0.123	0.979	9.518
rch-5	369306	4566315	20.6	4	1486	7.40	4.35	0.43	7.53	5.43	1.30	5.33	3.50	4.37	4.78	12.96	0.369	0.900	8.700
rch-6	369753	4567100	150	Depth	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
rch-7	369313	4562496	n/a	2	1096	8.20	2.44	0.20	2.84	6.91	1.72	6.26	2.50	1.69	2.64	9.75	0.271	0.674	7.586
rch-8	367302	4565377	4.05	OOB	2210	8.10	4.61	2.97	5.09	13.66	4.91	9.31	9.22	1.87	7.58	18.75	0.404	1.518	10.890
rch-9	368918	4564508	30	1	1488	8.40	3.70	0.31	4.89	10.28	3.13	6.16	4.93	2.11	4.00	15.17	0.264	1.309	8.098
rch-10	370783	4562750	28	OOB	592	7.8	1.09	0.08	2.69	2.14	0.65	3.16	1.62	0.73	1.16	4.83	0.241	0.719	3.571
rch-11	369313	4562496	30	1	1729	8.00	4.22	0.41	6.74	8.31	3.89	5.44	4.73	4.89	4.63	15.05	0.308	1.584	10.172
rch-12	369254	4561547	30	1	1535	8.60	3.09	1.30	2.45	7.40	2.74	5.59	3.89	3.95	4.39	9.85	0.446	1.186	9.115
rch-13	369291	4560515	9.7	4	1437	7.90	3.44	0.10	6.99	4.94	3.44	5.20	3.08	3.00	3.54	11.92	0.297	1.255	8.164
rch-14	369033	4559716	14.2	1	1389	8.00	3.74	0.92	1.90	9.46	3.53	9.08	2.67	1.13	4.66	11.36	0.410	0.682	9.782
rch-15	369209	4558512	11.2	1	1414	7.80	3.35	0.26	4.34	8.80	2.82	5.80	2.37	3.76	3.61	13.14	0.274	0.895	9.229
rch-16	369339	4558514	20	1	1147	7.80	3.83	0.49	5.59	2.96	1.86	5.57	2.48	2.08	4.31	8.55	0.505	0.779	6.663
rch-17	369837	4557330	17	1	932	8.10	1.74	0.13	4.29	4.20	1.61	6.75	1.15	0.47	1.87	8.49	0.220	0.408	6.993
rch-18	368902	4557236	9	OOB	1063	8.00	2.13	0.20	5.14	4.28	2.68	6.08	1.56	0.87	2.34	9.42	0.248	0.698	7.171
rch-19	370606	4556014	13.9	OOB	456	7.50	0.52	0.05	2.74	0.58	0.56	1.84	0.65	1.27	0.57	3.32	0.173	0.659	3.096
rch-20	368002	4555865	10.2	OOB	734	8.10	2.00	0.10	2.35	2.71	1.83	4.97	0.85	0.39	2.10	5.06	0.416	0.541	5.037
rch-21	369545	4559797	20	2	1119	7.80	3.57	0.08	4.49	4.36	2.14	6.59	2.04	1.06	3.64	8.85	0.412	0.635	6.918
rch-22	370391	4559822	150	Depth	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
rch-23	368631	4559366	400	Depth	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
rch-24	368537	4556643	0	OOB	829	7.80	1.65	0.10	5.09	1.81	1.35	4.95	0.56	1.66	1.76	6.90	0.254	0.387	5.897
rch-25	370648	4560956	20.9	OOB	727	8.10	2.61	0.15	2.00	1.97	1.69	3.13	2.64	0.05	2.76	3.97	0.696	1.385	2.774

Table 3-3: Clogging characterization. New properties pit profiles and determination of major clogging processes detected in the current clogging network stations, 2015 September. Situation of the stations placed in the map 3-29.

tation	Initial Station	Date	x	y	z	Main clogging process	Observations
C-1	IV-1	03-09-14	370007	4558001	799	Physical	Cake and physical
C-2		03-09-14	369842	4558835	797	Biological	Biological
C-3		03-09-14	369825	4558988	793	Biological and physical	Biological and physical by layers (*lemnas*)
C-4	IV-2	03-09-14	369768	4559590	790	Biological and physical	Sludges, *lemnas*
C-5	IV-3	03-09-14	369672	4560300	788	Biological	Organic matter and *lemnas*
C-6		03-09-14	369660	4560657	785	Biological and physical	*Lemnas*, banded profile
C-7	IV-4	03-09-14	369647	4561534	781	Physical, chemical and biological	Banded profile: physical, clear sand soil and biological. Carbonate and OM clods
C-8		03-09-14	369540	4561893	785	Physical, chemical and biological	Banded profile: clear sand + carbonates, OM clods
C-9	IV-5	03-09-14	369619	4562553	800	Biological, physical & chemical	Banded profile: “Rubens” seeds + clear sand + carbonates, OM clods, physical (grey colour)
C-10	IV-6	03-09-14	369556	4562927	792	Physical, biological and chemical	Cake, OM and carbonates. Un-banded profile
C-11		03-09-14	369570	4563181	790	Physical, biological and chemical	Cake, OM and carbonates and gravel. Un-banded profile
C-12	IN-8	29-09-14	369517	4563406	781	Physical	Banded profile: cake, physical and gravel.
C-13		29-09-14	369609	4563658	781	Physical	Banded profile: Cake, physical and gravel
C-14	IV-7	29-09-14	369403	4564395	781	Physical-biological	Horizon A (with clay and OM). Reduction conditions
C-15		29-09-14	369206	4565346	781	Biological-physical	Banded profile: biological, clear sand, OM, physical, OM
C-16		29-09-14	368837	4566159	781	Physical, chemical and biological	Cake, carbonates, OM
C-17		29-09-14	368446	4567175	772	Biological and chemical	Biological film, carbonates and OM
C-18	IN-11	29-09-14	368261	4567819	770	Chemical –biological & physical	Banded layer: ash-grey-black layer, carbonates, OM clods
C-19		29-09-14	367445	4569472	762		
C-20	IN-1	03-09-14	369781	4557457	769	Physical	Ash-colored layer
C-21		03-09-14	369696	4557634	806	Biological-physical	Physical, vectors and OM
C-22	IN-2	29-09-13	369687	4557696	795	Biophysical	“Crust”

Station	Initial Station	Date	x	y	z	Main clogging process	Observations
C-23	IN-3	29-09-14	369514	4558239	793	Biophysical	"Crust"
C-24	IN-3	29-09-14	369427	4558783	789		
C-25		29-09-14	369405	4559032	791	Physical	Gravel and cream-colored banded
C-26	IN-4	29-09-14	369457	4559658	789	Biophysical	OM clods, banded with white and cream-colored layers
C-27	IN-5	29-09-14	369131	4560267	789	Biophysical	
C-28	IN-6	29-09-14	369236	4561562	789	Biological-physical Biophysical?	Tangle of weed, clay and gravel, OM.
C-29	IN-7	29-09-14	369331	4562551	786	Biophysical Chemical?	Filamentous algae. Clay and gravel.
C-30		29-09-14	369372	4563306	784	Biophysical Chemical?	Filamentous algae. Banded layers
C-31		29-09-14	369359	4563828	780	Biological film-physical	Biological film. Clear sand, dark banded layer at 8cm depth.
C-32		29-09-14	369123	4564426	778	Biological film-physical	Biological film. Clear sand, dark banded layer at 8cm depth.
C-33	IN-9	29-09-14	368764	4565163	779	Biological & physical	Biological ("green") film. Alternative dark-clear layers
C-34		29-09-14	368524	4566058	773	Biophysical & chemical	Carbonates?

According to the spatial distribution of the key processes and combinations thereof, an initial mapping for characterization of clogging types, updating the scheme commenced in 2009 March situation (Fernández Escalante, in Martin R., 2013) and was upgraded four years later (in Fernández and Prieto, 2013). This new mapping presents more accurate contacts and new combinations of clogging, in order to monitor the general evolution of the system and to propose measures, what thus represents a DSS for the cleaning and preservation stages.

Figure 3-29 represents the new clogging processes distribution along Santiuste basin. There are some modifications with respect to the previous referenced characterizations, due to the fact that, as a general rule, the process is becoming more complicated and new clogging combinations are appearing in the field. The entrance of sand adhered to the bottom of the canals is causing banded profiles while previously the combinations were more simplistic below the surface cake. The alternation of dark and clear lenses is making the process more and more complex too.

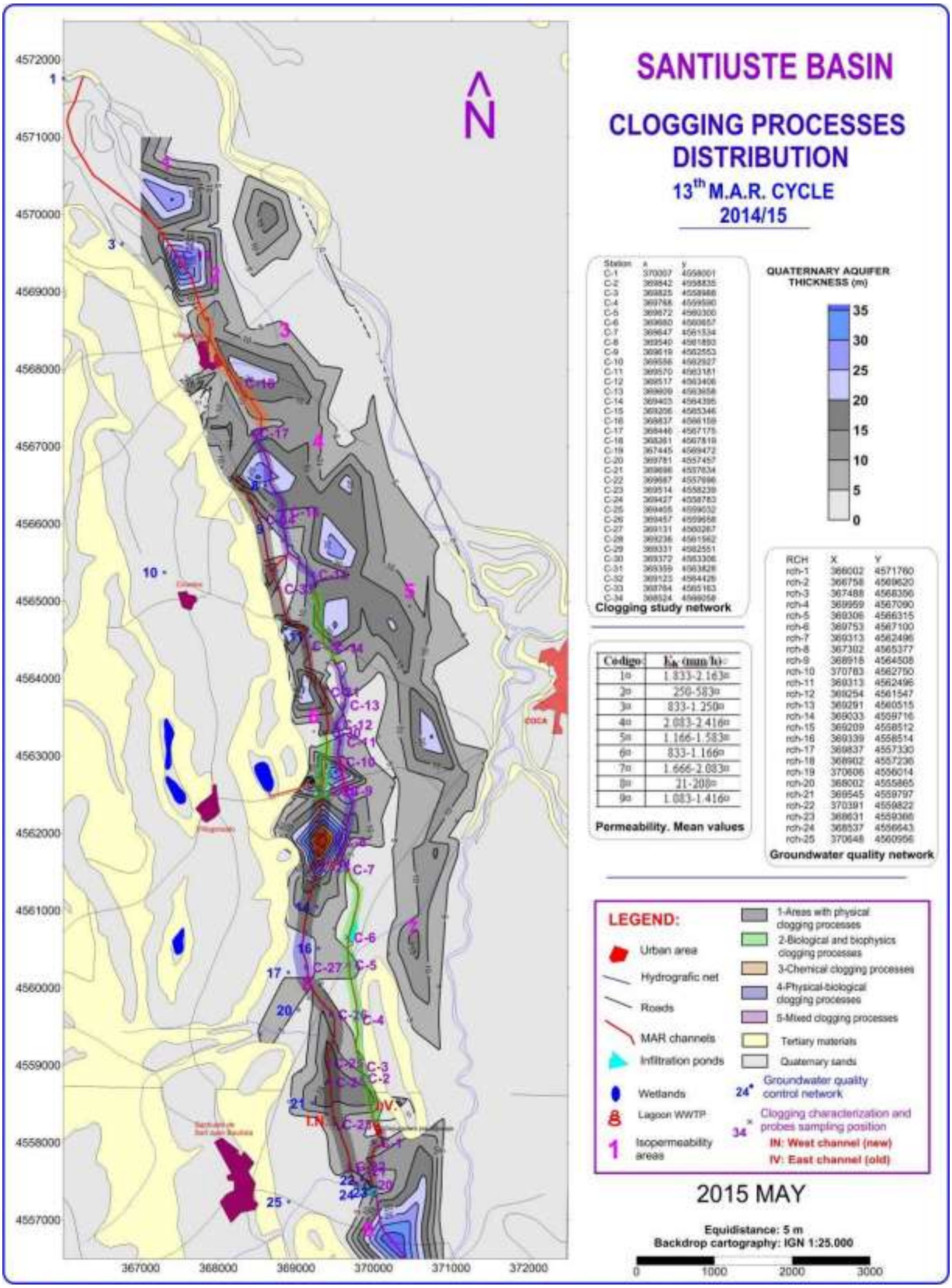


Figure 3-29: Cartography for Santiuste basin MAR devices and clogging processes distribution according to their nature for May 2015 situation. The map also exposes geological facies, the position of clogging stations, groundwater quality network, permeability distribution in the area and other singular elements. Graphic scale (Modified from MARSOL, 2015a).

3.2.6 Cartographies of distribution in the demo-site

Once characterized the clogging distribution in the area according to the presence of major processes, the next stage has been the comparison between stretches of certain clogging processes and the groundwater cartographies in the area, firstly attending to the groundwater quality in the preoperational phase.

The wells from the water quality network as near of the canal to be considered representative are posed in the table 3-2.

The relation between the different types of clogging and the groundwater composition has been based in the data sets obtained from the Spanish Ministry of Agriculture studies, the collection of datasets in the thesis of the first author performed in 2004 and new groundwater quality inputs published in the deliverables of DINA-MAR project until 2010. The groundwater quality cartographies selected to achieve the objectives have been eight, corresponding to the pre-operational situation (2002), when the MAR activity started in the area (taken from Fernández-Escalante, 2005). Other cartographies have been checked to test the congruency of the results. The procedure has been simply overlapping both cartographies (clogging processes and groundwater iso-contents):

1. Iso-bicarbonate
2. Iso-sulphates
3. Iso-chlorides
4. Iso-sodium+potassium
5. Iso-calcium+magnesium
6. Iso-nitrates
7. Iso-electrical conductivity

These cartographies and the clogging distribution have been paired in order to allow an easy comparison (pairs enclosed as annex I, paragraph 6-1-1). The overlapping and appraisal of each couple have provided some preliminary results about the congruency in the distribution of the clogging and the different existing isocontents in groundwater when MAR activity began in this area.

According to the exposed methodology, a Multivariable Geo-statistical Analysis (MGA) has been conducted. The statistical treatment representation by means of Scatter and Box-plot diagrams for the analysis completed in the closest wells and the different sorts of clogging are appended in the annex I (6.1.2.):

1. Areas with physical clogging processes
2. Biological and biophysics clogging processes
3. Chemical clogging processes
4. Physical-biological clogging processes.

3.2.7 Chemical and biological clogging analyses

Clogging samples have been collected in four specific points along the MAR canals during the last stage of the 2015-16 MAR cycle (2016 May).

The samples have been taken just before and after the connection between the WWTP spill of reclaimed water (SCE a and SCE d respectively) and at the end of the *triplet* scheme at Sanchón 1b artificial wetland (sample HS1 b) and in the MAR canal in parallel (SH).

A first chemical analysis for the sludge, separating the liquid fraction and the pure clogging processes has been accomplished. In this paragraph it is presented the methodology to determine the main constituents and parameters in the water (TDS, pH, conductivity, COD, BOD5, TOC, metals and nutrients).

Secondly, a specific identification of bacterial species is being done, starting by the DNA study within the specific identification of bacterial species phase.

The analytical results of this stage are attached as annex IV.

This line of action is still opened and final analyses for clogging characterization, including the second campaign after the MAR cycle finished (dry samples) will be exposed in latter deliverables.

METHODOLOGY FOR ANALYSIS OF CLOGGING SAMPLES

PHYSICAL AND CHEMICAL PARAMETERS (WATER SAMPLES)

1. TOTAL DISSOLVED SOLIDS

Samples were collected and placed in a crucible to be weighed and heated in an oven at 105 °C to proceed to evaporation. The difference between the weight of the crucible with sample before and after the evaporation represents the weight of the total solids contained in the sample.

2. pH

pH measurements were made with a pHmeter (CRISON LPG 21) previously calibrated at neutral pH (pH = 7) and acid pH (pH = 4).

3. CONDUCTIVITY

Conductivity measurements were performed with a conductivity meter (GLP 31 CRISON) previously calibrated with low (1413 µS / cm) and high (12.88 mS/cm) conductivity.

4. CHEMICAL OXYGEN DEMAND (COD)

It is the amount of oxygen that is consumed during the chemical oxidation of a sample under certain conditions.

This parameter is determined in the laboratory using a Spectroquant (Merck, USA) commercial kit. After preparation of the samples, these are introduced into the digester for 2 hours at 150ºC and then its absorbance is measured by UV-Vis spectrophotometer at a wavelength of 620 nm.

The method used is equivalent to DIN ISO 15705, EPA 410.4, 5220 D APHA, ASTM D1252-06 and-B standard.

5. BIOCHEMICAL OXYGEN DEMAND (BOD 5)

Is the amount of oxygen required for aerobic microorganisms to metabolically oxidize the organic matter present in a water sample. It is determined by difference between the dissolved oxygen in the initial sample and measured by the incubation time. The incubation is done in known volume vials placed at 20 ° C in absence of light.

For the BOD_5 the incubation time are 5 days and does provide a measure of the existing biodegradable organic carbon in the sample. It is expressed as mass of oxygen consumed per unit volume of water (mgO_2/L).

6. TOTAL ORGANIC CARBON (TOC)

It is an instrumental method based on catalytic combustion at high temperatures (> 900ºC) in the presence of oxidation catalysts (V_2O_5) and subsequent quantification of CO_2 generated by non-dispersive infrared detector. The equipment used is a Shimadzu TOC-V

7. METALS

Metals were analysed by atomic emission spectroscopy with inductively coupled plasma (ICP). The equipment used to perform the analysis is a Varian Vista AX model simultaneous ICP-AES.

8. NUTRIENTS

The nutrients analysed are nitrate, nitrite, ammonium, total nitrogen (organic and inorganic after digestion), total phosphorus (inorganic + organic, after digestion), phosphate and potassium. The equipment used is a segmented flow nutrients analyser (SKALAR / SAN SYSTEM SA3000-5000).To estimate the potassium there is a flame spectrophotometer coupled to the autosampler. This device measures the intensity of radiation emitted by the excited potassium flame, the amount of emitted light is directly proportional to its concentration in the sample.

BIOLOGICAL PARAMETERS (CLOGGING SAMPLES).

1.-SPECIFIC IDENTIFICATION OF BACTERIAL SPECIES

For bacterial identification samples DNA extractions were performed using a DNA extraction kit Microbial Isolation (MoBio Laboratoires. Solan Beach, CA, USA). For DNA amplification were used, primers 16S-GC 338F and 518R S 16, according to the protocol of DNA polymerase ExTaq HS (LaboratiorsConda). From the extracted DNA bacterial identification was performed following the protocol of Caporaso (2010) sequencing with Illumina and using the Quantitative Insights Into Microbial Ecology (QIIME) software tool. The primers for PCR were F515 / R806 V4 (16Sr RNA).

[**SCE a**: Santiuste Canal Este before WWTP; **SCE d**: Santiuste Canal East after the WWTP; **SH**: Canal Sanchón; **HS1-b**: Artificial wetland (=Humedal artificial) Sanchón 1b].

The results of the chemical analyses performed at the King Juan Carlos University laboratory have been included as ANNEX IV (SAT-MAR studies).

3.2.8 Results and data-sets treatment

The MGA has provided a set of histograms relating to the main parameters measured in groundwater and the clogging process associated has been charted. The parameters represented have been pH, sodium, potassium, calcium, magnesium, chloride, bicarbonate, sulphate, nitrates, Na+K, Ca+Mg (all of them in meq/l expression –r-), the Cationic Index, the Anionic Index, the Base Interchange Index and finally the total of dissolved oxygen (TDO). The histograms and the box charts for all the samples are attached as figures 3-30, 3-31 and in annex I (6-1-2).

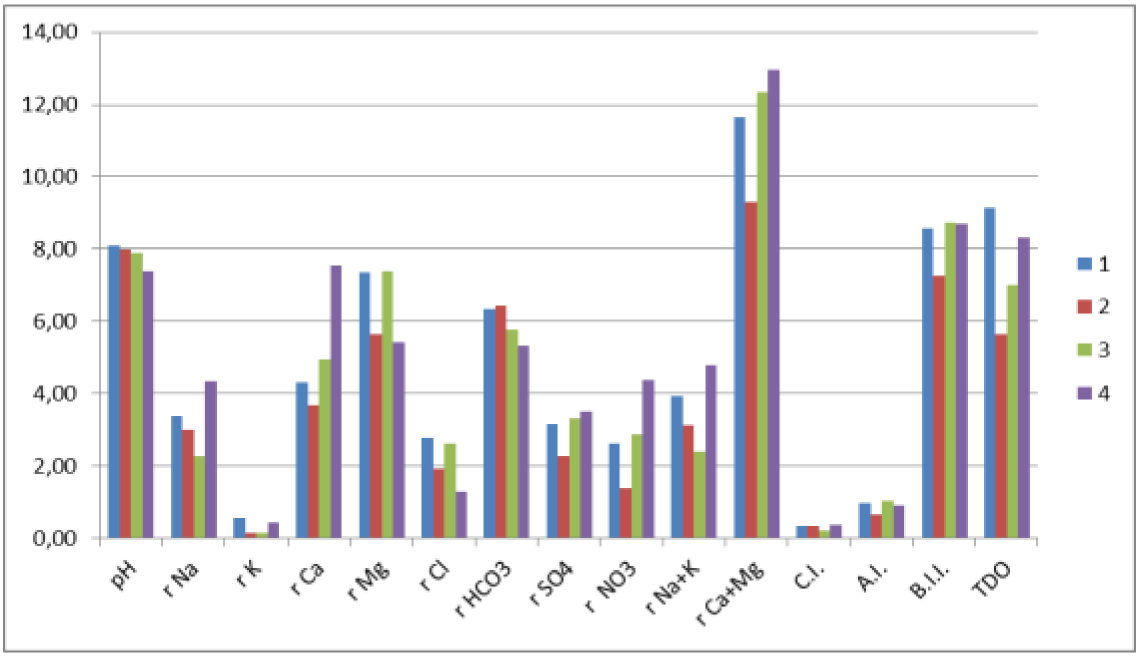


Figure 3-30: Histogram charting all the analysed wells (mean values) grouped according to their associated clogging processes.

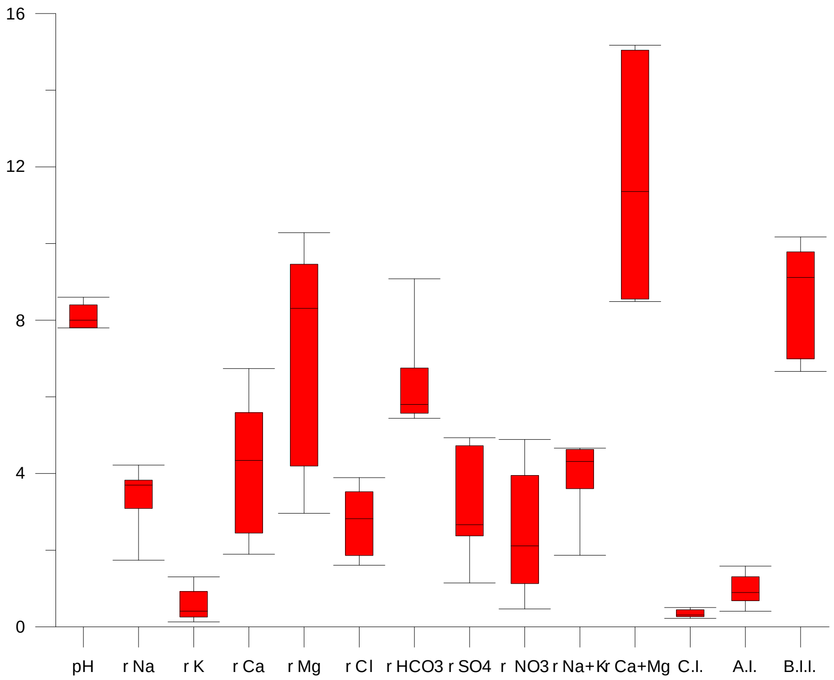


Figure 3-31: Box-plot charting all the analysed wells for 15 chemical parameters.

Annex I (6-1-2) encloses the specific histograms for each clogging type.

The study of the main compounds in the charts and in the comparison between maps has released the following observations:

Regarding **Conductivity**, the interval ranges between 932 and 1,729 µS/cm, with a certain direct relation with marls and gypsum outcrops.The comparison between both maps (annex 1, 6-1-1) allows observing a certain parallelism between conductivity and bicarbonate isolines. It also presents a likeness to Ca+Mg isolines. Likewise the presence of high inflexions in zones where the abundance of physical-biological clogging processes is remarkable. In general, the relations between conductivity contours and clogging distribution are coherent.

According to **pH**, the measures collected oscillate in a narrow interval between 7.4 and 8.6, with higher values in winter than in the summer time. The histogram for mean values presents a pH reduction alike with the four categories, the highest pH for physical clogging (sort 1) and the lowest for physical-biological clogging processes (sort 4).

Regarding **Sodium and Potassium**, the intervals ranges between 1.74 and 4.35 and 0.08 and 1.30 meq/l respectively. The mean highest concentrations are associated to physical-biological clogging processes (4).The singular maximum values are placed in the Northern area, where there is an important concentration of chemical clogging processes (3). The Southern zone presents high values associated to physical processes (1). There are isolated anomalies in areas with mixed clogging processes (purple colour in the map 3-29, code 5 has been assigned), which correspond frequently with super-imposed profiles. The comparison with other maps of isolines presents consistence with the iso-bicarbonates map, without outstanding analogies with the rest.

Considering **Calcium and Magnesium**, the intervals ranges between 1.90 and 7.53 and 2.96 and 10.28 meq/l respectively. The distribution is equivalent to the previous case for alkaline ions, except for the chemical clogging processes, which have a solid dependence with these components higher than the previous case. The SMA results indicate a maximum relation with physical-biological clogging (4) and minimum with biological-biophysical (2). The isolines of these components fits also de bicarbonates isolines map, and contours fit to the contacts between the different clogging types.

Talking about **Chlorides**, the values determined ranges between 1.30 and 3.89 meq/l. The maximum values are concentrated close to wetland fossilized areas, which include a high sulphates concentration too due to the presence of gypsum in the west border of the basin. The areas with minimum concentration have developed, mostly, chemical clogging processes (3). The SMA indicates a larger presence of physical clogging associated to chlorides (1). Oddly enough the chemical clogging presents a scarce linkage, due to the fact that some isolated wells in the centre of the basin have extreme chloride concentrations. The chlorides isolines have certain similarities with bicarbonates and calcium+magnesium distribution maps, moreover the consistency is not as clear as in the previous case.

Regarding **Bicarbonates**, the values measured ranges between 5.20 and 9.08 meq/l. The concentration usually increases along the MAR canal, with maximum values in the Northern area, where have been detected carbonates precipitation, crusts of calcite and other forms of chemical clogging. The SMA indicates a larger presence of biological and biophysics (2) and physical (1) associated to bicarbonates. The concordance with chemical clogging is scarce. The isolines distribution is congruent with, at least, the sodium+potassium and the calcium+magnesium maps, with a certain resemblance with the one of chlorides.

Considering **Sulphates**, the values measured ranges between 1.15 and 4.93 meq/l. The maximum sulphates concentration are located in areas with an abundant presence of “mixed” clogging (purple) and physical processes (1). The SMA indicates a larger presence of chemical clogging (1) associated to sulphates, being the minimum values related to biological and biophysics clogging (2). Thus, sulphates could be behaving as biocides.

The boundaries of the areas with different clogging types are congruent, in general, with the contours of the iso-sulphates map.

Regarding **Nitrates**, the values measured ranges between 0.47 and 4.89 meq/l. The maximum nitrates concentration appears in areas with physical and biological clogging (4) and filamentous algae colonies, especially in the West channel and in the Southern area.

The isolines distribution of nitrates corresponds accurately with the limits of the different sorts of clogging identified. The SMA indicates a larger presence of chemical clogging (3) for mean values of nitrate.

Regarding the **Cationic Index (CI) and the Anionic Index (AI)**, the values measured and analysed do not present differences large enough to drive conclusions. The trends display minimum concentrations of chemical clogging processes (3) associated to cations, and biological and biophysics clogging processes (2) to anions, similarly to the ICB trend.

According to **Total Dissolved Oxygen**, the data collected are between 3.3 and 8.9 ppm. The maximum values are related to physical clogging processes (1), and the minimum for biological and biophysics clogging processes (2). This observation is consistent with the water origin. The water diverted from Voltoya River has a charge of suspended solids larger than in the rest of the canal, despite pre-treatment filters. The stagnation of solids along the canal is larger at the initial stretch than in more advanced positions.

3.2.9 Conclusions conducted on clogging studies

The relation between clogging types and groundwater quality might have a solid connection for this specific demo-site, taking into account that the groundwater table is close to the surface, with a mean depth of 6 m.

The clogging characterization completed in 2015 has had outstanding results in comparison to the one of 2011. Photographs of some clogging profile columns collected at some sampling stations in 2009 and in 2015 have been attached in the Annex I (6-1-3).

It is worth mentioning that the clogging process is becoming increasingly complex. New combinations of clogging are appearing in the field; however some areas show enhanced preferential clogging development.

External processes bring multiple superimposed profiles due to sand deposited by the wind, fossilizing previous clogging profiles (photos enclosed in annex I, 6-1-3), which brings the necessity of frequently updated characterizations. It entails the need for the revision of the clogging contours of the maps of clogging distribution and the increase of costs too.

There is a bi-directional influence of MAR water in the groundwater and the opposite. The fact that groundwater has a direct action on clogging processes might not be a general rule, but it is likely to happen in MAR facilities with a shallow water blade.

In short, there is an interaction between the water employed for recharge, the native groundwater and the geological conditions of each specific area, what supports the statement that clogging is the result of the interaction between many different elements and processes, not only a dual relation between the recharge water and the receiving medium.

There are many different clogging processes which require a good characterization. They have been grouped in five typologies:

1. Areas with physical clogging processes
2. Biological and biophysics clogging processes
3. Chemical clogging processes
4. Physical-biological clogging processes
5. Mixed clogging processes

There is a congruent relation between the different limits of the clogging processes and the maps of isolines, especially for nitrates, bicarbonate, calcium+magnesium and sulphates.

According to the Multivariable Geostatistical Analisys (MGA) conducted, there is a relation between groundwater compounds and clogging types:

1. The first sort of clogging (1) is specially related to high concentrations of calcium, magnesium, TDO and basic pH values.
2. The second (2) has the maximum correlation with pH and bicarbonates.
3. The third (3) has a bigger appearance with the interaction with groundwater with high concentration of calcium, magnesium, sulphates and nitrates.
4. The fourth (4) sodium, calcium, nitrates and dissolved oxygen.

The pH of the recharge water is neutralized by interaction with rocks opposite areas along the channels where reactive soils have been identified to provide pH buffering. Although changes are modest, the results are, in general, good.

Clogging treatment must be considered an integral action rather than in response to a system failure, as there is a complex relationship between all clogging types, recharge water, groundwater quality variations and the specific geological conditions for each point.

The knowledge of the distribution of the incipient clogging processes allows improved designs and scheduled maintenance operations to become more efficiently and the application of the Best Technological Solutions for prevention, cleaning and maintenance.

The alternation of dark and clear lenses, even layers, makes the process more and more difficult and the cleaning costs are increasing considerably as the activity continues.

Modifications to the design of the infiltration canals and basins have been made by trial and error using the best scientific judgment, due to the limited information in the literature on clogging remediation. After each modification testing and monitoring is carried out to gauge the success or otherwise of the modification.

The design changes and management parameters must be created “a la carte”, depending on the climate, local characteristics and other intricacies, and of each system.

The findings, in general, can be extrapolated to practical conclusions to other less known sites from the same aquifer and/or analogous scenarios. It also suggests a methodological proposal to correlate clogging-groundwater quality and the specific geological conditions for each site.

Between the results, it is especially remarkable the bi-directional influence of MAR water in the groundwater and the opposite: groundwater has a direct action on clogging processes generated on the surface, at least for the environmental conditions of this aquifer.

3.3 SAT-MAR studies

The improvement of the water quality for MAR has three different lines of action: pre-treatment, purification “in itinere” (what means along the system itself (at the same time water is flowing is being purified) and a final post-treatment. The last task has not been considered in this chapter, due to the fact that it is related to its final use.

This group of activities has been included into the set of techniques called “SAT-MAR” or Soil and Aquifer Treatment measures for Managed Aquifer Recharge, according to its initial terminology (Krul and Liendfrich, 1946). It is worth to mention that the term “SAT” had a later evolution being employed for activities relating a Waste Water Treatment Plant (WWTP) and connected artificial recharge activities. In this chapter SAT-MAR is employed according to the initial and broader definition of the term.

Two different studies have been performed regarding this topic: Purification *in itinere* along a “triplet scheme” and by means of filters and Disinfection By Products (DBPs).

The first term, “triplet”, has been adopted to design the combination of a Lagooning WWTP, a canal for MAR with vegetation acting as a biofilter and a final artificial wetland to finish the water improvement process. The initial scheme has been defined in deliverable 5-1, MARSOL 2015, with good examples of implementation at Santiuste and Carracillo plants.

For the second case, studies regarding purification measures along the conductions have been carried out at Alcazarén plant, where new complementary facilities have been stood by MARSOL team. Little facilities have been implemented in order to study the water quality improvement by means of sieving with filters made of gravel and sand, biofilms, geofabrics; and some complementary measures, such as the addition of specific chemical substances (DBPs) and solar exposure of water. These minor constructions have allowed testing different filters in “hyper-controlled” conditions (irrigation community and local authorities provided permission to conduct these studies without any interference with agro-industry activity).

3.3.1 Experimental tests on “treatment in itinere”. Triplet schemes

The demo-site has become a living-lab for MARSOL project by means of the partner Tragsa and new developments are permanently tested, as the “triplet” schemes, a relatively new SAT-MAR technique introduced in this chapter. They consist on a sequence of naturalized structures to improve reclaimed water quality for MAR in the case of Santiuste basin, and also to minimize the Dissolved Oxygen content at El Carracillo.

Some authors have concentrated their efforts in the study of actions to improve MAR water previous contamination and general treatment concentrating in the attenuation of any specific compound: They are desirable standards to be achieved, such as the elimination of nutrients and organic matter from the water, to get the longer service life-span for any MAR plant (Bouwer, 2002).

The Total Dissolved Solids (TDS) determines largely the chemical and biological clogging. The standards found in the bibliography are fixed at 150 ppm for superficial devices (Pyne, 1995; CSIRO, 2002). and 100 ppm in deep injection devices (ASR) (Dillon and Pavelic, 1996); and the quality requirement for suspended matter is below 2-3 mg/l (Bouwer, 2002).

The quality standard for Total Organic Carbon (TOC) varies within wide limits in the consulted regulations. For example, the desirable limit is set to 10 mg/l In California, but other studies set the threshold between 8 and 18 ppm (Bouwer, 2002). In deep injection devices interval ranges between 3 and 12 ppm for South Australia, etc.

The main parameters to be taken into account and its qualitative limit have been the target of numerous research works. To mention a few of them, the Total of Solids in Suspension (TSS) and Turbidity has been established in 10 ppm from certain MAR experiences in California (Aiken, 2002). Other experiences in Colorado have demanded a greater severity, reducing the standard for fluvial origin recharge water from 8 down to 2.8 mg/l (Mills, 2002). Experiences in Texas have determined the limit in 20 mg/l, with a qualitative optimal limit inferior to 10 mg/l (Fryar, 2001). For deep injection devices a 2 mg/l concentration may be sufficient to significantly reduce the infiltration rate in wells and boreholes (Pyne, 1995).

The addition of disinfectants in MAR water, known as DBPs technique (Disinfection By Products) is used on all around the world experiences, although there have been various positive and negative cases as a result of – among others - chlorination (Tsuchihashi , 2002); microfiltration (Pyne, 2005); iodination (Fox, 2002); ozonification and UV radiation (Cushing et al., 2003); the pH control additives (Stuyfzand, 2002); the combination of different techniques at the same time (Dillon and Pavelic, 1996); control of the temperature of the water (Olsthoorn, 1982) or shortage of dissolved gases (Bouwer, 2002).

Among these references, most of them consider the pre-treatment of MAR water, but very few consider the “in-treatment” or purification of water “in itinere”, main target of this article.

MAR water pre-treatment is still considered the most effective measure to enlarge the life-span of the facilities and to avoid clogging processes (Fernández, 2013). The most applied technical solution during MARSOL project at Los Arenales has been the device called “*a triplet*”, composed by an assemblage of a stagnation structure-a green bio-filter and an artificial wetland.

This chapter exposes the achievements in these lines of action and how the scheme is improving the MAR water efficiency in these living labs. The study area where these activities are being accomplished has already been described in previous chapters and references. A broad overview of the MAR plants can be obtained from the figures 3-21, 3-35 and 3-44 for Santiuste, Carracillo and Alcazarén respectively and in the table 3-4).

It is important to note that almost 100% of the water is used for irrigation and that each MAR cycle or period when water is diverted from the rivers to the recharge facilities begins about November 1st and ends on April 30th, with eventual exceptions and depending on weather conditions: in case of water shortage in rivers the enhanced recharge is banned by the River Basin Authorities (CHD).

Table 3-4: Principal components at Los Arenales aquifer MAR systems

DEMO SITE	Operability (years)	MAR transport pipe (km)	MAR infiltration canal (km)	Infiltration ponds	Infiltration wells	Artificial wetlands	RBF	WWTP for SAT-MAR
Santiuste	14	9.8	27	5	3	3	1	1
Carracillo	13	46	17	17	1	1	1	0
Alcazarén	4	19	7	1	0	3	1	1

OBJECTIVES OF THE MAR EXPERIENCES IN TRIPLETS

The design and employ of “triplets” as an element to improve the water quality for MAR is an objective already considered in MARSOL project. The most remarkable adhered objectives are:

- To identify the processes taking place along the water transport by means of analysing the water quality evolution from the Santiuste WWTP by lagooning along the green biofilter until the artificial wetland.
- To assess the improvement of the MAR water quality along canals and pipes by monitoring some selected unstable water quality parameters. These conductions must fulfil two requirements: to be environmentally fitted and low-cost.
- To study what SAT-MAR processes are working in the artificial wetlands related to MAR activities, testing their efficiency by means of monitoring a series of indicators specifically designed and their influence on the final MAR water quality, including in the first row the reduction in the total dissolved oxygen (TDO).
- To develop a line of action scarcely referenced in the hydrogeological literature related to studies of gas clogging: El Carracillo´s triplet has been explicitly designed to reduce the TDO parameter until acceptable limits prior the MAR water arrives to a spreading infiltration field in order to avoid hyper-oxidizing conditions.

DESCRIPTION OF THE TWO TRIPLET SYSTEMS: SANTIUSTE AND EL CARRACILLO

In order to study the water quality changes and possible purification processes along opened conductions and pipes, two specific structures have been prepared for these targets, which have been called Santiuste and Carracillo “triplets” described below and in previous references (MARSOL, 2015a).

SANTIUSTE BASIN´S TRIPLET: LAGOONING-BIOFILTERING CANAL-ARTIFICIAL WETLAND

It is a 2.7-km-long-structure within a MAR canal which starts at the point where the reclaimed water coming from a lagooning Waste Water Treatment Plant (WWTP) connects to the main MAR East canal, which is transporting and infiltrating MAR water from fluvial origin.

This SAT-MAR structure is integrated by three consecutive elements (figure 3-32), the “SAT-MAR” device (1), a green biofilter (2) and two consecutive artificial wetlands (3) to finish the purification process. Next water returns to the MAR canal and continues advancing Northwards.

In short, for the Santiuste case the lagooning WWTP pours reclaimed water into the canal, which conserves the natural vegetation in this stretch, working as a green bio-filter, until it can be derived to two artificial wetlands where it can also be sent back to the MAR canal again. Water is treated “in itinere” *during it flows throughout the infiltration canal.Santiuste Basin´s triplet: WWTP by lagooning*

It begins in the junction of the WWTP spill with the MAR canal coming from the initial decantation pond. It is formed by four ponds where treatment occurs by lagooning.

The volume of reclaimed water in comparison to the MAR water in the canal is always below 5% during recharge season. Then, there is an important initial dilution of the vectors which might be insufficiently purified within the MAR water volume, which fulfils all the required norms and requisites *(“dilution as a solution to pollution“).*

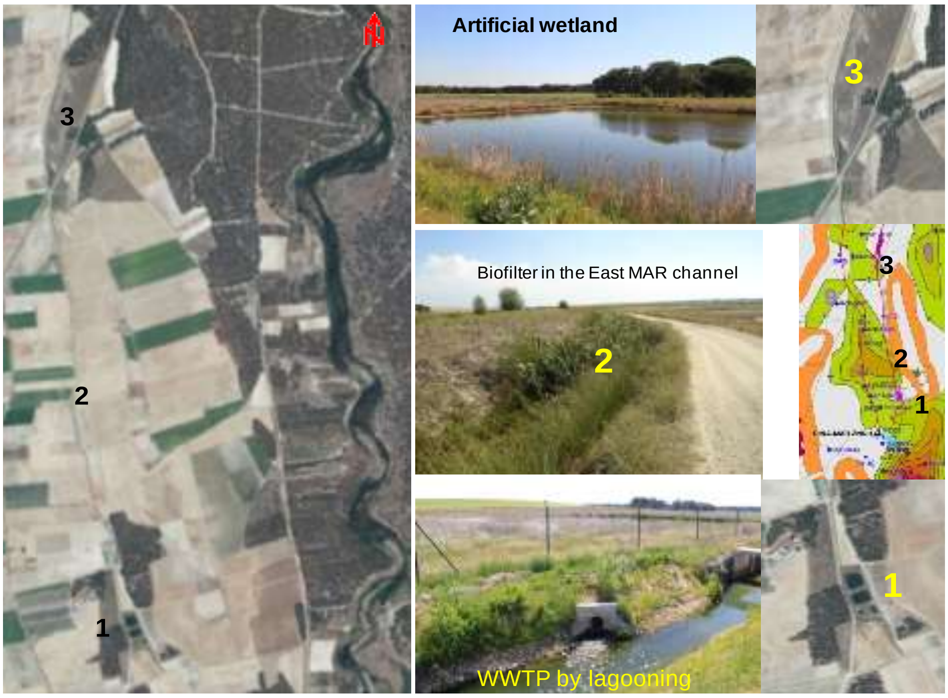


Figure 3-32: “Triplet” at Santiuste basin, a combination of elements to play a purification process on reclaimed water from a lagooning WWTP: spill of reclaimed water in the MAR canal (1); natural treatment along a green biofilter (2) and final treatment along two artificial wetlands (3).

Santiuste Basin´s triplet: Green biofilter

A stretch of 1,129 m of infiltration canal followed by another 1,577-meter-length section of semi-impermeable ditch connect the WWTP outflow with the artificial wetlands. The whole infiltration canal net occupies more than 25 km on the sandy aquifer and only 30 m slope.

It plays a double role: on the one hand the wild plants perform an important purifying activity on the potential pollutants which could have remained after the irregular water treatment process, even by single absorption of nutrients. On the other hand, roots penetrate and break the clogging in the bottom of the canal, where complex clogging processes are combined, increasing the infiltration rate despite their direct consumption of water through evapotranspiration and photosynthesis.

The second line of action was initiated in 2005 (Fernández Escalante, 2006). Considering the convenience of the green biofilter and the most appropriate plants to be induced to settle in this section, some species have been inventoried which are prone to penetrate the clogging layer, increasing the subsequent passage of water, and decreasing the amount of nutrients in the soil. Most listed species are those hydrophilic herbaceous with an annual cycle, rapid growth, high root expansion and ease of extraction with roots. The plants must be specific to each area of action, depending on the climate conditions, the substrate, etc. Some species that can meet these requirements in the demo site are (modified from Fernández Escalante, 2005):

Dactylis glomerata	*Elymus hispidus susp. hispidus*	*Tetragonolobus maritimus var. hirsutus*
Agrimonia eupatoria	*Galium palustre*	*Triglochin palustris*
Althaea officinalis	*Iris pseudacorus*	*Ranunculus repens*
Althaea hirsuta	*Lolium rigidum subsp. rigidum*	
Carum verticillatum	*Sparganium erectum*	

Santiuste Basin´s triplet: Artificial wetlands

This three-pond-group (Sanchón 1: 2,361 m^2, Sanchón 2a: 2,916 m^2 and Sanchón 2b: 13,000 m^2) is laterally placed near this infiltration canal and reconnected in the northern extreme back to the main East infiltration canal when fulfilled. They were built in 2008.

As the third element of the triplet they also play a double function: the purification of the water stored in the vessel, and an environmental function, as an ecologic spot of interest: shelter for wild fauna and restored water landscape.

As the bottom of the wetland stays slightly higher than that of the parallel canal, water does run all through the ditch (only Sanchón 2a stays flooded) avoiding usually the whole cover of the wetland though a high flow enter the infiltration canal further the south spillway. For that reason, the biggest wetland (Sanchón 2b) is randomly covered by water.

(a) (b) (c)

Figures 3-33 a to c: Sanchón 1 wetland (2,361 m^2) (a-b), and Sanchón 2 (2,915,8 m^2) (c).

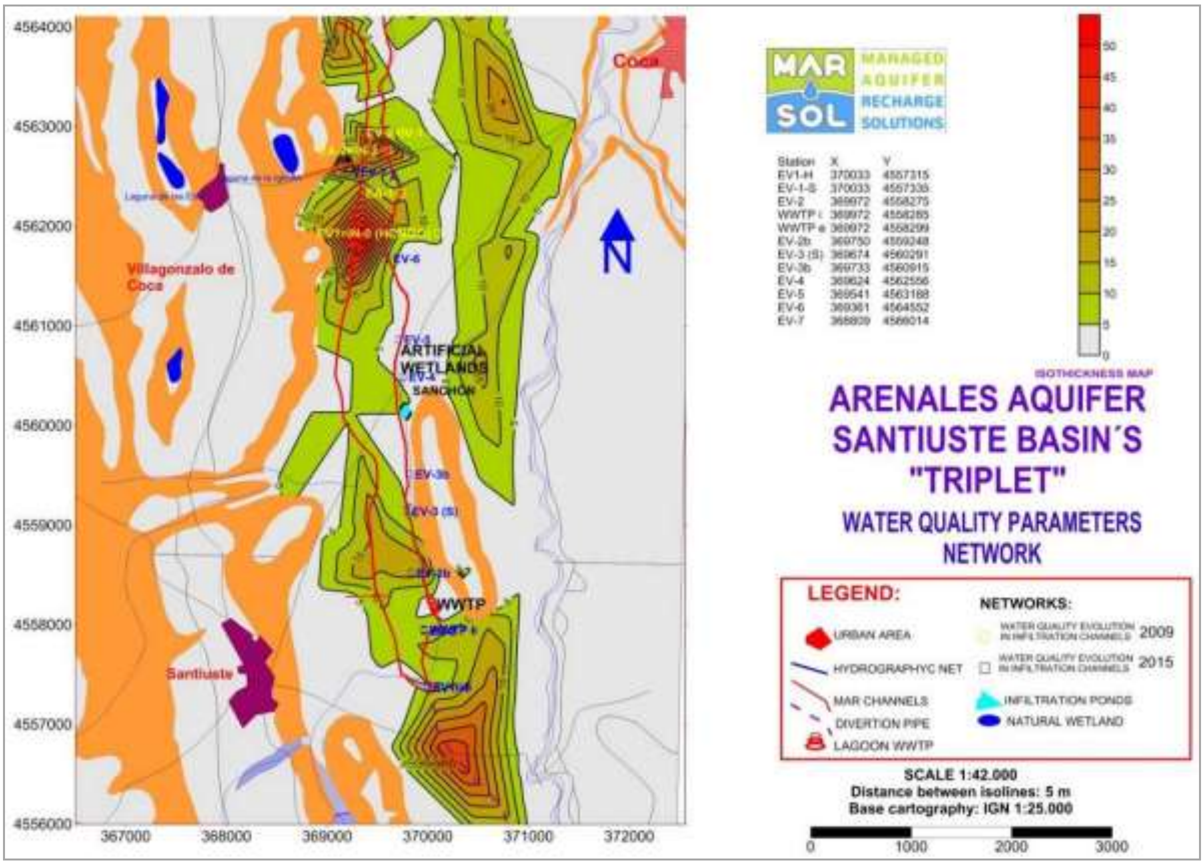


Figure 3-34: Santiuste *triplet*´s map representing the different elements and the sample point's network to monitor water quality evolution.

The importance of this site as a purification enhancer and a habitat for aquatic species is very relevant. It occupies the functionality of many old temporary ponds that have been desiccated by years of ploughing because of an old tradition to decrease the run-off and thus the water table level displays the network with the different stations where water has been analysed along the MAR system, triplet included. The obtained data-sets and their representation are posed in Annex V (6-5-1 and 6-5-2). The results are interpreted in the last paragraph of this chapter.

EL CARRACILLO BASIN´S TRIPLET

The topologic scheme for Carracillo with the main water resources management components and structure is displayed in the figure 3-35, where the *triplet* occupies the Eastern side.

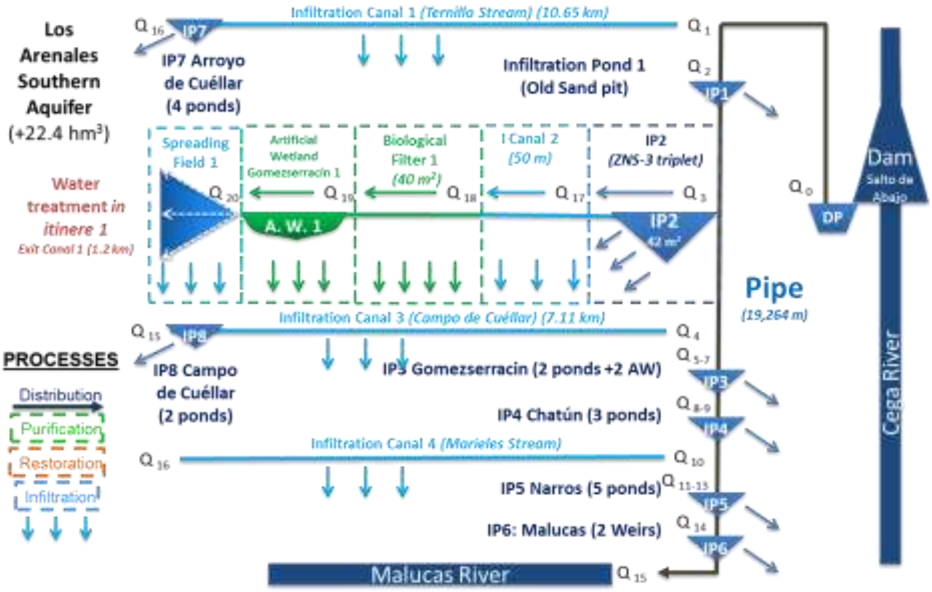


Figure 3-35 Operational sketch of El Carracillo MAR plant. The *triplet* is situated at IP3.

This “triplet” is shorter than the previous one (150 m long) and the water come directly from a river without WWTP source contributions. This “triplet” scheme is integrated by the following elements: a stagnation strainer-infiltration pond-green biofilter-artificial wetland-spreading area for recharge of the aquifer. Anyway, it has been designed and adapted to collect samples to study the MAR water quality evolution all over its respective components between altitudes 823 and 821 m.a.s.l.

El Carracillo Basin´s triplet: Stagnation strainer and infiltration pond

The 3rd valve in El Carracillo is located in the corner of the area called “Dehesa Boyal”. Water diverted thru a pipeline from Cega River passes through an initial filter going straight into a 42 m^2 infiltration pond (figure 3-35).

El Carracillo Basin´s triplet: Green biofilter

It is a 50 m long canal (figure 3-36) where natural plants have not been removed in order to extract nutrients from water, decrease the dissolved oxygen by direct consumption and penetrate the bottom in order to increase the infiltration rate through their roots, breaking the possible clogging layers as well.

El Carracillo Basin´s triplet: Artificial wetland

Little artificial wetland with a well dug in a corner to keep studying processes when the wetland gets dried. It achieves a purification process by lagooning and at the same time a recharge activity. It has a spillway assembly pouring water in the spreading field for infiltration. It also works as a security measure in case of floods (figure 3-37c).

Figure 3-36: El Carracillo “triplet” components: stagnation strainer and infiltration pond (1), green biofilter along the MAR canal (2) and artificial wetland (3) with a spillway directed northwest wards to a spreading field for MAR.

El Carracillo Basin´s triplet: Stagnation strainer and infiltration pond

The 3rd valve in El Carracillo is located in the corner of the area called “Dehesa Boyal”. Water diverted thru a pipeline from Cega River passes through an initial filter going straight into a 42 m^2 infiltration pond (figure 3-35).

El Carracillo Basin´s triplet: Green biofilter

It is a 50 m long canal (figure 3-36) where natural plants have not been removed in order to extract nutrients from water, decrease the dissolved oxygen by direct consumption and penetrate the bottom in order to increase the infiltration rate through their roots, breaking the possible clogging layers as well.

El Carracillo Basin´s triplet: Artificial wetland

Little artificial wetland with a well dug in a corner to keep studying processes when the wetland gets dried. It achieves a purification process by lagooning and at the same time a recharge activity. It has a spillway assembly pouring water in the spreading field for infiltration. It also works as a security measure in case of floods (figure 3-37c).

(a) (b) (c)

Figure 3-37: El Carracillo “Triplet” composed by an infiltration pond surrounded by a piezometer network (left), a bio-filter in the MAR channel (centre) and an artificial wetland (right) prior a spreading area for infiltration.

El Carracillo Basin´s triplet: Spreading field

It is a sandy and flat extension where water is conducted from the artificial wetland to be infiltrated in the aquifer by simply spreading over a fallow (figures 3-38).

The spreading field occupies a prairie for the cattle where in case of overflowing the little infiltration pond, water can spread all over. In fact at the northern extreme of this field there are 4 little pools that are fed by the run-off and elevate the water table.

(a) (b) (c)

Figure 3-38: El Carracillo “Triplet” last elements: spillway (a) to pour water from the artificial wetland into the spreading infiltration field (b). Triplet seen from the spillway to the heading direction (c).

WATER ANALYSIS IN THE TRIPLETS: PARAMETERS AND DATES

Water quality analysis has been carried out in a series of sample points (figures 3-34 and 3-37) to test processes in both triplets.

The measures of unstable parameters, conducted again with a multiparameter HANNA HI 9829, accomplished after fixing and geo-referencing the stations have been pH, ORP (mV), TDO (ppm), EC (µS/cm), TDS (ppm), salinity (PSU), turbidity (NTU), T (ºC), pressure and time of collection. In 2009 were collected two data-sets in two campaigns (DINA-MAR project) in 2009 January 22th and February 18th. In the last MAR cycle have been measured the unstable parameters monthly (MARSOL project) in dates 2015 Feb 17th, March 16th and April 15th. In 2016 two new campaigns were conducted (April 21th and May 26th). Sampling points and results are enclosed in the annex V-1.

RESULTS

These structures provide real demo-sites to study different techniques to improve the water quality along conductions and pipes. It is worth to assess the water quality evolution in both schemes and the processes taking place in each element.

MAR water quality evolution along Santiuste triplet

Seven water samples have been collected for detailed analysis along the “triplet” mock-up, and the unstable parameters have been determined too.

Santiuste water sampling for chemical analysis and unstable parameters

Regarding the conditions during sampling campaign and measurements, it is worth to remark for the lagooning WWTP the following conditions:

- Low/medium flow rate in surface water (reducing dilution of organics).
- Constant mixing ratio Treated Waste Water (TWW) /Surface Water (SW) during sampling. Optimum: portion of TWW <<< SW.

Figures 3-39 and 3-40 for the campaigns of 2009 and 2015 respectively represent the compounds and parameters analysed (and included in annex V-1 as tables B1 and B2). Considering the parameters in the Infiltration Heading (EV1) as a 100% (in order to avoid wide intervals because of difference in unit ranges) and the rest in the system (including the main triplet sample points from EV2 to EV4) as a percentage related to that first one. A grey stripe marks the +/- 15% interval to point out substantial changes.

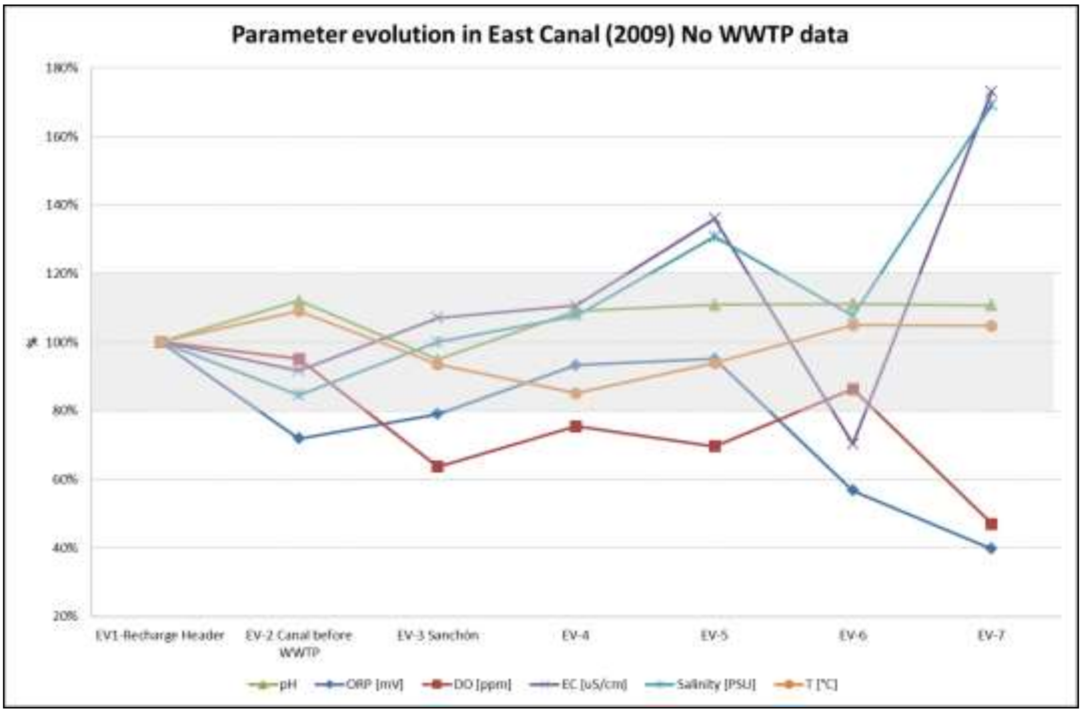


Figure 3-39: Unstable parameters evolution graph in Santiuste triplet (2009).

Data graph for 2009 (figure 3-39) shows that Dissolved Oxygen (DO) notably falls in the canal after the WWTP inlet (60%) and recovers a little within the wetland but finally falls down to 40%. Salinity and conductivity show similar down-up-down profiles. Redox potential (ORP) fluctuates in canal though it shows a general decreasing trend.

Temperature hardly changes in the infiltration canal once water gets out of the pipe. pH decrease after WWTP (EV3) but later it gets back to the EV2 level. This couple of parameters gets numbers within the +/-15% band so they are not considered very pertinent.

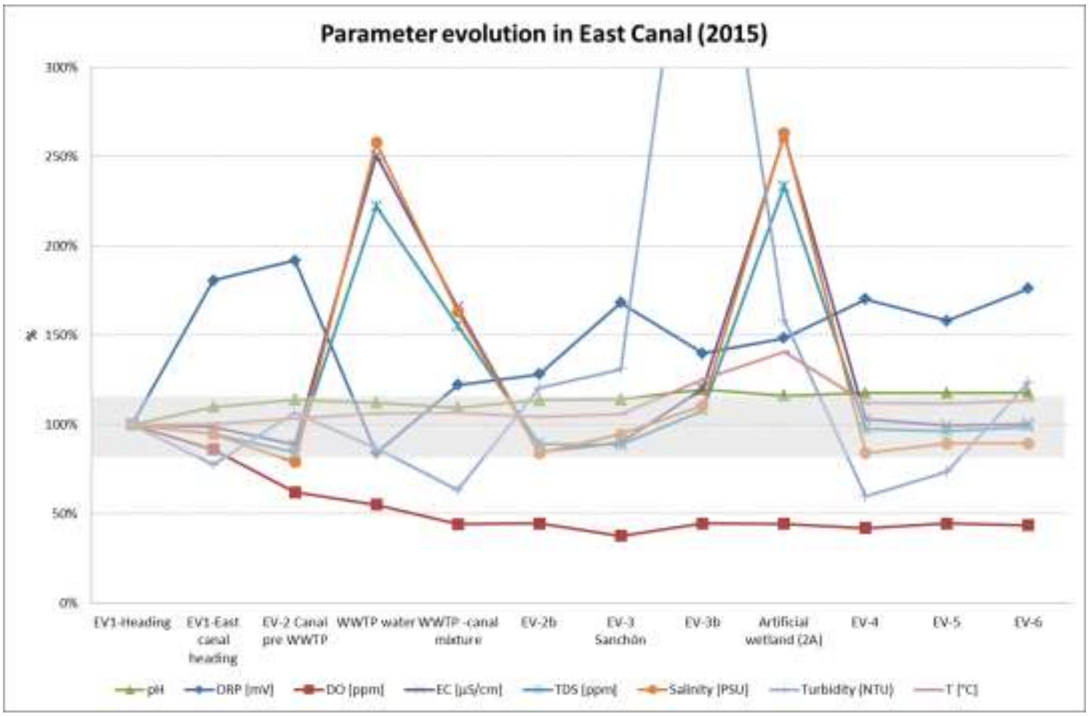


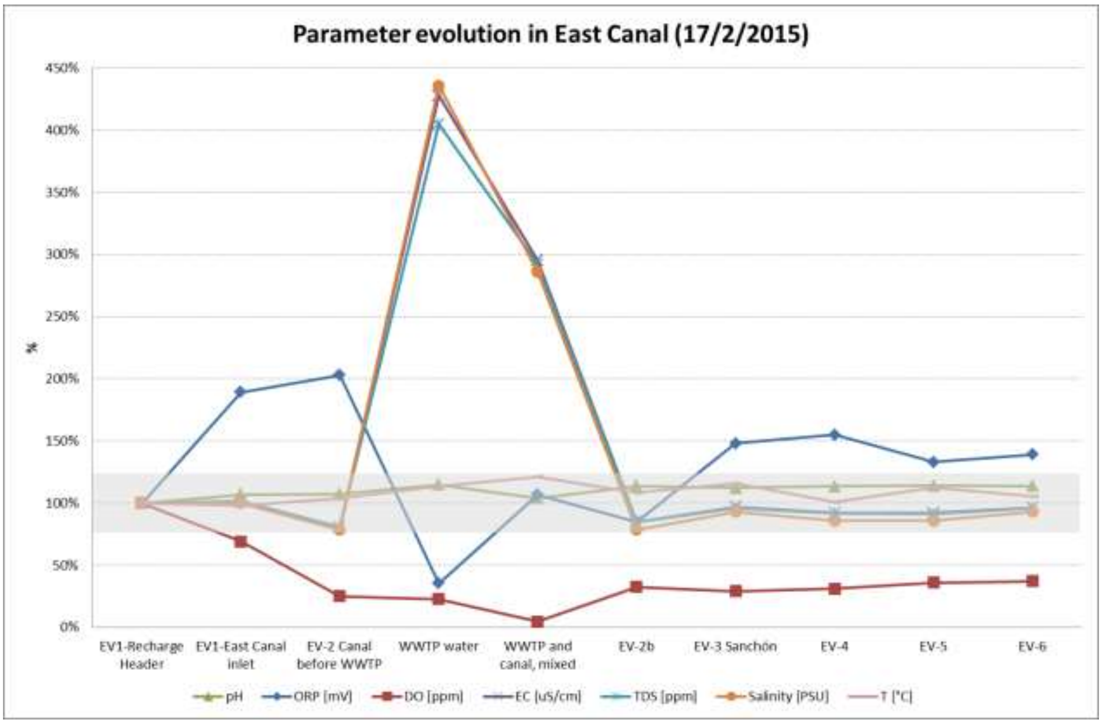
Figure 3-40: Unstable parameters evolution graph in Santiuste *triplet* (2015).

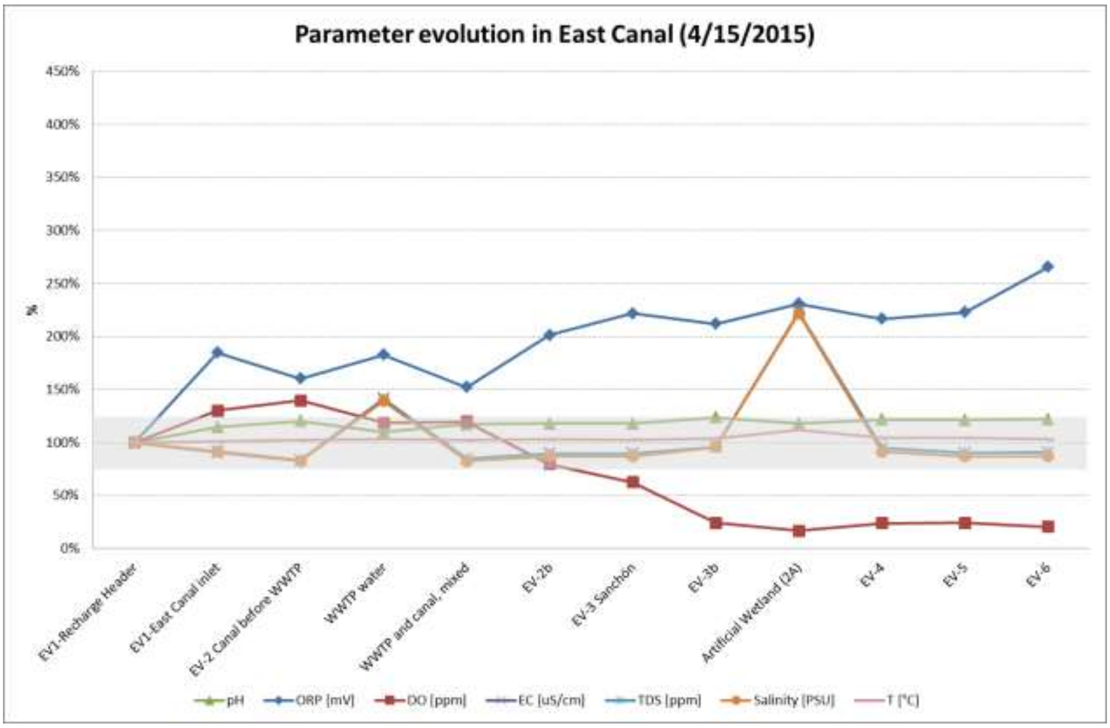
The data that were obtained through 2015 campaign can be interpreted in a similar way than in 2009 despite in the last year the number of sample points was conspicuously increased from 5 to 12 (Figures 3-39 where the triplet includes 5 sampling points, and 3-40 were 7 more were included).

DO falls again in the canal (40%) independently of WWTP inflow. Temperature only changes particularly in artificial wetland where water becomes stagnant. ORP concentration drops after WWTP mixture but then follows a clearly rising slope until it achieve a 1.5 fold balance. Turbidity goes up and down with a surprising out of range figure in canal (EV3b) at the same height than the artificial wetlands.

EC, TDS and salinity display a similar drift, as the high peaks in WWTP and artificial wetland are clearly restored to the baseline within the infiltration canal. The slender change of pH cannot be considered as related because it stays in the relevance border.

If data from the 2015 winter recharge season and spring recharge season are compared (figures 3-41), the effect of the WWTP dilution and the performance of artificial wetland can be observed in some parameters. Winter illustrates the rapid effect of treated water on recharging flow and how it gets subsequently neutralized on the canal. Spring induces some changes in the lower WWTP and EC, TDS, salinity, turbidity and temperature change in the wetland. Available parameters values from Santiuste are graphically illustrated in Annex V-1 for winter and spring circumstances.





Figures 3-41 a & b: Winter (a) and spring (b) unstable parameters evolution graph for Santiuste *triplet* (2015).

Santiuste biochemical parameters

The effect of lagooning WWTP efficiency seems to be rather limited according to the analytical results of the main 19 parameters selected (tables 3-5 and 3-6) from the 111 determined which are listed in the annex V-2, where have also been exposed their evolution graphs along the triplet.

This lagooning plant has been annually spilling around 0.5 hm^3 into the recharge canal since 2005 from the near little village of Santiuste de San Juan Bautista. Considering the concentrations that have been found in the WWTP water, some changes must be remarked: sulphates, Ca, DOC, Cl, alkalinity, hardness and As are increased between 200 and 400%, conductivity, Mg, Na, turbidity and nitrates in a range of 500-700%, K, P and phosphates in almost 2,000%. Caffeine and Ammonia content are respectively 5,600% and 14,211% higher in sewage. Only Fe and Cu concentration is lower in the effluent (63 and 74%).

Main chemical parameters suffer a quick recovery that sometimes is obviously a consequence of plain dilution as soon as WWTP spillway gets mixed with the huge volume of river water in the infiltration canal. Nevertheless, seven parameters (Figures 3-40 and 3-41) show a different behaviour in their decrease depending if they follow the canal (Cu, turbidity and Dissolved Organic Carbon) or they enter the artificial wetland (Fe, P, PO_4 and NH_4). Changes below 12% have been considered irrelevant.

Table 3-5: Parameter comparison with significant differences in canal (3 negative figures) and artificial wetlands (4 positive figures) 17/2/2015 (see Annex V-1).

STATION	Cu mg/l	Turbidity NTU	DOC mg/l	Fe mg/l	P mg/l	PO_4^{3-} mg/l	NH_4^+ mg/l
EV-2 Canal pre WWTP	100%	100%	100%	100%	100%	100%	100%
WWTP water	74%	546%	273%	63%	1902%	1910%	14211%
Artificial Wetland (2A)	84%	94%	125%	92%	130%	130%	263%
EV-4	32%	66%	97%	104%	149%	149%	289%
Difference EV4-AW2A	-53%	-28%	-27%	12%	19%	20%	26%
	Lower in canal			Lower in wetland			

El Carracillo triplet water sampling

Unstable parameters have been determined in five points along the "triplet" mock-up as shown in Figure 3-36 in order to check its performance.

Table 3-6: El Carracillo triplet water quality. Parameters collected in the 2015 and 2016 campaigns during the MAR cycle (Means taken from 2 measurement campaigns)

Description	ORP [mV]	pH	TDO Kit (ppm)	TDO [ppm]	EC [µS/cm]	Resistivity (mOh)	TDS [ppm]	Salinity [PSU]	Turbidity (FNU)	T [°C]
Infiltration pond	110,8	7,5	8,8	9,97	239	0,0042	120	0,11	3,4	5,56
Canal	119,1	7,3	5,25	4,11	249	0,0040	125	0,12	5,2	5,1
Artificial Wetland inlet	123	7,5	7,6	8,9	228	0,0044	114	0,11	4,7	6,1
Artificial Wetland outlet	125,2	7,6	8,7	10,4	220	0,0045	110	0,11	5,7	6,03
Infiltration field	140	7,05	10,1	10,2	203	0,0049	101	0,1	3,1	9,8

The data from tables 3-5 and 3-6 have been represented in the figures 3-42. Considering the parameters in the infiltration pond as a 100% and the rest in the triplet as a percentage related to that one. A grey stripe marks the +/- 15% interval to point out substantial changes.

- Dissolved Oxygen concentration in water (both Hanna and Merck Kit measurements) goes down significantly in the canal (60-40%) but then rises again in the wetland so it is back to the same level in the infiltration field.

- Water temperature rises high, up to 1.8 times, as soon as water depth shrinks in the spreading field and increases its surface in contact with air.
- The ORP and Resistivity (R) grow all through the triplet length.
- Turbidity increases in the canal and wetland as water gets mixed with vegetal and microorganism growth (x 1.5 times) but it finally recuperates the primary value in the spreading field.

The other water parameters do not show a noteworthy change in the triplet by now.

- Conductivity, TDS and salinity follow the same trend: increase in the canal and fall as water goes across the triplet but changes are not noteworthy.
- pH falls in canal and infiltration field but rises in the wetland surface.

As water comes directly from a river, MAR quality is quite acceptable, being the biggest constraint the high TDO concentration, exceeding 12 ppm frequently, enough to be rejected due to hyper-oxidizing conditions and the pairing “Lisse effect”. The TDS concentration is brought down by means of wetland. Reducing the TDO requires the full triplet´s intervention.

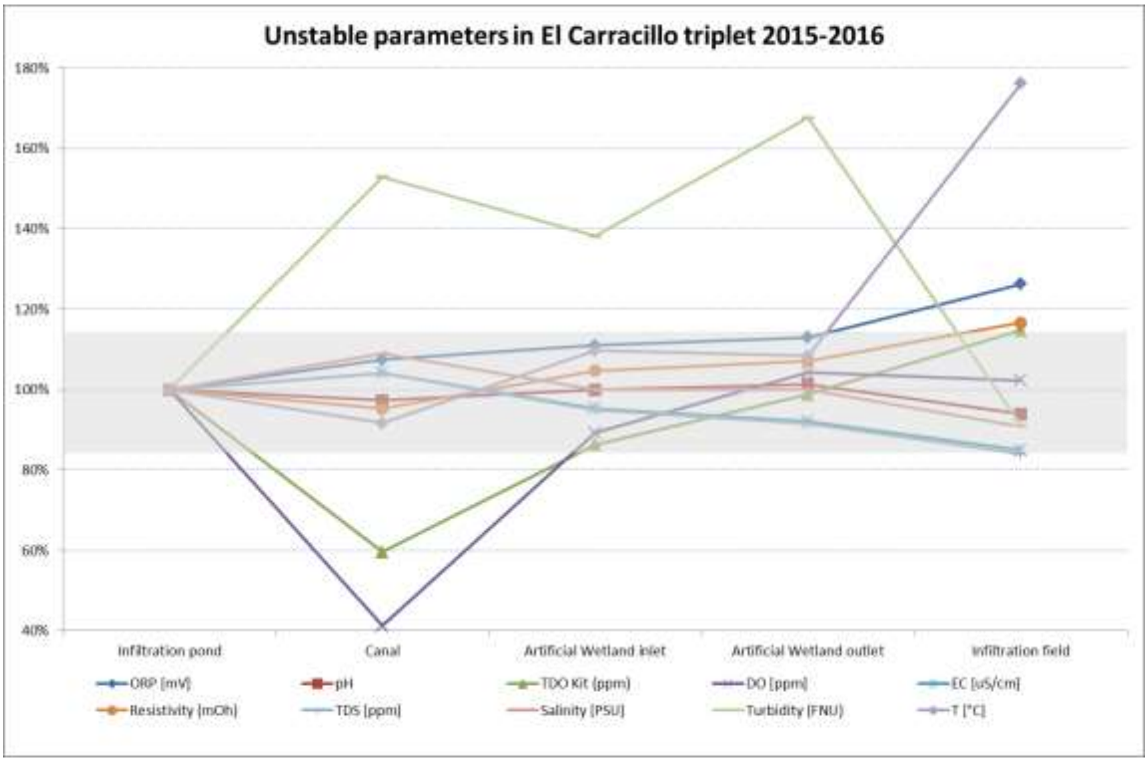
After analysing the results, in this case, the triplet is providing a general water quality improvement smaller than in the previous case, due to the fact that it is about 1/50 shorter and the quality of incoming water is better so improving is less notable.

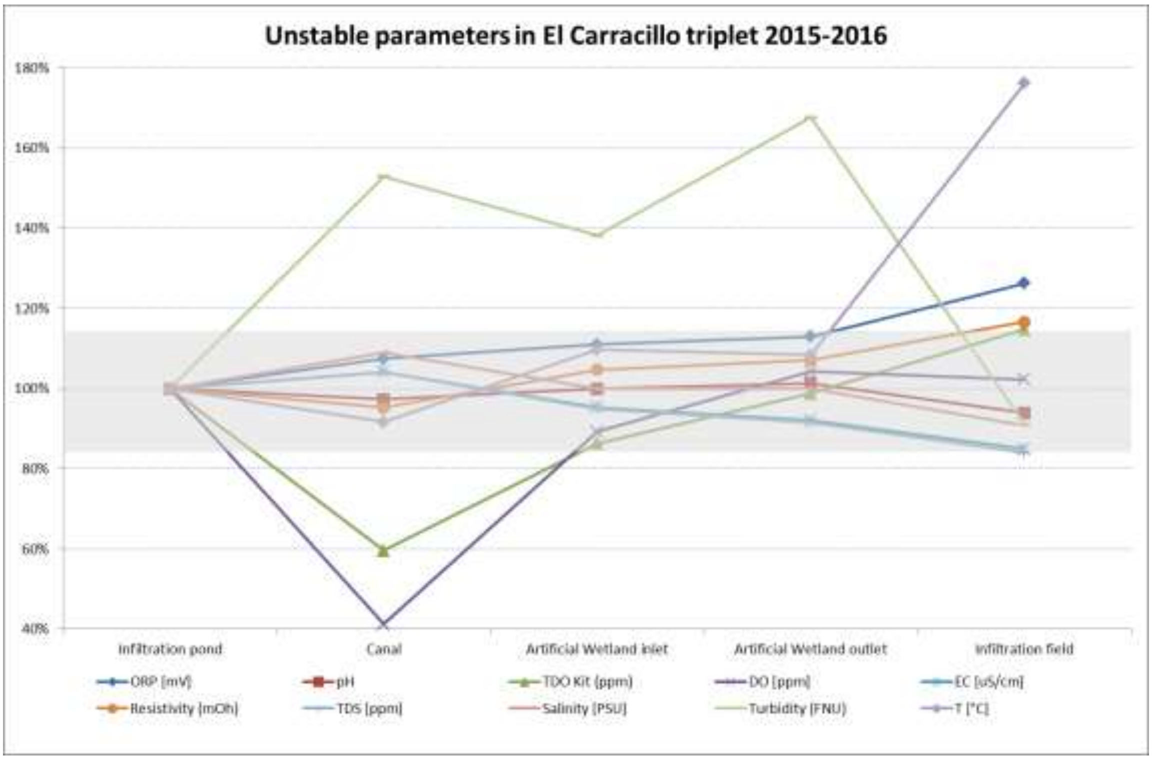
The main target, that is to bring down the total dissolved oxygen parameter, is achieved in canal. Any cascading effect is avoided along the whole assembly, where are not stopping devices and the gate at the exit of the infiltration pond works as a communicating vessel system.

Infiltration field is a distorting element in the comparison of both triplets as it plays the role of an upper water level outlet from the wetland, acting as a decanter, which permits a shallow clean water supernatant to run on a broad grassland. This does not happen in Santiuste, thus, El Carracillo triplet final step has not been inspired in any previous device.

Artificial wetland plays a very valuable ecological role as a shelter for bird life in a zone where agriculture pressure has dried many temporal natural ponds.

Though it cannot be considered as a general solution for floods, the facility implemented at the end of the triplet represents a new available emergency solution in Los Arenales for flood events.





Figures 3-42 a & b: Unstable parameters evolution graph in El Carracillo triplet (2015-2016).

COMMENTS ON THE RESULTS

According to both Triplets results, some general conclusions can be obtained:

- The water flowing along a vegetated infiltration canal helps to decrease the Dissolved Oxygen, diminishing the risk of clogging in the canal bed and the subsequent decrease in recharging rate.

- There are some hints about the evolution of parameters along the triplet as well as some seasonal trends:
- pH, in general increases along the triplets.
- ORP tends to stay balanced along the canal.
- TDO gets the highest values in winter time. In spring it decreases with the purification process and the presence of blooms. After the artificial wetland it registers a slight upward trend along the canal. In Santiuste Triplet TDO has a downward trend up to 5.2 ppm, whilst in El Carracillo, only gets to 0.3 as an average. All through the infiltration canals TDO tends to decrease.
- EC, salinity and TDS show their highest peaks in the vicinity of the WWTP and in the artificial wetland in spring. In the canal they stay balanced.
- Temperature rise at the top of the column in the artificial wetland in spring.
- The effect of the plants in the MAR canal breaks the clogging layer with a direct positive effect on the infiltration rate. El Carracillo biofilter (due to its short 120 m length) induces a very slight change of water quality properties.

The analysis of 19 biochemical parameters in Santiuste has also shown some preliminary data about:

- Improvement in water quality: Decrease of NO3 (29%), Cu (68%) and turbidity (34%) in canal (EV-4) related to the inflow from Voltoya River (EV-2).
- Passive biological purification by dilution, sedimentation and biological activity in every single parameter (EV-4) in comparison to WWTP and according to data in some elements as Fe, P, phosphates and Ammonia in artificial wetlands (AW2a) in contrast to the canal (EV-4).

CONCLUSIONS ON TRIPLETS PERFORMANCE AS A SAT-MAR TECHNIQUE

“Triplet” has been the name adopted to define a SAT-MAR structure for surface MAR facilities integrated by three elements to purify MAR water during the recharge process: a WWTP which effluent is used for recharge, a green biofilter and at least one artificial pond to finish the purification process. Hence mixed water volume receives a treatment as long as the recharge process is accomplishedin the canal and ponds. In the demo-sites the triplet structure length has 200 m (El Carracillo) and 2.7 km long (Santiuste) respectively.

It starts at the junction WWTP-MAR canal with water from fluvial origin. After the purification process, the water returns to the MAR canal.

The lagooning WWTP presents a volume of reclaimed water / fluvial water below 5%, posing a high concentration of biological processes at the bottom.

The green biofilter has a double function: on the one hand has a purifying activity on the potential pollutants by plants; and on the other the roots pierce and break the clogging in the canal, increasing the infiltration rate.

Most of the inventoried species are hydrophilic herbaceous with an annual cycle, rapid growth, high root expansion and ease of extraction with roots. According to the currently obtained datasets [23], the balance between the water infiltrated and the amount consumed by the biofilter plants is still positive for the aquifer storage.

The artificial wetlands cover a double function as well: the purification of the water stored in the vessel and a complementary environmental function, as a shelter for flora and fauna.

Water proceeding from a WWTP is scarce in these examples (<5%). Unfortunately, the effects with a bigger volume cannot be tested in these facilities in Los Arenales aquifer.

The advantages of water quality improvements permit to obtain new volumes from increasing sources as WWTP and SWTP in order to balance the decrease or instability of natural origin (as more exceptional winter surpluses) in a Mediterranean area.

By means of appropriate SATs techniques such as water pre-treatment, in itinere filtering, and the “in-treatment”, the efficiency of the system has increased considerably regarding not only water quality but also groundwater quantity storage.

SAT-MAR facilities might be included in the current operative schemes and each “triplet” mock-up must be “tailor made” according to each aquifer´s characteristics.

This experience throws excellent opportunities for a bigger presence of MAR facilities in IWRM schemes, especially for those involving SAT-MAT elements.

It cannot be considered as a general solution for floods but the facility implemented at the end of theCarracillo triplet represents a new option available in Los Arenales extrapolable to other assimilable zones.

3.3.2 Chemical assays and purification measures along the conductions in Alcazarén MAR Plant

In order to fulfil the objectives mentioned in DoW, task 5.2, pg. 22 and to test different filtering systems and materials under hyper-controlled situations, it has been designed a new pilot-scale device attached to Alcazarén WWTP, with a slight modification of the current infrastructure.

A series of tests have been conducted between 2016 March and August, straining the reclaimed water with inorganic and organic different filters.

The permanent presence of the WWTP worker has allowed a permanent track of the different tests and series of datasets ready for interpretation.

Firstly, field trips were made in order to collect the necessary information for find the most suitable location to perform SAT-MAR techniques. As a result the selected place is the Waste Water Treatment Plant in Pedrajas de San Esteban, in Alcazarén Area, the most recent plant of Los Arenales demo-site. This area is depicted in figures 3-43 and 3-44.

DESCRIPTION OF THE FACILITIES AT ALCAZARÉN SITE

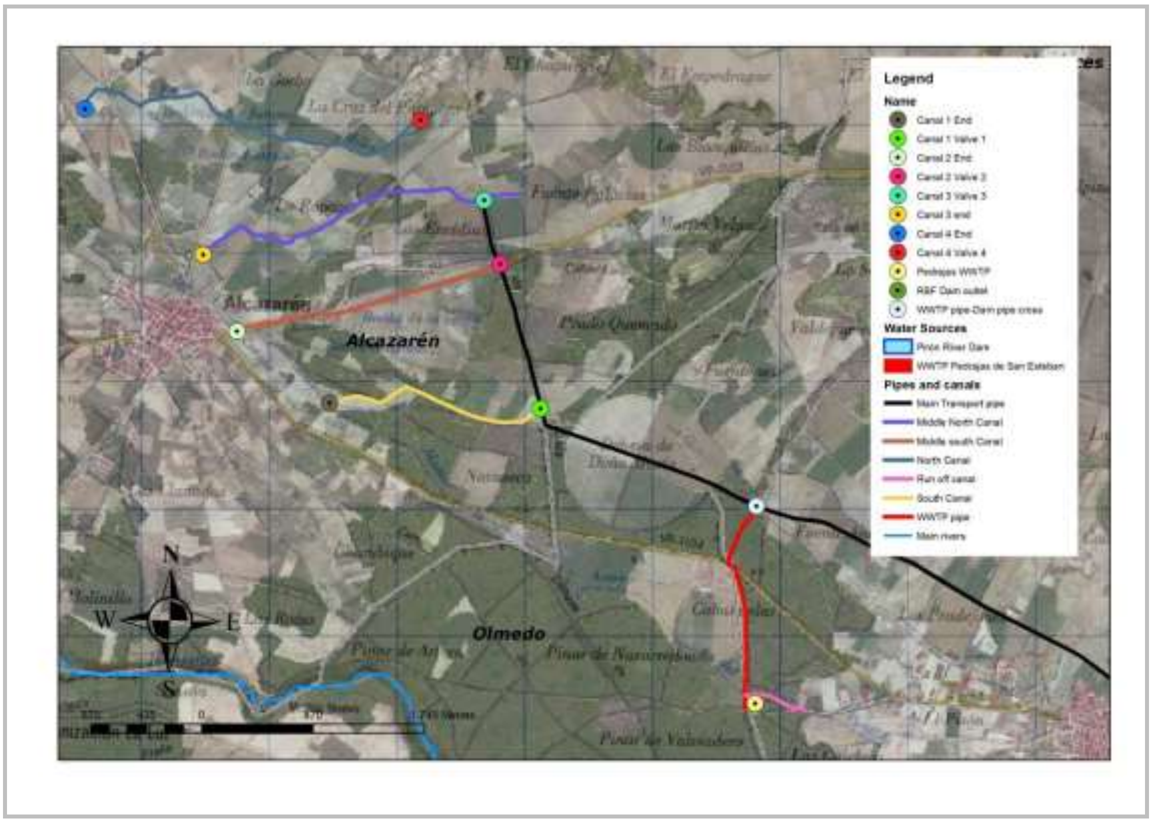


Figure 3-43: Alcazarén area. Cartographical mock-up for the MAR facilities in the area.

Figure 3-43 presents the Alcazarén area sketch where these tests have been accomplished. The description of the aquifer and its hydrogeological conditions have already been exposed in MARSOL deliverable 5-1 (MARSOL, 2015a).

Water proceedings from the WWTP has been driven to the “connection point” where is eventually combined with water proceeding from Pirón River and from the Pedrajas Village runoff (figure 3-44). The connection point has a concrete chamber where different filters have been tried. There is a 2-km-long stretch between this point and the spillway used to test the *in itinere* treatment inside the same pipe (blue triangle in the accompanyning figure). The final collecting samples point is the place where the disinfectants addition effect has been analysed and monitored in the valve 2. The figures 3-45 complement this scheme by means of six photographs that capture these singular points.

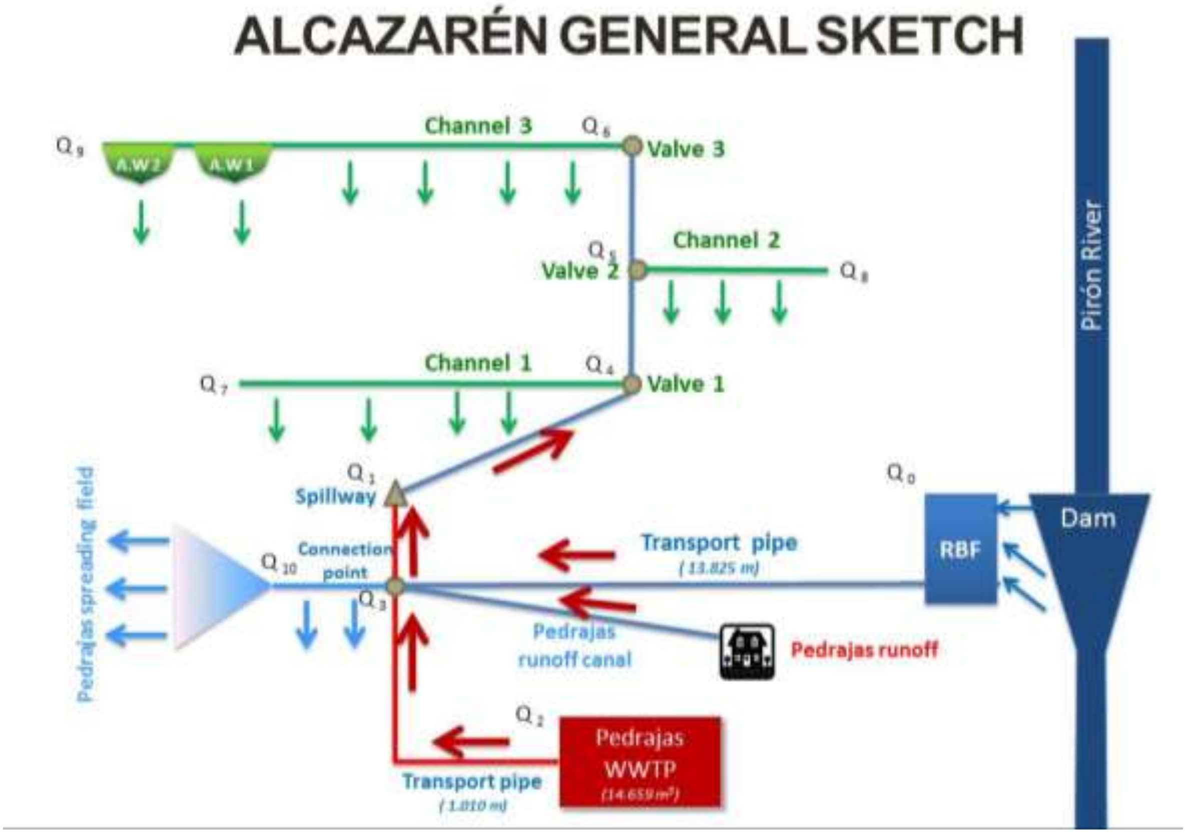


Figure 3-44: Alcazarén area general sketch where the conductions and piping tests have taken place. Topologic scheme.

Real distances between the referred points at figure 3-44 are:

- Input and output points in the WWTP: 56 m.
- Distance between the exit point and the different water sources connection: 117 m.
- Distance between the connection and the spillway: 1,190 m.
- Distance between the spillway and valve 1 point: 3,430 m.
- Distance between valve 1 and valve 2 points: 552 m. (spillway to valve 2: 3,982 m).
- Distance between valve 2 and valve 3 points: 990 m approximately.

OBJECTIVES

The design of filtering and interaction systems to improve the water quality for MAR is another important target within MARSOL project objectives. The most remarkable adhered objectives have been:

1. Reclaimed water quality evolution after the interaction with filters made of gravel/grit/sand and geofabrics.
2. Reclaimed water quality evolution after filtration across reactive layers (biofilm).

3. Purification measures along the conductions after filtering, interaction with different disinfectants and with biofilms “in itinere“.
4. Reclaimed water quality evolution and response to chemical additives or Disinfection By Products (DBPs)
5. Solar exposure´s effect on reclaimed water.

Figures 3-45 a to f: Alcazarén MAR system´s singular points: Pedrajas WWTP (a); connection point where converge water proceeding from the WWTP, runoff and Pirón river diversion pipe (b); runoff canal proceeding from Pedrajas village (c); spillway (d); valve 2 monitoring cage (e) and final sandpit used as a infiltration pond (A.W. 2) (f).

MATERIALS AND METHODS

The planned activities consist on the filtering of the WWTP effluent by different materials (gravel, grit, sand, organic compounds) next to the WWTP (figure 3-44, red point). The point to drop the disinfectant liquid has been at the exit of the WWTP. Sample collections spots have been the spillway (blue triangle) for the filtering results and valve 1, 2 and 3 for the three respective disinfectants.

Results have been tested in the green points, collecting samples which will be sent to laboratory.

ADDITIONAL CONSTRUCTIONS IN THE DEMO SITE (ALCAZARÉN PLANT)

- First stage: At the beginning of 2016 February, some modifications were applied to the previous casket at the exit of the WWTP where samples were being collected. Gravel was inserted inside the casket to enhance the filtration process, closing the spillway to Pirón River and constructing a security mechanism to avoid over floods (figure 3-46).

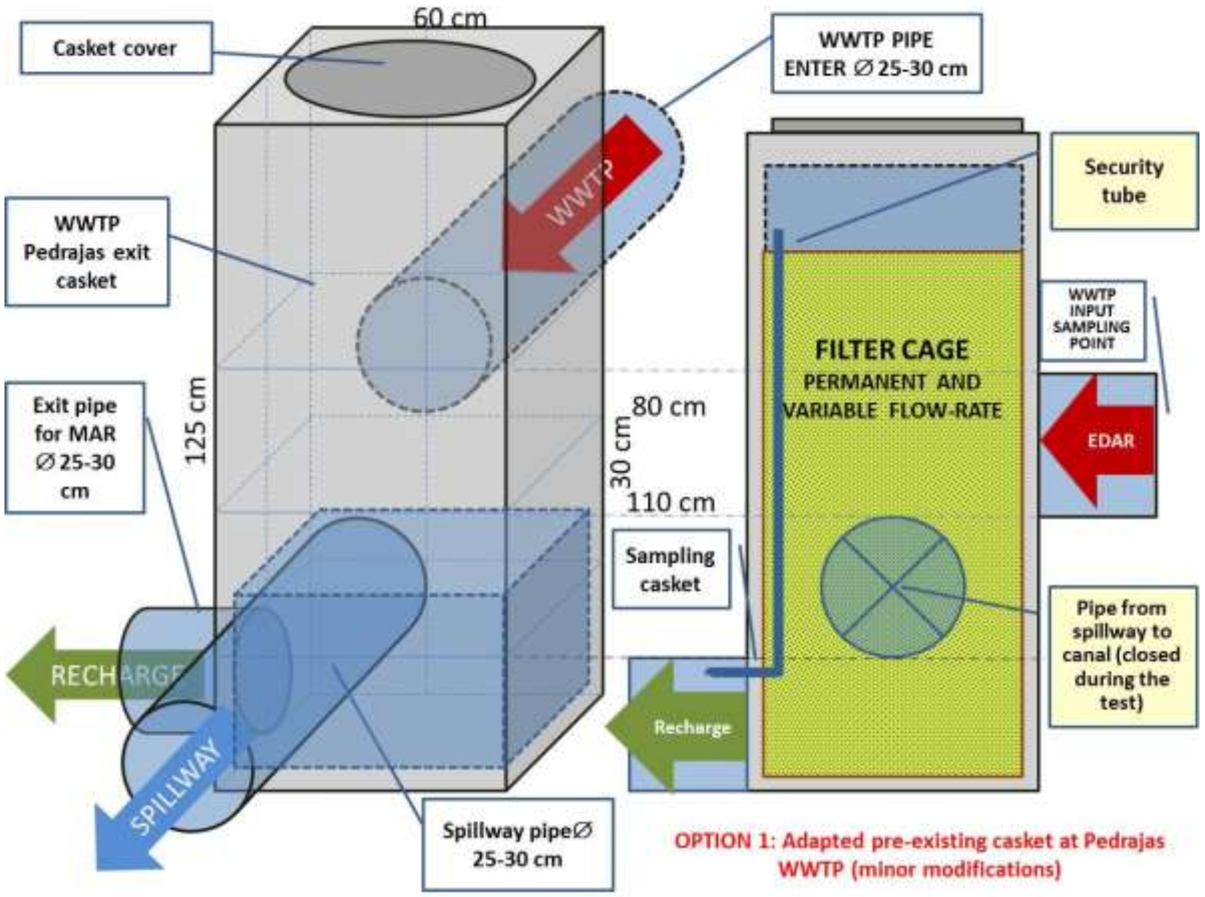


Figure 3-46: Initial filter casket with slight modifications

Figure 3-47: WWTP casket at the exit of Pedrajas de San Esteban WWTP (a), modifications for the gravel box (b) and preparation of the filter box and double spillway after the WWTP (c). 2016, February.

Due to the fact that over friction by loss of load increased over expected forecasts, a new and specific construction 100 m down the pipeline was built (2nd stage).

- Second stage: From 2016 March to August some in-pipeline modifications at the convergence point of runoff, river and WWTP waters were conducted. This option required the construction of new elements such as lateral concrete walls to avoid flooding, a cage with embedded channel filter material, a lift gate and a tube to connect the runoff canal and the admixture chamber. Inorganic and organic filters were inserted into plastic boxes refilling completely the chamber capacity (figure 3-48).

The new structure has several advantages, e.g. the over flooding risk was minimized, installation of multiple modular filter cages adapted to the chamber in length and depth, large volume capacity to filter on continuous and its use is independent of the WWTP.

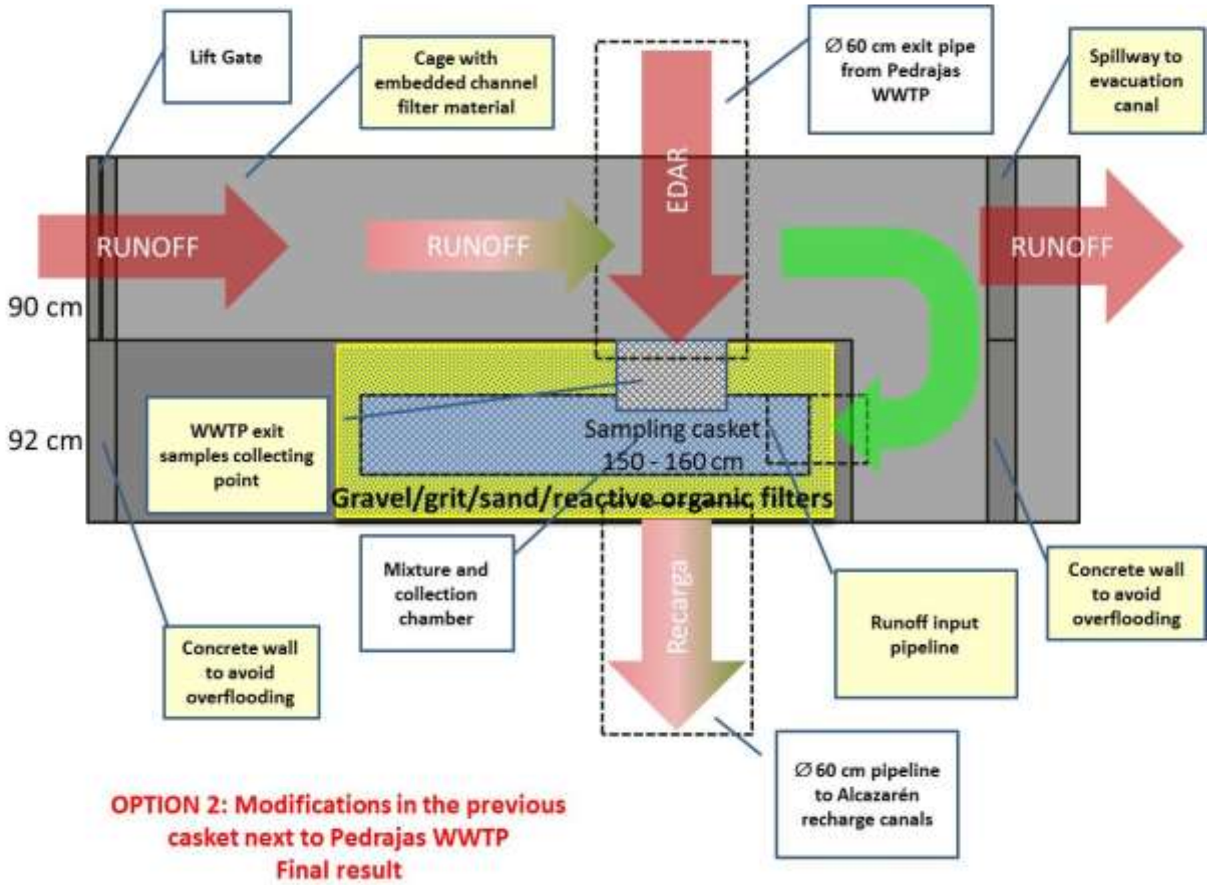


Figure 3-48: Specific system to perform the tests constructed in the point where the three different water sources converge.

METHODOLOGY. MEMORY OF ACTIVITIES

There have been combined five types of different filters, three inorganic and two reactive materials, three DBPs tests using two different disinfectants (hypochlorite and hydrogen peroxide) and water samples have been collected in six consecutive campaigns in different points of the circuit.

The activity started in February 2016 when the already described constructions were finished.

1. On March 10th was inserted the first filter in the final location, composed by 12-20 mm Ø siliceous gravel. Samples for chemical analysis were collected on March 15th (1st campaign) in the spillway point (figures 3-49) and later displaced to the connection point (figures 3-50). The parameters analysed in the laboratory were: Temperature in situ; O_2 (TDO); Conductivity; BDO_5; CDO; TDS; pH; SS; turbidity (NTU), DOC, nitrogen phases (total, Kjeldahl, nitrates, nitrites, ammonium); nematodes and *E. coli*.

Figure 3-49: Alcazarén area. Initial installation to test different filters next to Pedrajas WWTP. 2016, March.

2. -April, 6 and 7th the filter was replaced by 20-40 mm Ø calcareous gravel, proceeding with a new sampling campaign on April 20th (2nd campaign) in the spillway point too.The parameters determined in the laboratory were the same than in the previous case, including faecal coliforms as well.

Figure 3-50: Alcazarén area. Test with an inorganic siliceous gravel filter combined with a metal grid in the final testing area 100 m downstream the WWTP.

3. May 27th, after a rainy period, a new filter was set up composed by 6-12 mm Ø siliceous grit combined with sand inside geofabrics satchels. The first DBP took place dropping 50 l of hypochlorite during 36 h on June 8th. Samples were collected in valve 2 point on June 9th in with valves 1 and 3 closed (3rd campaign, figures 3-51). Parameters analysed were the same than in the previous campaign including residual Chloride.

Figures 3-51: Alcazarén area. Test with an inorganic calcareous gravel filter combined with a metal grid.

1. June 28th, the grit filter was replaced by an organic reactive one composed by 150 kg of pine bark (reactive layers employ materials cheap and abundant in the area) inserted into geofabrics sacks and compressed by gravel sacks located above in order to pressurize the filter. Samples were collected in valve 2 point on June 29th (4th campaign, figures 3-52 and 3-53). Residual chloride was not analysed in this case.

Figure 3-52: Alcazarén area. Test with an organic reactive layer (pine bark filter).

Figure 3-53: Alcazarén area. Organic reactive layer.

2. July 13th, maintaining the organic filter, the second DBP took place, dropping 60 l of hydrogen peroxide 60% concentration (71,46 kg) during 36 h. Water samples were collected on July 14th in valve 2 (5th campaign; figures 3-54 and 3-55). Residual chloride was not analysed in this case.

Figures 3-54: Alcazarén area. DBP test dropping hypochlorite at the exit of the WWTP, samples collection at valve 1 point and determination *in situ* of unstable parameters.

Figure 3-55: Alcazarén area. DBP test dropping hypochlorite at the exit of the WWTP and samples collection.

The results of the chemical analyses of the different campaigns collected by Aqualia Company and analysed in their own laboratory have been included as ANNEX V-3 (SAT-MAR studies). None free Chloride from the DBP was found at the end of the circuit.

Nº campaign	Date	Filter
1	15-mar-2016	12-20 Ø siliceous gravel
2	20-abr-2016	20-40 Ø calcareous gravel
3	09-jun-2016	6-12 Ø siliceous grit/gravel
4	29-jun-2016	Pine bark + geofabrics + DBP 50 l Cl_2
5	14-jul-2016	Pine bark + geofabrics + DBP 50 l H_2O_2

During the whole testing period, precipitations data were measured in the Pedrajas village´s meteo station. The results are presented as figure 3-56.

In these facilities there is an unique area to test the effect of the solar exposure on reclaimed water, due to the fact that it is an in-pipe line circuit. It is a little pool at the exit of the WWTP circuit where reclaimed water is submitted to solar exposure just after the sludge digestion process.

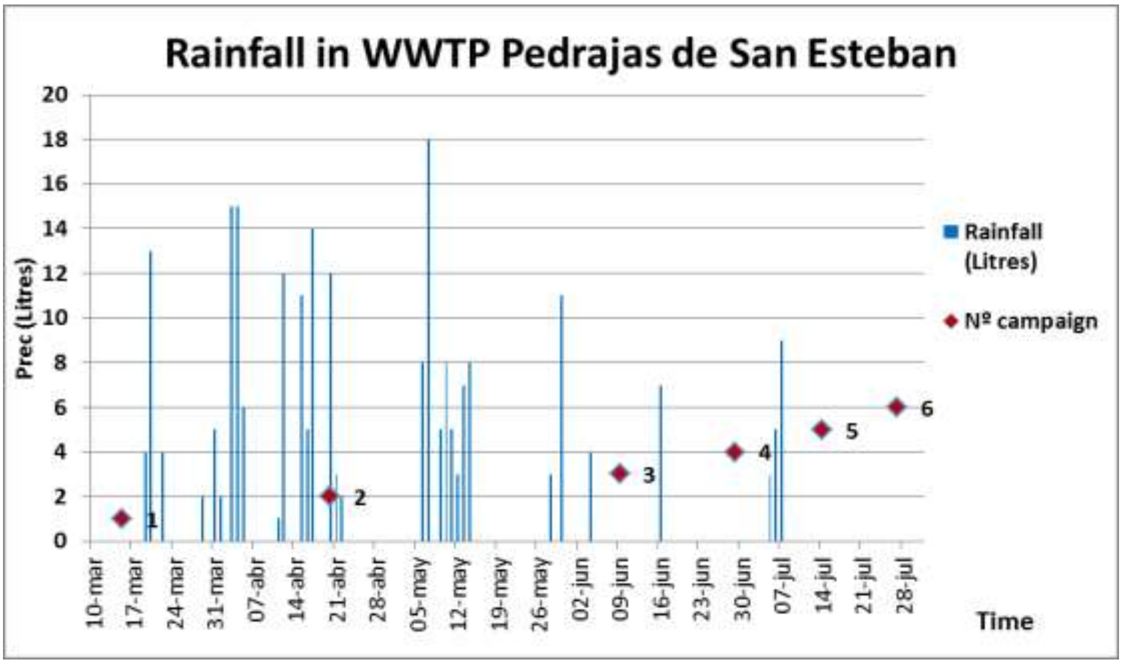


Figure 3-56: Precipitations measures along the tests slot. Water sample campaigns are included in the chart.

In order to achieve some practical advices regarding solar exposure, input and output water have been compared. The effect of the solar light on reclaimed water appears to be satisfactory and a good design criteria for improved designs (see paragraph 3.3.3 where initial solar exposure is complemented with a later light and heat reception in the recommended artificial wetlands).

In order to improve the reclaimed water quality to become a source for secure irrigation and eventual indirect potable reuse purposes, all contaminations with pathogens as well as organic and inorganic pollutants should be avoided. To this end, understanding and enhancement of the degradation biogeochemical processes occurring within the post-treatment and during the aquifer infiltration are capital.

RESULTS AND DISCUSSION

Reclaimed water quality evolution after the interaction with filters made of gravel/grit/sand and geofabrics.

SAT-MAR is considered a series of techniques willing to enhance the attenuation of pollution using natural processes occurring through infiltration in the unsaturated zone.

The presence of inorganic filters has had the constraint of the scarce time of residence; water has crossed the filter in a matter of seconds, and the interaction processes have been very short in time.

There have not been observed important differences in the resulting chemical composition of the water using calcareous or siliceous gravel packs. A fact that, logically, has been adverted was the reduction in the total amount of suspended solids, especially with the gravel and grit filter.

The use of geo-fabrics has also retained a certain amount of suspended solids, with a rather scarce or unappreciable influence on the reclaimed water composition.

Regarding organic carbon (TOC) it has become the most important parameter to be controlled, due to the fact that a certain amount of TOC has been observed in an ascending trend at the closest piezometers. The reduction of this parameter is adverted with all the filters employed, and especially with those of organic composition.

Reclaimed water quality evolution after filtration across reactive layers (biofilm).

Permeable Reactive Barriers (PRBs) are installed in the flow path of the recharge circuit in order to improve the water quality in the MAR system. The contaminants in the plume react with the media inside the barrier to either break the compound down into harmless products or to immobilize contaminants by precipitation or sorption.

The main objective of the action was the evaluation of the efficiency of the organic substrate layer installed along the circuit in terms of the evaluation of DOC and the variation of redox conditions by the reactivity of the organic layer. To characterize the studied system and to evaluate the effects above mentioned several physical-chemical parameters were selected and analysed such as global indicators (pH, conductivity), nitrogen compounds, organic bacteria colonies and some inorganic combinations.

The organic filters to be installed in the demonstration site were selected due to their high availability in the zone and cheap prize. Both organic reactive filters, pine bark (figure 3-52b) and pine rachis (figure 3-54b), were mixed with natural soil. Moreover, a small fraction of clay (2% of the total volume) and iron oxides (1% of the total volume) were added to improve the ionic adsorption.

Both have had a clear interaction on TDS and DOC parameters improvement. These tests must be studied separately because some disinfectants were poured during the different stages of the experiments.

The geofabrics tested had rather a function of retaining the organic filter units than a filtering process. Gravel used as a weight to pressure the reactive layer sacks did not have any effect on the filtering process. The ultrafiltration process has not been achieved in these tests, characterized by the fast speed and the high porosity of the filters used.

Purification measures along the conductions after filtering, interaction with different disinfectants and with biofilms "*in itinere*".

The SAT-MAR tests applied have required a set of reagents in order to optimize the operation, such as: hypochlorite, sodium hydroxide, hydrochloric acid, anti-fouling to prevent precipitation of salts, bisulphite to prevent oxidation of membranes and biocides for periodic cleaning. This group of additives are usually used in the purification process.

Three of the experiences carried out had an addition of some disinfectant in order to perform a DBP post-treatment. The chosen compounds were hypochlorite and hydrogen peroxide.

It is important to advance that the chloride doses dropped into the reclaimed water did not retain any amount of residual chloride in the observation points. This fact is attributable to the presence of organic matter in some stretches inside the pipeline, where, according to oral manifestations from the farmers, a certain amount of organic carbon is concentrated in zones with a very low slope and it is detected by its stench. The interaction between the additional chloride and the water along the course has caused purification in itinere, guaranteeing that zero residual chloride has been directly aggregated to groundwater.

The interaction between chloride and the reactive layer has been practically negligible; no modifications along the canal have been detected.

Regarding Hydrogen peroxide addition and its effect on TDO, several measures were taken along the circuit by means of a multiparameter sensor. As in the previous case, oxygen reacted with the TOC in the reclaimed water, reducing the organic vectors, but, no increase in the TDO parameter has been detected in the areas where recharge water arrives to MAR infiltration facilities. The observed effect has been positive in all the measured parameters except for turbidity, with a slight registered elevation.

After the post-treatment process and close to the recharge canals, reducing conditions are mainly observed in unsaturated zone. Higher concentrations of nitrites and N-ammonia (compared to untreated recharge water) were found (campaign 3), exposing a significant decrease on nitrate concentration in the passage of the infiltration water towards the receiving medium, except in the 1st and 2nd campaigns, when total nitrogen content raised slightly.

Reclaimed water quality evolution and response to chemical additives (DBPs)

According to the water quality evolution charted for most of the analysed parameters (see graphs in annex V-3); some of them have significantly changed and all of them deserve a separated treatment:

- **Conductivity**: The evolution of this parameter along the circuit (from the WWTP to the valves in the heading of the MAR canals) has not a clear trend, coming down in the tests where thick gravel was used as a filter for both, siliceous and calcareous (1st and 2nd campaigns). In the 5th campaign, with addition of H_2O_2 for a DBP test, conductivity descended down along the in-pipe circuit, what is coherent with the expected “in itinere” purification.

- **BDO5**: The effect on BDO5 is clearly positive. There is a general descent along the pipeline except for the 2nd, using calcareous gravel as a sifter. The use of disinfectants products has conducted a progressive decline for this parameter.
- **COD**: The trend is parallel to the previous one, with a parallel behaviour, as it is expected.
- **TDS**: This parameter increased abruptly in the first campaign, using siliceous gravel as a filter. In the remaining campaigns TDS tends to come down slightly along the in-pipe circuit.
- **TSS**: Suspended solids and dissolved solids evolution do not keep a parallelism. The general trend is to decrease, except for the 2nd campaign, using calcareous gravel as a filter, when the tendency was opposite to the general behaviour.
- **Turbidity** (NTU): Oddly enough the line tends to rise, except for the 3th test, where the use of a finer filter constituted by grit and gravel caused the expected effect. Even the addition of Hydrogen Peroxide did not bring down the turbidity, thus, presumably, it has a high inorganic component.
- **DOC**: This is the sole parameter with a general bearish tendency. The biggest slope was caused by the finest filter. The addition of chloride has also caused a direct descent on DOC, being steeper with the addition of H_2O_2.
- **Total nitrogen**: The evolution is not very clear for most of the nitrogen phases, except for nitrates, with a crisp descent trend during the episodes when both disinfectants were dropped in the reclaimed water and reactive filter layers were employed.
- ***E. coli***.: The trend has been notably descending during the spring. Once the summer time began, this sort of bacteria has appeared with a certain intensification along the circuit. Obviously they were removed in itinere by the addition of chloride.

Solar exposure´s effect on reclaimed water.

In these facilities there is an unique area to test the effect of the solar exposure on reclaimed water, due to the fact that the rest of the plant is an in-pipe line.

There is a little pool between at the exit of the WWTP circuit where reclaimed water is submitted to solar exposure after the sludge digestion process. In order to achieve some practical advices regarding solar exposure, input and output water have been compared. The effect of the solar light on reclaimed water appears to be satisfactory and a good design criteria for improved sketches (see paragraph 3.3.3 where initial solar exposure is complemented with a later light and heat reception in the recommended artificial wetlands). Due to the short distance between the output point and the connection point, the evolution of the parameters is insignificant and it has not been tracked.

CONCLUSIONS

The results have demonstrated that all the filters had a certain effect on water quality, resulting obviously maximum for the finest ones. The organic layer has had a positive effect on water quality and especially for the Organic Carbon, with a direct reduction and a clear purification in itinere along the pipe-line circuit.

Neither TOC nor free chloride has arrived to the infiltration canals in unacceptable conditions. The treatment with both disinfectants, chloride and hydrogen peroxide, has been powerful, reducing the impact on the aquifer by progressive TOC accumulation.

The tests, therefore, have been useful as a demo activity to reaffirm its main objective: the incorporation of a reactive layer prior recharge of reclaimed water has a positive effect on the reduction of groundwater pollutants, enhancing their biological degradation and therefore, improving the general water quality for the final intended uses.

The tests have successfully validated the use of both, inorganic and reactive organic filters removing certain pollutants from reclaimed water to be used for recharge. It has been demonstrated that it is possible to improve natural decontamination processes and increase natural sorption capacity with the installation of reactive organic material in different additional points along the MAR course. It is worth also to mention that after several weeks of continuous post-treatment and recharge, the reactive layer was still active. Therefore, this technology is likely to be useful for longer-term applications, considering the little scale of the experiment and also the short time of exposition.

The project demonstrated that physical, chemical and biochemical processes associated with MAR plants represent a natural, passive and affordable way to reduce the presence of certain contaminants, with economic and environmental benefits. No negative effects have been observed in the infiltration rate due to the post-treatment processes, according to the scarce variations in the piezometers water table level.

Regarding energy savings, soft techniques should be used for sprinkle and drip irrigation. Greater improvements require hard treatments such as ultrafiltration membranes (UF) and reverse osmosis (RO) technologies, what require enormous power needs and an investment difficult to recover in the cost-benefit binomial.

These results have been transferred to the working group in charge of revision of the Water Framework Directive (2000/60/EC), where two MARSOL individuals take part, providing modifications for the future text of the major water Directive.

3.3.3 Proposal for an improved lagooning Waste Water Treatment Plant design

Within the MARSOL SAT-MAR objectives (Task 5.4. SAT-MAR studies), there is another remarkable target related to rural development which is the *improvement of lagooning WWTP designs willing to improve the reclaimed water quality by means of advanced techniques*. It is worth to remark that lagooning WWTP facilities are very often in several zones of Los Arenales aquifer and there are some important examples of the relation between them and some MAR facilities.

This study must be based in a legal background. In this demo site applies the Spanish 2007 Royal Decree 1620 , about the reclaimed water reuse (*Régimen jurídico de la reutilización de las aguas depuradas en España*). It focusses on the possible uses of reclaimed water, as well as the quality criteria that they must comply for each specific use. Regarding the point 5.1 about "quality" the regulation specifies the maximum allowable values for certain parameters and compounds to use reclaimed water for environmental uses, and more specifically, for artificial recharge of aquifers, using the term: "localized percolation through the ground" (Table 3-7).

Table 3-7: Quality criteria required for environmental use of reclaimed water according to R.D.1620/2007; point 5.

INTENDED WATER USE	**MAXIMUM ALLOWABLE VALUE (M.A.V.)**				
	NEMATODES	**ESCHERICHIA COLI**	**SUSPENDED SOLIDS**	**TURBIDITY**	**OTHER CRITERIA**
5.- ENVIRONMENTAL USES					
5.1 QUALITY **a) Aquifer recharge by localized percolation through the ground.**	**No limit is set**	**1,000** **CFU/100 mL**	**35 mg/L**	**No limit is set**	**Total N[1]: 10 mg N/L** **NO_3 : 25 mg NO_3/L** **From art. 257 to 259 of *RD 849/1986***
5.2 QUALITY a) Aquifer recharge by direct injection.	1 egg/10 L	0 CFU/100 mL	10 mg/L	2 NTU	
5.3 QUALITY a) Irrigation forests, parks and other non-public. b) Forestry.	No limit is set	No limit is set	35 mg/L	No limit is set	OTHER CONTAMINANTS contained in the wastewater authorization for the discharge: It should limit the input of these contaminants into the environment. In the case involved of hazardous substances shall ensure compliance with the Environmental Quality Standards (EQSs).
5.4 QUALITY a) Other environmental uses (maintenance of wetlands, minimum flows and similar).	The minimum quality required will be studied case by case basis				

[1] **Total Nitrogen**, sum of the inorganic and organic nitrogen present in the sample

This regulation also states that each River Basin Authority has the ultimate responsibility for the final quality of the effluent to be reused, in the following terms: "River Basin Authority, in the resolutions that grant concessions or authorizations for reuse, can set values for other parameters or contaminants that may be present in reclaimed water or provided under the sectoral regulations applicable to the intended reuse. In case they impose more stringent levels of quality, these latter ones must be established in a reasoned manner".

SAT-MAR recharge techniques applicable for lagooning WWTP put apart that sort of measures relating MAR by "direct injection". SAT-MAR techniques are normally aimed at removing or minimizing certain pollutants from wastewater, especially organic vectors and nitrogenous compounds, reducing physical, biological and chemical clogging, removing a certain amount of suspended solids and microorganisms as well as reducing phosphates, metals and air dissolved concentrations in the water. In short, these techniques take advantage of the soil / aquifer complex capacity for the regeneration of water.

In a first approach, it is important to consider the dimension assessment of the plant prior applying SAT-MAR techniques. It is also essential to define low-cost complementary treatments optimizing the processes to remove different pollutants from wastewater, in order to achieve the quality standard required by law. These type of actions are usually applied at the soil and thus, indirectly, the aquifer.

There are many lagooning treatment plants in the Spanish territory which initial design is unable to accomplish the quality objectives at current mandatory levels (specified in 91/271/EEC Directive) for the treatment of urban wastewater (transposed into Spanish legislation under the "Real Decreto 509/1996, de 15 de marzo, por el que se establecen las normas aplicables al tratamiento de las aguas residuales urbanas" or RD of applicable guidelines for urban wastewater treatment).

Once the system has been correctly dimensioned and the required quality parameters are granted for both: water treatment and artificial recharge of aquifers by percolation; the envisaged low cost budgets and their affordable implementation and operation make these systems a very interesting technical solution for areas where this activity is suitable.

It is usual to consider wastewater treatment by lagooning activity a LOW COST technique and even a SOFT METHOD, whose philosophy is based on several criteria; such as to make compatible low operating costs, reduced hand work, integration in the landscape from the ecological point of view, short maintenance costs, etc. These guidelines are relevant to relate reclaimed water and environmental improvements.

The lagooning wastewater treatment system is based in a series of stabilization ponds, usually a group of consecutive ponds called "Waste or Wastewater Stabilization Ponds" (WSPs). Depending on the number and characteristics of these ponds, the purification system varies and the result can either be depurated water (anaerobic lagoons + facultative lagoons) or reclaimed water (=treated wastewater) when it is applied an additional or complementary treatment (one or several maturation ponds) which helps to bring quality up to the intended use.

The implementation of a complete lagooning properly sized according to the wastewater volume should provide a sufficient quality effluent, under normal conditions, for environmental uses.

The conventional sequence for a lagooning WWTP consists of: anaerobic ponds + facultative ponds + maturation ponds (figures 3-57 and 3-58).

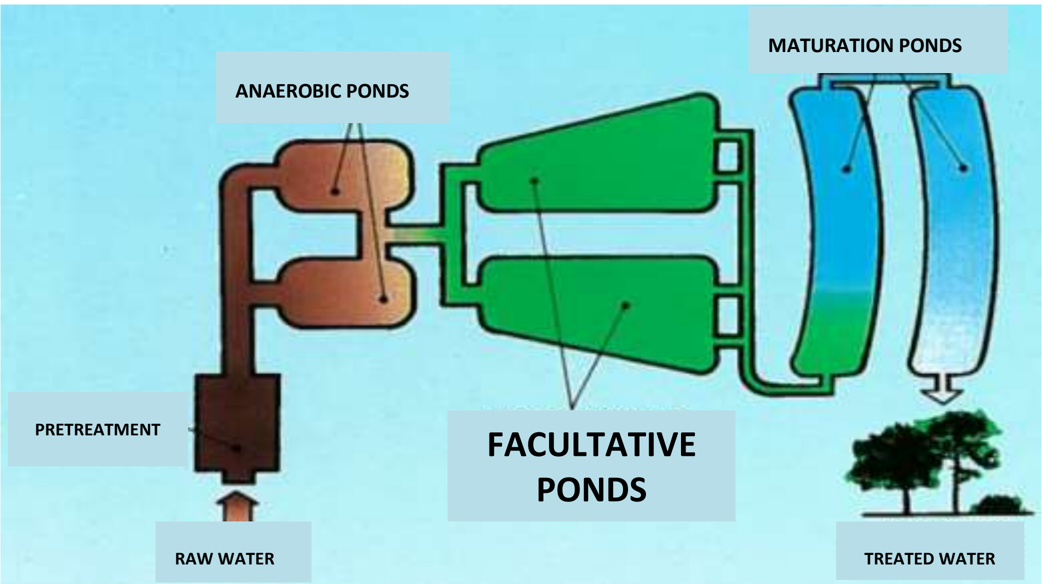


Figure 3-57: Most common scheme used in the natural lagooning.

Figures 3-58 a & b: Real examples of natural lagooning plants in Castile La Mancha (Spain).

A summary of the main **characteristics** and **design recommendations** for the improved lagooning WWTP are:

1) ANAEROBIC PONDS:

- **Operating conditions: Proposal for r**etention time and volumetric and surface loads (Tables 3-8 and 3-9).

Table 3-8: Basic operational parameters. Source: Own elaboration.

BASIC OPERATIONAL PARAMETERS			
Surface organic load (Ls)	2,000	3,000	Kg BOD_5/ha*day
Volumetric load (Lv)	100	180	g BOD_5/m^3*day
Retention time (T)	2	5	days
Depth (m)	3	6	m

Table 3-9: Recommended values of volumetric load in anaerobic lagoons, depending on the design, temperature and the required quality yields. Slightly modified from the MARM (2011).

Design temp (º C)	Volumetric load (Lv) (g BOD_5/m^3*day)	Removal of BOD_5 (%)
< 10	100	40
10 - 20	20T-100	2T + 20
20 - 25	10T + 100	2T + 20

2) FACULTATIVE PONDS:

- **Objective:**
  - Stabilization of organic matter.
  - Reducing nutrient content.
- **Basis:**
  - Symbioses of algae and bacteria.
  - Large surface for illumination and aeration.
- **Design parameters:**
  - Multitude of methods according to the approach; complete mixing, dispersed flow, etc.
  - Basic calculation parameters depending on the surface organic load (Kg BOD_5/ha*day).

Table 3-10: Basic calculation parameters depending on the surface organic load (Ls) (Own elaboration).

Surface organic load (Ls)* (Kg BOD_5/ha*day)	Climatic characteristics
< 10	Very cold areas with seasonal ice cover, water with low temperature and partly cloudy
10 - 50	Cold climate with seasonal ice cover and warm summer temperature in a short season
50 - 150	Between temperate and subtropical climate, occasional ice cover, without persistent cloudy conditions

*In tropical climates they can be used organic surface loads above 300 BOD_5/ha*day.

3) MATURATION PONDS:

- **Objective:**
  - Reducing the content of pathogen bacteria.
  - Reducing nutrient content.
- **Pathogen removal process:**
  - Physical: Decanting + Temperature.
  - Chemical: high pH for photosynthetic activity.
  - Shock O_2 concentrations.
  - Light intensity.
  - Low concentration of organic matter.
- **Design parameters:**
  - Retention time > 5 days. Preferably > 7 days.
  - Minimum depth in order to favour illumination: 0.80 – 1.00 m.

In general, the main characteristics and dimension parameters of these type of ponds (anaerobic, facultative and maturation) are shown in the following table for Spanish conditions:

Table 3-11: Summary of recommendations for the design of lagooning. Source: Manual para la implantación de sistemas de depuración en pequeñas poblaciones (MARM, 2011).

Parameter	Anaerobic ponds	Facultative ponds	Maturation ponds
Retention time (day)	≥ 2	-	≥ 5
Volumetric load (Lv) (g BOD_5/m^3*day)	100 - 150	-	-
Surface organic load (Ls) (Kg BOD_5/ha*day)	-	≤ 100	≤ 75
Depth (m)	3.0 – 5.0	1.5 – 2.0	0.8 – 1.0

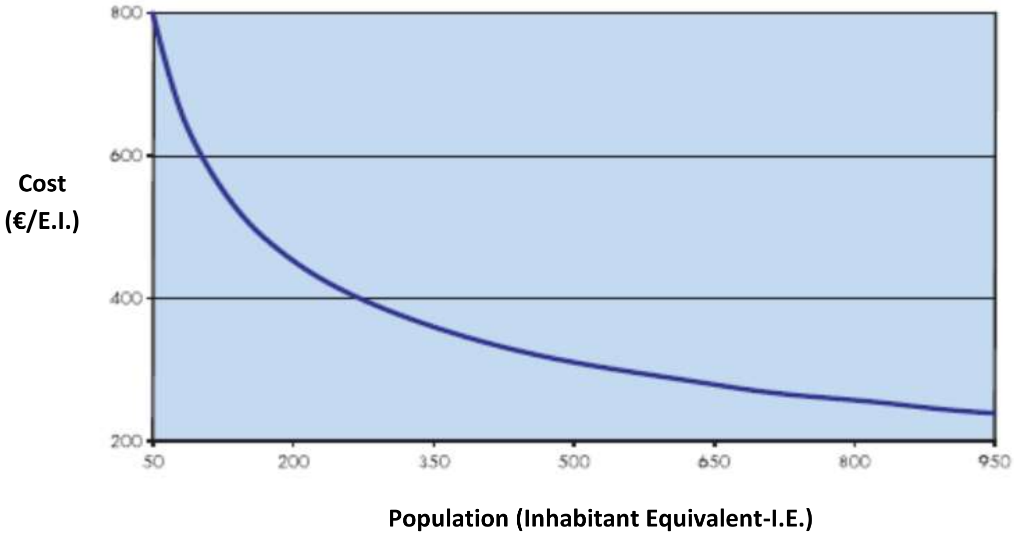


Figure 3-59: Lagooning implementation costs depending on the equivalent population. Source: Manual para la implantación de sistemas de depuración en pequeñas poblaciones (MARM).

The following chart shows the implementation costs of lagooning plants based on the equivalent population, according to data from the *Guideline for the implementation of purification systems (Manual para la implantación de sistemas de depuración)* published by the Spanish Ministry of Agriculture and Environment (MARM).

With regard to operating costs, a factor that influences the ratio €/m^3 is the scale factor of the installation. In this case, a larger size of the WWTP (Wastewater Treatment Plant) and the treated flow causes a decrease in the specific cost €/m^3 by the economy of scale effect (ACA, 2014), as can be observed in the following table:

Table 3-12: Operating costs of lagooning depending on the flow treatment (m^3/day).

Flow treated (m^3/day)	Operating costs (€/m^3)
From 0 m^3/d to 999 m^3/d	0.47099
From 1,000 m^3/d to 1,999 m^3/d	0.23957
From 2,000 m^3/d to 4,999 m^3/d	0.14116
> 5,000 m^3/d	0.19000

The expected average yields for properly dimensioned lagooning treatment plants are listed in table 3-13.

Table 3-13: Expected average yields in lagooning treatment plants. Source: Authors.

	Removal (%)				Concentration	
Type of ponds	Anaerobic ponds	Facultative ponds	Maturation ponds	GLOBAL	Influent (mg/L)	Effluent (mg/L)
BOD_5	40-50	60-80	25-40	80-90	300	45
COD	40-50	55-75	20-35	75-85	600	120
SS	50-60	30-70	40-80	60-80	300	90
Total N	05-10	20-40	15-40	40-80	50	20
P (Phosphorus)	0-5	0-30	30-45	30-60	6	3
					Influent (log units)	Effluent (log units)
Faecal coliforms	0.2-0.5 log units	2.2 log units	0.7-1.3 log units	3-4 log units	107	103-104

In light of the previous table, values are detected above the maximum allowable values for 5.1. Use (Aquifer recharge by localized percolation through the ground), with special attention paid on:

- Presence of excessive Suspended Solids in the effluent largely due to the high concentration of algae in the effluent.
- High content of Total N.
- Concentration of faecal coliforms close to the limit stablished in the R.D. 1,620/2007.

For faecal coliforms the proposed solution is based on the retention times for different lagoons; e.g. in the case of the maturation ponds, about seven days. Any excess would be solved by increasing this value above ten days and the disposition in series of maturation ponds. This is not the case for Suspended Solids and Total N content in the effluent. In the case of Suspended Solids, excess could be solved by arranging a filtration system in the output, although it is intended the use of soft methods for this approach. In the particular case of Total N content, it is necessary to employ other complementary processes combined with the lagooning in order to achieve values below maximum limits (Total N <10 mg/L).

The main constraint is the unfeasibility of retaining effluents in the ponds for long periods. An interested measure proposed to solve this problem is the adoption and combination of new "soft methods" such as the use of artificial wetlands (in their different variants) according to the different parameters to be reduced:

1. **Surface flow artificial wetlands.** Artificial wetland used as tertiary treatment might provide an additional treatment to the effluent, achieving the following characteristics:
    a. 60-80% removal of residual organic contamination.
    b. 50-70% removal of Suspended Solids.
    c. 50-60% extra on nutrient removal.
    d. 1-2 logarithmic units of pathogen removal.

The following table summarises the expected average ranges in lagooning WWTP with a complementary post-treatment in artificial wetlands. Notice that the parameters Total N and S.S. fulfil the 5.1 use limits stated in the R.D. 1620/2007 (table 3-7).

Table 3-14: Expected average yields in surface flow artificial wetlands. Source: Authors.

	Removal (%)	**Concentration**	
Complementary treatment	Surface flow artificial wetlands	Influent (mg/L)	Effluent (mg/L)
BOD_5	60-80	45	13.5
COD	60-80	120	36.0
SS	50-70	90	**27.0**
Total N	50-60	20	**9.0**
P (Phosphorus)	50-60	3	1.4
		Influent (log units)	Effluent (log units)
Faecal coliforms	1-2 log units	103-104	101-102

2. Subsurface flow artificial wetlands.

a. **Horizontal:** They present similar ranges to the previous sort of artificial wetlands except for those corresponding to remove nitrogen forms by means of denitrification processes favoured due to anaerobic conditions. The system itself would serve for the direct application of treated effluent to the ground for direct intentional recharge.
b. **Vertical:** No special measures are needed for nutrient removal and/or pathogen and the system itself would serve for the direct application of treated effluent to the ground. In this case, organic load would not be the limiting factor for dimensioning the artificial wetland and instead the permeability of the soil would be.

To conclude, the improved scheme lagooning proposal would consist of the following elements:

Anaerobic ponds + Facultative ponds + Maturation ponds + Artificial wetland with three different variations: surface flow, horizontally subsurface flow or vertically subsurface flow (depending on the ultimate objective pursued).

3.3.4 Proposal for a water pre-treatment standard specific for Los Arenales aquifer

The qualitative study of recharged water and the receiving medium hydrochemical conditions have enabled some practical recommendations in design and proposing standards of quality for Managed Recharge Water.

According to Bouwer (2002) water pre-treatment is one of the most effective measures to be applied in MAR facilities in order to obtain successful infiltration parameters and a longer lifespan of the devices. After that, there is a vast amount of references in the hydrogeological literature considering different standards and regulations. A collection of those is compiled in Fernández Escalante (2005); MARSOL (2015a and b).

One of the most important targets regarding water pre-treatment is the requirement of a specific standard of quality for MAR, which depends of each case circumstance. So, it is impossible to propose a common range of concentrations for all the demo sites.

An initial standard has been proposed for Arenales aquifer, based on the premise that standards should be proposed at local or regional level; after realizing proposals for water quality at national level is providing bad results in most of the countries studied (Fernández *et al.* 2016b). This proposal is presented in table 3-15.

Despite the low turbidity determinations in the water used for MAR at Los Arenales demo site, eventual viscous processes have been detected at the bottom of the device after each cycle of artificial recharge, which become, in general, physical clogging crusts.

Therefore, although the 10 ppm as TSS standard might be appropriate for this specific situation, it would be advisable to carry out more water pre-treatment operations with a manual management of the valves as well as maintenance operations.

On the subject of DOC, according to the analytics results, it seems likely to find biological clogging problems in conditions where recharge is taking place. Bacteria, algae, lichens etc. have been detected in recharge waters by microscope inspection.

Dissolved Oxygen (DO) is a difficult parameter to control in surface along the constructions. In our specific case, the agitation of the water should be avoided by means of burying some conductions and improving device designs to decrease the dissolution of oxygen from the atmosphere, bubbling, foaming.

Using SAT techniques along the canals for pH control is emerging as the most advisable option to minimize precipitation of carbonates, formation of crusts or, simply, to improve the groundwater quality. These corrections must be performed after characterizing and learning about changes in the pH of the medium and the predominant reactions in each sector.

The exposed initial draft for a regulatory standard should be permanently improved as well as new data sets are being obtained and new studies accomplished.

Table 3-15: Quality standard for artificial recharge water in the specific case of Los Arenales aquifer applicable to other parallel scenarios. Data based on bibliographic references and experiences obtained in field, laboratory and office (slightly modified from Fdez. Escalante, 2005).

DETERMINATIONS / RANGES	QUALITY STANDARD
TSS 5-8 ppm	TSS < 10 ppm
TDS 101,8 ppm	TDS < 150 ppm
TOC < 5,5 mg/l	TOC < 10 mg/l
DOC 1,8-2,8 mg/l	DOC < 2 mg/l
DO 5,1-8,8-11 mg/l	DO < 8 mg/l
$[CO_2]$= 0,5 – 0,9 mg/l	$[CO_2]$ < 0,50 mg/l
pH = 8	pH < 7,5-8
Cond = 191 μS/cm	Cond < 200 μS/cm
Tª W = 5,9 ºC	Tª water ≈ Tª soil
Tª SOIL = 6,1 ºC	Tª water > Tª aquifer
Alkalinity= 64 mg/l CO_3Ca	Alkalinity <200 mg/l CO_3Ca
$[NO_3]$= 2 mg/l	$[NO_3]$< 10 mg/l
Supersaturation SiO_2 = 35 mg/l.	Supersaturation ≈ 0
Supersaturation Ca Mg $(CO_3)_2$= 37,86 mg/l.	Supersaturation ≈ 0
Salinity = 0.1 – 0.7	Salinity (to be determined)
H_2S ≈ 0	Avoid H_2S
MFI: 25 - 30 s/l^2	MFI < 3-5 s/l^2
Bacteria and virus to be determined	Bacteria and virus to be determined

4. CONCLUSIVE REMARKS REGARDING OPERATIVE ASPECTS OBTAINED AT LOS ARENALES DEMO-SITE

According to the different studies conducted at Arenales demo-site with the main aim of achieving an "appropriate MAR methodology and a tested know-how", a set of operative and practical criteria has been obtained from the different activities.

The most important practical recommendations or "smart practices" (what author have called SMARTS or Sustainable Managed Aquifer Recharge Technical Solutions) obtained from the different lines of action exposed along this report, have been grouped according their application in space and time in the following groups: design and construction criteria, management operations, MAR water pre-treatment, improvement *"in itinere"*, practical recommendations for cleaning and maintenance of the MAR facilities and, generally speaking, a set of "technical solutions *(SMARTS)*" willing to be applied in analogous sceneries.

Another conclusive remark is the practical list of problem/solution binomials conducted at Los Arenales demo site (see MARSOL 2015 b) summarized and modified at the end of this paragraph.

4.1 Smart practices and technical solutions to be applied at Los Arenales demo-site

Some of the recommendations to avoid clogging were already reported in MARSOL deliverable 13-1 (MARSOL, 2015b). In order to shed some more light on this issue, there have been distinguished three different sorts of techniques, related to design, management and cleaning/maintenance.

4.1.1 Design and construction criteria

- The design of the infiltration ponds and channels can help reduce ongoing maintenance requirements and costs. The construction of service roads and access ramps to the bottom facilitates the O&M operations.
- Ridges and furrows may be designed at the bottom of the infiltration ponds to reduce clogging. Sediments and other components of physical clogging that settle on the ridges will tend to fall into the furrows, so that any clogging develops preferentially in the these ones, maintaining the permeability of the ridges (Peyton 2002).
- Shallow ponding depths in order to reduce pressure on the clogging layer and the upper part of the receiving medium (soil/aquifer).
- pH control by means of mudstone gravel filters.
- Control of the flow velocity of MAR water by the installation of stopping devices.
- Preservation and reinforcement of slopes with rubble works, gabions...
- Stable slopes for MAR ponds and canals, with good results for 2V:3H and 3H/2V trials for the environmental conditions of this demo-site.
- Decantation/stagnation systems at the origin must be incorporated in the design of the facilities from the initial stage.

- Use of pre-existing artificial elements adaptable for MAR uses; e.g. reuse of an abandoned well for MAR in Santiuste Basin, reuse of an old dam to divert recharge water in Carracillo Council, reuse of sand-pits as infiltration ponds, etc.

4.1.2 Management

- Pre-treatment in origin: choose the best water possible for the intended use: recharge the aquifer. This is, together with pre-treatment, the best action to prevent and delay clogging effects.
- Pre-treatment *in itinere*: improve water quality from its diversion from the river to the MAR plant heading, in general by means of inorganic filters interbedded in the conductions.
- Manual control in the entrance valves: managing recharge depending on climatic conditions, e.g. avoid recharging during freezing periods (MAR at minimum levels) or close the entrance gate when river water gets brown due to downpours and /or storms. Manual management is usually transferred to stakeholders.
- Treatment *in itinere*: improving water quality at the same time that recharge occurs. For example, triplet schemes, gravel filters embedded along the pipeline.
- Wet-dry cycles have demonstrated to be a very effective action against clogging. They also act in the recovery of the seepage rate to conditions close to initial stages.
- Specific plantation of shrubs in infiltration ponds or channels in order to maximize the infiltration rate.
- Making the infiltration channel in a green biofilter so as to achieve a double function: purifying activity on the potential pollutants by plants direct consumption, and use of the roots to pierce and break the clogging crusts at the bottom of the MAR canals and infiltration ponds so as to increasing the previous infiltration rate.
- Management of spillways in order to avoid over-flooding episodes.
- Development of monitoring system to provide a depth-knowledge of the aquifer characteristics, to find out the requirements regarding new constructions as well as the general evolution of the MAR scheme.
- SAT-MAR facilities might be included in the current operative schemes.
- By means of appropriate SATs techniques such as water pre-treatment, in itinere filtering, and the "in-treatment purifying techniques", the efficiency of the system increases considerably regarding not only water quality but also the groundwater quantity storage as a repository for the case of need.
- One of the main problems associated with MAR systems is the excessive dependence of MAR facilities to climatic conditions. The only permanent MAR plants are those which water source comes from a WWTP. The technical solution involves Managing water from different origins. E.g. for Santiuste Basin: recharge water from WWTP combined with water coming from Voltoya River deviation. In Alcazarén Area are combined the recharge water from the WWTP, the runoff from Pedrajas de San Esteban village roofs is driven to a specific canal, and the diversions from Pirón river finishes in the connection point where converge the different water sources conductions.

4.1.3 Practical recommendations for maintenance

- Promote participation of stakeholders, specially farmers or beneficiaries and other social agents in water management and MAR activities.
- Protected perimeter around MAR facilities in order to avoid contamination of the water and some improper uses such as the use of the facility as a dump.
- It is important to conduct infiltrometer tests at several locations in the recharge facility (monitoring as a Decision Support System) because the infiltration rates may decrease severely and this activity helps managers to decide when to start the cleaning cycle and the subsequent recovery of infiltration rates.
- Specific protocol against clogging; monitoring of the main parameters, cleaning cycles, specific mechanical and chemical treatments, etc. Stakeholder must be aware of these protocols and these must be public.
- Avoid shaking water, since air clogging is perhaps the main impact related to the reduction of the infiltration capacity at Los Arenales living lab.

4.1.4 Cleaning and maintenance operations in channels and infiltrations ponds

- Stablish a proper frequency of cleaning: A recharge facility needs a cleaning cycle when percolation rate has declined to approximately 30% of the initial rate.
- Decisions must be made regarding cost and time. The cost of the cleanings would reduce the net value of the recharged water. The optimum cleaning frequency is unique for each facility and must be determined on a case-by-case basis.
- The frequency of clogging depends on the water quality, loading rate, and the permeability of the subsurface material. These parameters should be monitored at each MAR site.
- Installation of geofabrics to make easier cleaning activities.
- Mechanical cleaning over chemical treatments: scraping, cracking, scarifying the bottom, etc.
- Removal of clogging layer and replacement with new clean sand layer (15 cm approximately).
- Spill of chemical additives must be minimized, e.g. many authors are against of pouring free chloride in the aquifer (this is an alive and vivid issue discussed in most of the MAR conferences with more technicians against than in favour).
- In case of using chemical additives for cleaning and breaking the clogging layer, the product of the interaction should be recovered and deposited in treatment plants.
- Managing vegetation cleaning. It is also a controversial activity and depends on the amount of vegetation and the type of plants (some are beneficious whilst others are contra-productive.
- Use of Basic Cleaning Vehicles (BCV). They act by removing the clogging layer once it has been formed. The cost-effectivity of this action is another key-issue, because its efficiency and relation with the infiltration rate recovery has been proved.

4.1.5 Actions to prevent clogging development

- Clogging processes must be avoided since the MAR facilities conception.
- The knowledge of the distribution of the incipient clogging processes allows improved designs and scheduled maintenance operations to become more and more efficient.
- It is important the surveillance and application of the Best Technological Solutions and the best available techniques for prevention, cleaning and maintenance. This action requires incorporating usual technological watching activities.
- Control of the flow velocity of MAR Water in the canals in pursuance of avoiding turbidity and dissolving air from the atmosphere.
- Among the factors affecting water quality that can contribute to clogging are included the levels of total suspended solids (TSS) and biological oxygen demand (BOD). Both should be comprised in the future monitoring campaigns to be envisaged.
- Specific cleaning practices adapted to each type of clogging once their distribution is known. Clogging distribution cartographies are usual tools to program the cleaning and maintenance protocols (DSS).
- Clogging treatment must be considered an integral action rather than a response to any system failure, as there is a complex relationship between all clogging types, recharge water, groundwater quality variations, the specific geological and environmental conditions for each point, etc.
- As *"clogging will happen"* special measures must be adopted since the beginning of MAR implementations.

4.2 Conclusions on problems and solutions at Los Arenales demo site and its application to rural development

Comparing the three areas in Los Arenales demo-site, some of the binomials are shared due to the fact that there are many elements in common and many technical solutions must be widely applied.

Some of those elements are: diversion dam, infiltration canals, pre-existent ditches, extraction wells or recreated wetlands. That is due to local conditions related to history, current uses or environmental restrictions can share a global idiosyncrasy.

Aniway, applications in a different area might be totally different. MAR has a broad disposition to offer successful solutions to different rural conditions where dominant uses (mining, fishery, forestry…) could imply a diverse array of problem-solution binomials.

The table 4-1 exposes some of those binomials proposed for Los Arenales aquifer in a decision tree shape. Most of them are specific examples.

The order of this table shows the actual order of the problems faced in Santiuste. The asterisk in the tep column shows the common problems found in El Carracillo. The starter of the project was the fall of watertable and its consequences on the availability of irrigation water for farmers. In other cases MAR could be assumed for instance as a solution to a sewage spill or a quarry restoration so the corresponding decisions should have a very different sequence, even though the options could not be so variable.

Table 4-1: Problem/Solution binomials in decision tree for Santiuste Basin Recharge System design.

STEP	PROBLEMS	OPTIONS (Issues)	SOLUTION
1*	Water Scarcity (irrigation)	Groundwater (Same body/Near?) Surface (Winter surplus runoff) Reclaimed water (WWTP)	Diversification of the source: Surface Source (river diversions) + reclaimed water + runoff + groundwater conjunctive use
2*	Water diversion	Direct catchment Diversion dam (pre-existent)	Diversion dam Use of the river banks (RBF) Pre-treatment in the capture zone
3	Water storage	Surface(ETP+Land use) Subterranean (Pre-existent well supply system)	Enhance subterranean storage Eventual use of deposits and surface storage cells combined with groundwater options
4	Water transport	Aquifer transmissivity (impermeable barriers) Canal/Pipe (Cost/route)	Pipe Canals Use of the aquifer itself as a distribution network
5	Water carriage	Pumping (E cost) Gravity (upstream far location)	Gravity (use of passive systems except for extreme situations
6*	Water distribution	Surface (Canals) Surf/Buried (pipes) Buried (aquifer)	Mixed and combined nets Pipes/canals Sand aquifer
7*	Recharge expanse	Intensive (Localized) Extensive	Extensive Preference for pre-existing structures (sand pits, abandoned wells, previous canals… Avoid earthworks as much as possible
8	Recharge method	Injection (wells) Infiltration (sand)	Infiltration. Tendency for passive and intermittent systems

STEP	PROBLEMS	OPTIONS (Issues)	SOLUTION
9	Infiltration facilities	Reservoirs Canals	Canals and diversification within integrated water resources management (IWRM) premises
10*	Infiltration network	New (Cost) Pre-existing (ditches)	Pre-existing (Canal network) diversification
11	Resource extraction	Pools (Distribution/Collective) Wells (E Cost/private use)	Wells Best facilities for collective use (ruled by commoners associations)
12	Resource usage	Irrigation Environmental Industrial Urban supply	Irrigation +Environmental Further uses require demanding quality standards.
13*	Overflowing risk	Smart manual control since the diversion/heading Good forecasts for over floods Early alert systems Spillways	Spillways + Spreading fields Spillways + deposits (well/water tanks) Return to the source of origin (rivers) Diversion of extra water volumes to forests and areas with no damage or low risk/impact
14*	Wetland desiccation	Recreation Restoration	Recreation Public use regulation of the artificial wetlands

In summary, some extra conclusions not mentioned before are:

- Demo site counts with abundant, diverse and successful examples of MAR implementation for rural development.
- There are remarkable instances of water management (aquifer as an underground water supplier to every well) and energy efficiency (reduced pumping needs by increasing groundwater level) improvements by means of MAR technique that help to improve socioeconomic conditions for the population.
- The future target is linked to the supply guarantee without restricted climate dependence (CC: drought in summer but little rain in winter). So, reclaimed water must be integrated (WWTP) as the unique 24h/7d resource to be combined with the whole cast of intermittent systems. In this sense, sewage (a problem as a spill) becomes an opportunity (a source of water for different purposes; irrigation, landscape restoration…).
- There are significant varieties of scales into the stakeholders, from individual farmers to big industries (agroindustry, waterworks) and their usage of MAR water is very different, not only in quantity but also in the way they extract and use it. An important advice is the “association as a fortress” for general rural development (collective effort results are more efficient than the disconnected individuals’ effect).
- The SATs techniques applied are appropriate and their effectiveness is increasing cycle after cycle: Water consumption, farm energy cost, water treatment… As a consequence, the social and economic parameters and indicators improve in rural areas as a constant.
- There are plenty of cases of good water management conducted by end-users upon technical advice. Santiuste spillways, Santiuste and Alcazarén sewage…

Transmission of knowledge to local population has become a very relevant issue in the MARSOL project.

- Environmental Impact Assessment approach shows the double face of MAR as a human activity. The assorted techniques are mainly used to solve problems while they also incite others. Fortunately most of the possible impacts can be mitigated by the same MAR methodology mechanisms once they are adapted to each local conditions.
- MAR techniques have a great ability to reuse old infrastructures (quarries, mines, sand pits, old ditches, swallow dry wells, dry wetlands, dry springs, old and abandoned qanats…) so they can be transformed not only into recharging facilities but most of the times into new ecological hot-spots, e.g. artificial wetlands. Once again, negative issues can become positive by means of MAR.
- The low cost of related to the reuse of pre-existent infrastructure as well as performing recharge with no energy cost (water transport by gravity and passive infiltration) and low land use (subterranean storage) are relevant issues to be proposed for the revision of the Water Framework Directive, specially talking about the cost/benefit chapter and water management costs.
- Regarding MAR, in broad sense and as a general rule, profits overcome the inconveniences. That is the main reason why successful schemes should be exported to equivalent areas, prompting a "domino effect". Rural areas are especially sensitive to these processes and the "contagious effect" or adoption of good practices by neighbours works well as a general rule.
- The water footprint is really high; huge amounts of green water are being exported abroad in the fruits and vegetables produced in MAR areas, but the impact is lower than in the case of the areas where MAR is not practised.

4.2.1 Connecting technical solutions and dissemination for rural development

An important effort conducted at MARSOL project has been to connect the practical technical solutions obtained along the project with dissemination activities for irrigation community's members. In that sense, different workshops has been organized such as MAR4Farm and MARenales. A third workshop in rural areas is foreseen for the next 2016 October (MAR$_2$FARM).

The connection between technical solutions and farmers has also had another line of action, which has been the design and post of metal posters in the field. These posters contain the information transferred in the different workshops. They have been produced in Spanish language so as to transmit the information to those farmers involved in the management of MAR facilities and also in the best use of the aquifer.

In order to assess members in the three irrigation communities at Los Arenales aquifer, there are three different designs relating the binomials problem-solution and the practical advises to reduce the impact. These sorts of activities are considered key for rural development: farmers receive technical support regarding their activity in order to make their impact on groundwater resources as low as possible, thanks to advised, accurate, sustainable and improved technical solutions *(SMARTS)*.

In this sense it is important to remark that, up to date, the communication with the irrigation communities' board has always been excellent.

A detailed description of the workshops has been presented in deliverable 13-1. This report includes the dissemination panels made of metal and exposed physically in the stations MARSOL ZNS 1 and 3. It is also planned to post the last metal poster in Alcazarén area on the WWTP wall (expecting permission from the City Council).

The next paragraph exposes these posters especially conceived to involve farmers in the best use of water in MAR areas (Figures 4-1 to 4-3), as a direct contribution from MARSOL to rural development in the area of Los Arenales aquifer.

The P/S binomials were explained in deliverable 13-1 too, and the posters must be considered a practical summary of these groups of techniques and activities.

Figure 4-1: Poster on Technical Solutions made of metal and exposed in the MARSOL station ZNS-1 (Santiuste).

Figure 4-2: Poster on Technical Solutions made of metal and exposed in the MARSOL station ZNS-3 (Gomezserracín).

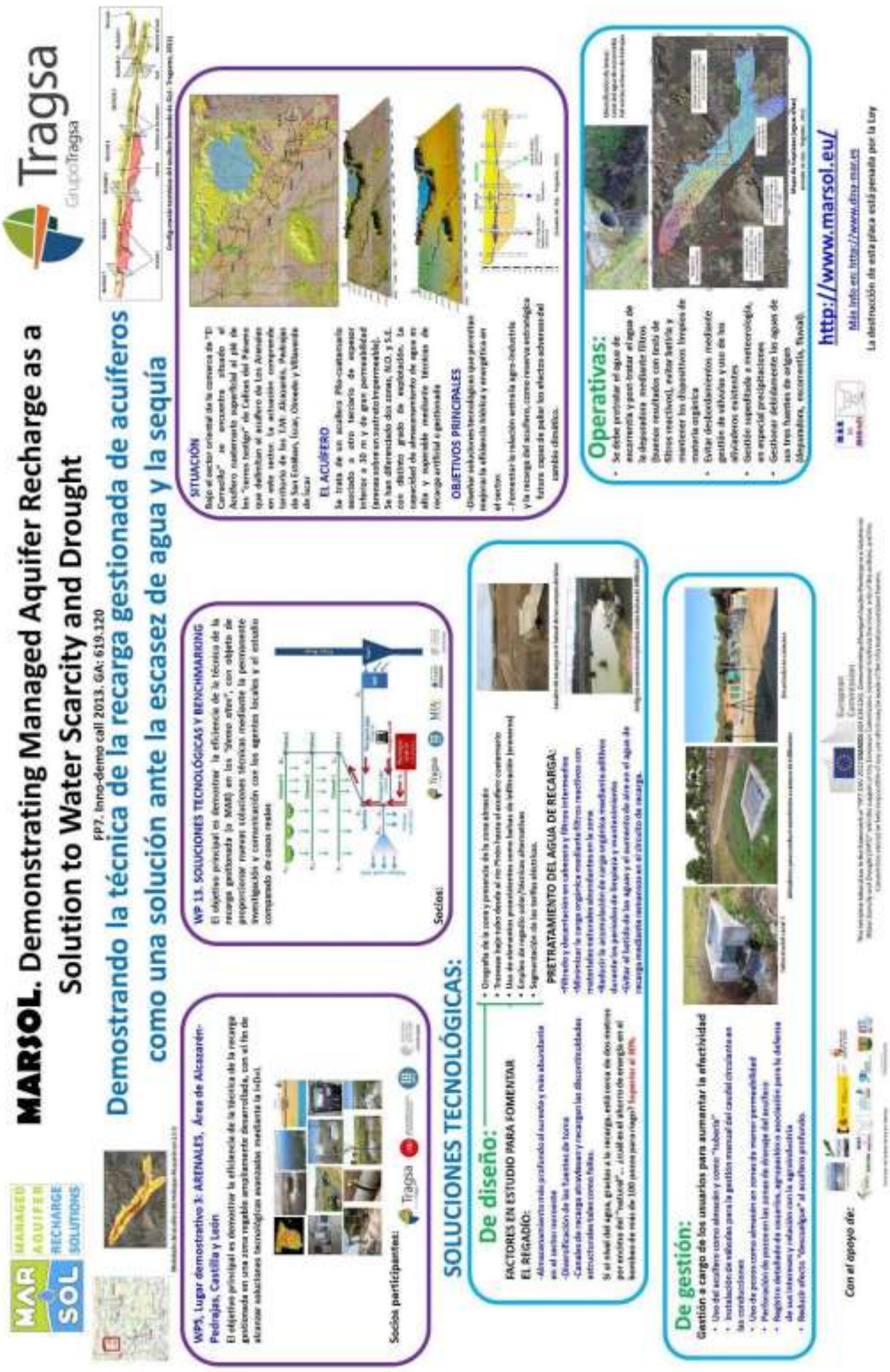


Figure 4-3: Poster on Technical Solutions made of metal and exposed in Alcazarén area close to the WWTP where the different sources for MAR are connected at the heading of the canal and recharge is managed by commoners.

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- MARenales training workshop: http://www.dina-mar.es/post/2015/03/16/PONENCIAS-e2809cMARenalese2809d-CELEBRADO-EL-e2809cTRAINING-WORKSHOPe2809d-DEL-PROYECTO-MARSOL-EN-EL-ACUIFERO-DE-LOS-ARENALES-MARenales-PRESENTATIONS.aspx
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6. ANNEXES

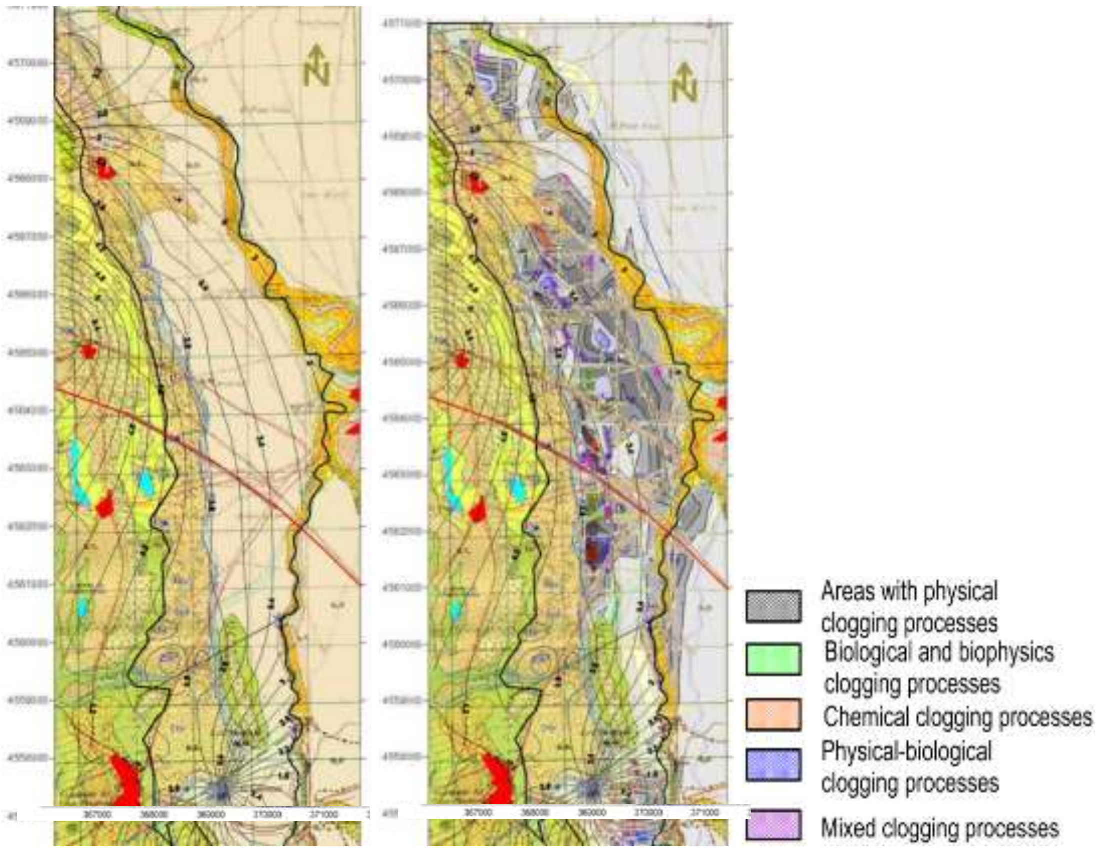
6.1 ANNEX I: Studies on clogging. Graphical resources

The chapter aims a new characterization of clogging processes in the area, developing distribution cartographies for the different clogging processes and combinations, and correlating the results by means of multivariable geostatistical analyses and calculations with the groundwater quality cartographies obtained by other procedures. That way, the different clogging processes are mapped by their nature in relation to the distribution of the major components of groundwater.

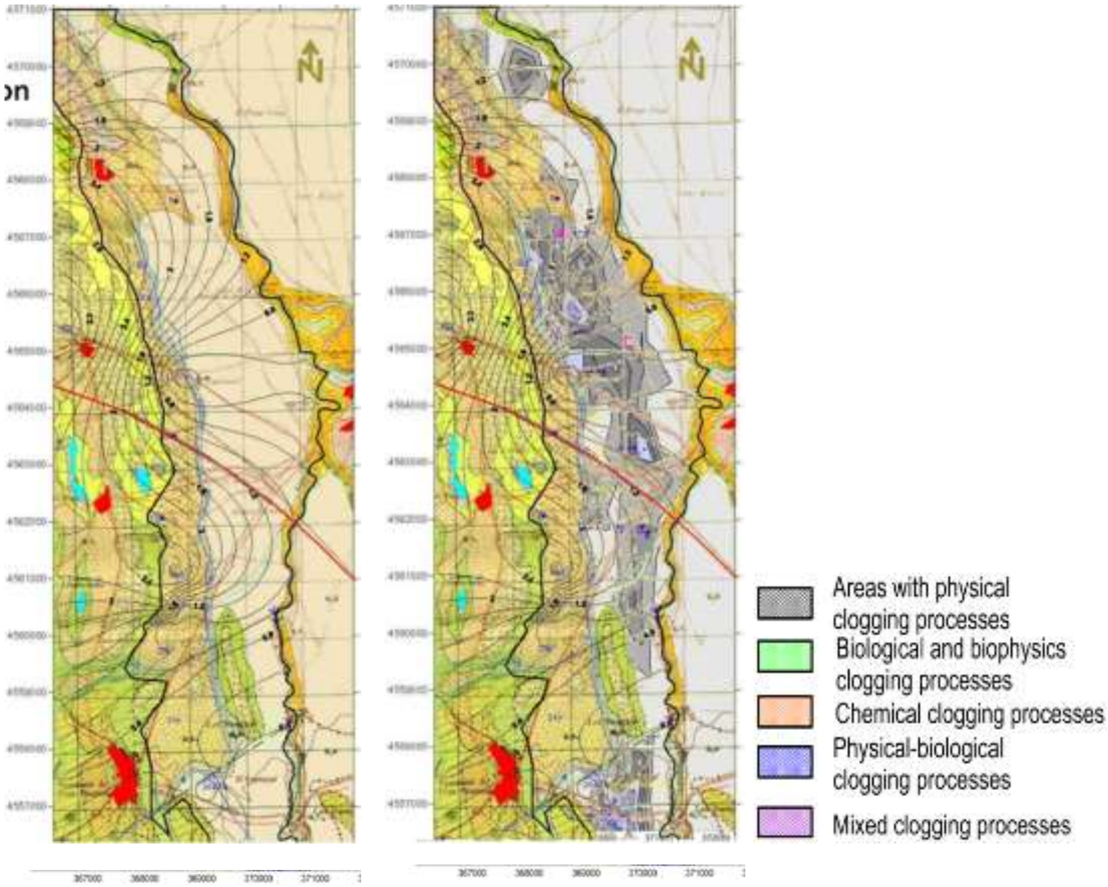
6.1.1 Clogging distribution cartographies at the demo-site

PAIRS OF CARTOGRAPHIES FOR GROUNDWATER ISO-CONTENTS AND CLOGGING DISTRIBUTION AT SANTIUSTE BASIN

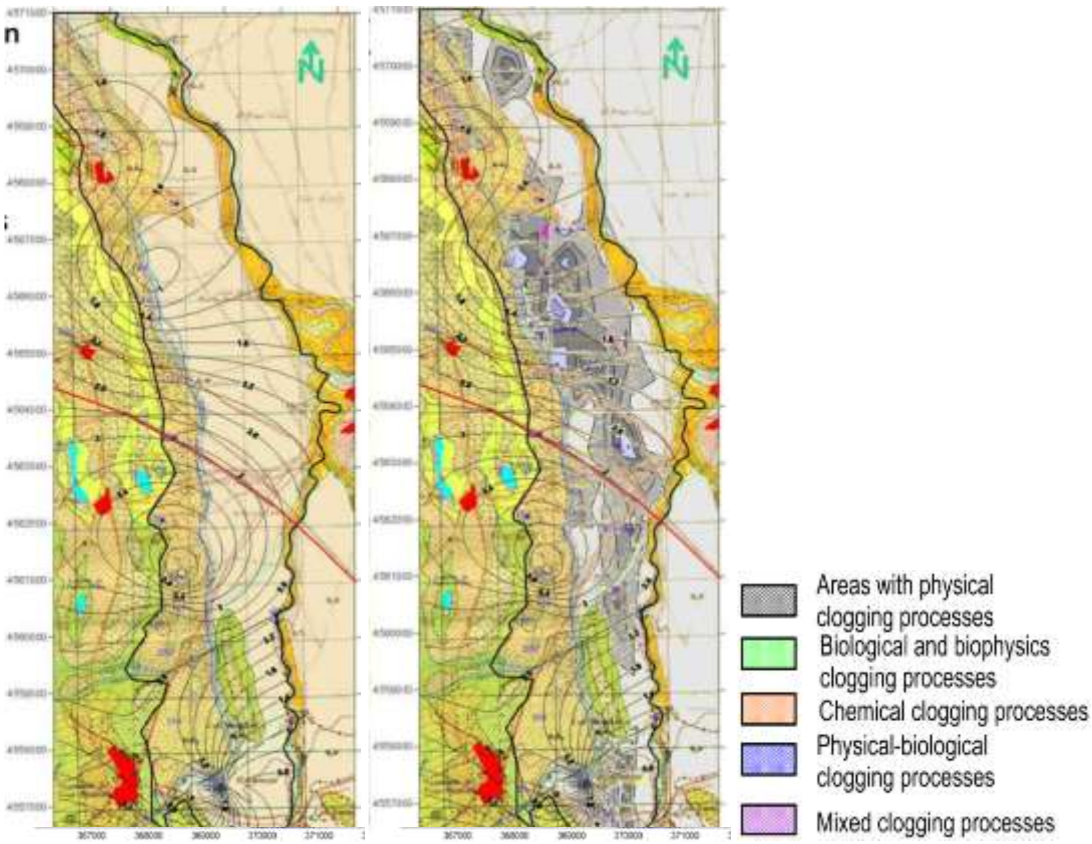
1. Iso-bicarbonate
2. Iso-sulphates
3. Iso-chlorides
4. Iso-sodium+potassium
5. Iso-calcium+magnesium
6. Iso-nitrates
7. Iso-electrical conductivity



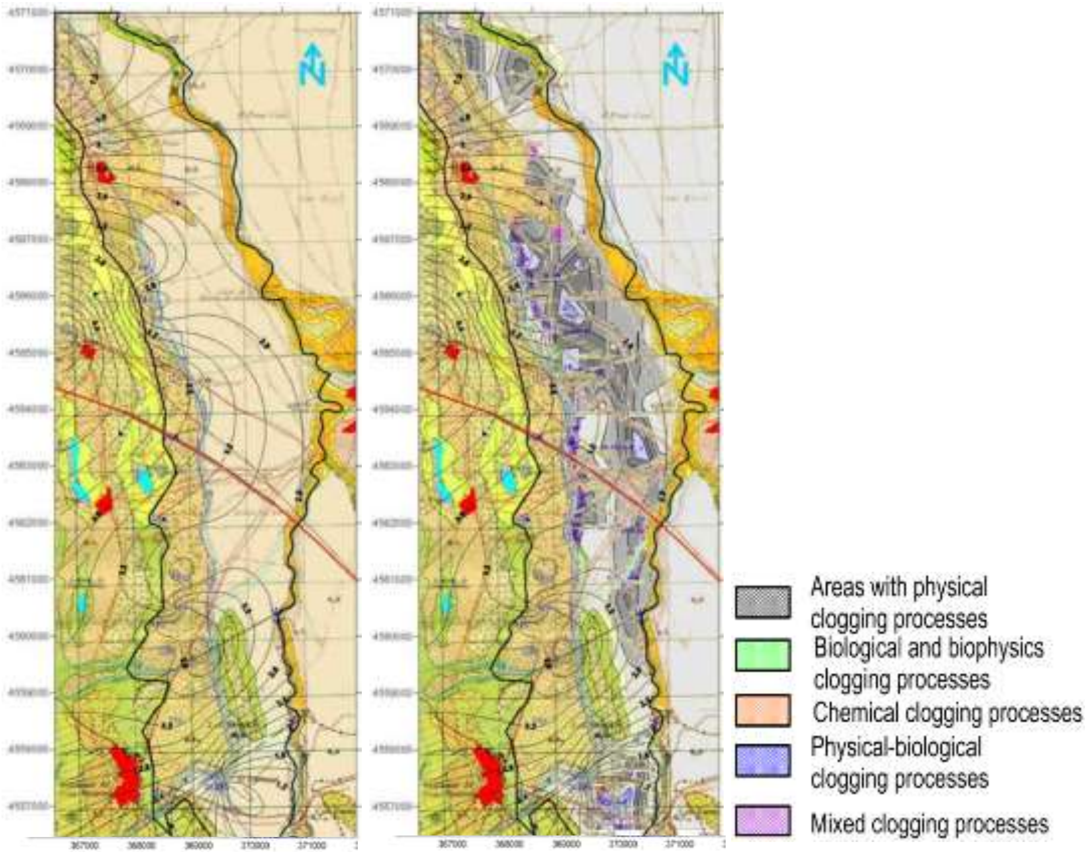
1-ISO-BICARBONATE



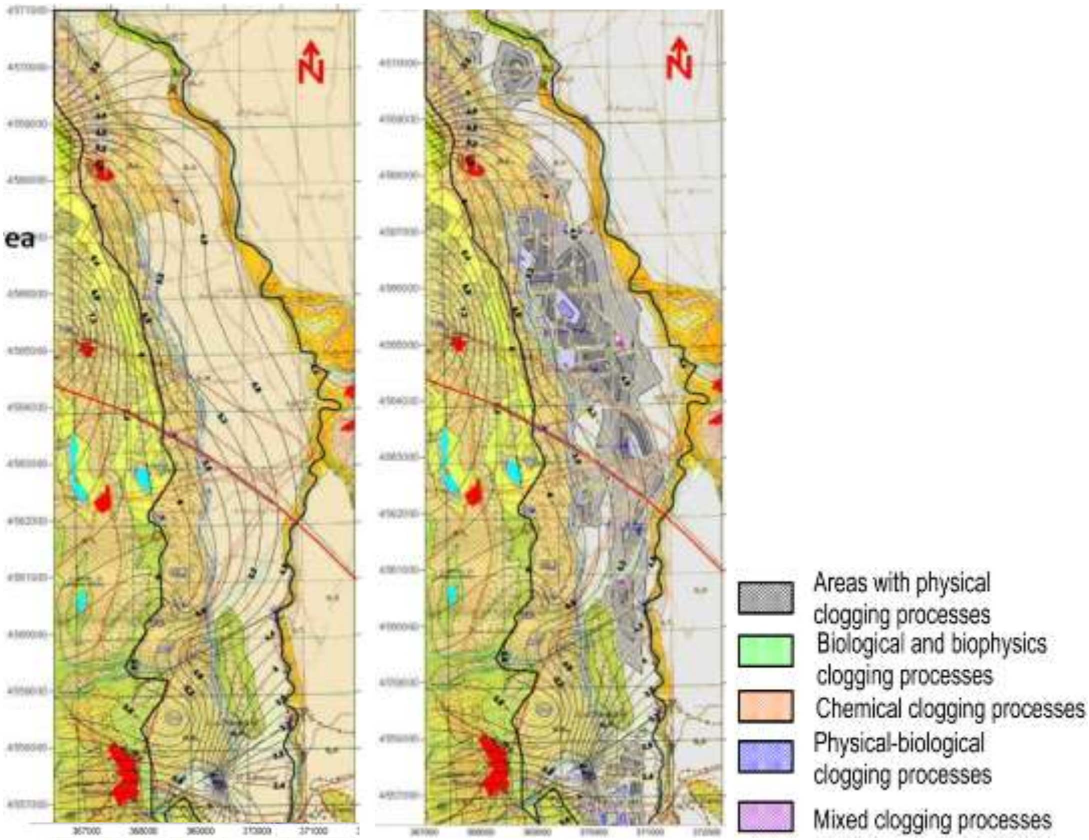
2-ISO-SULPHATES



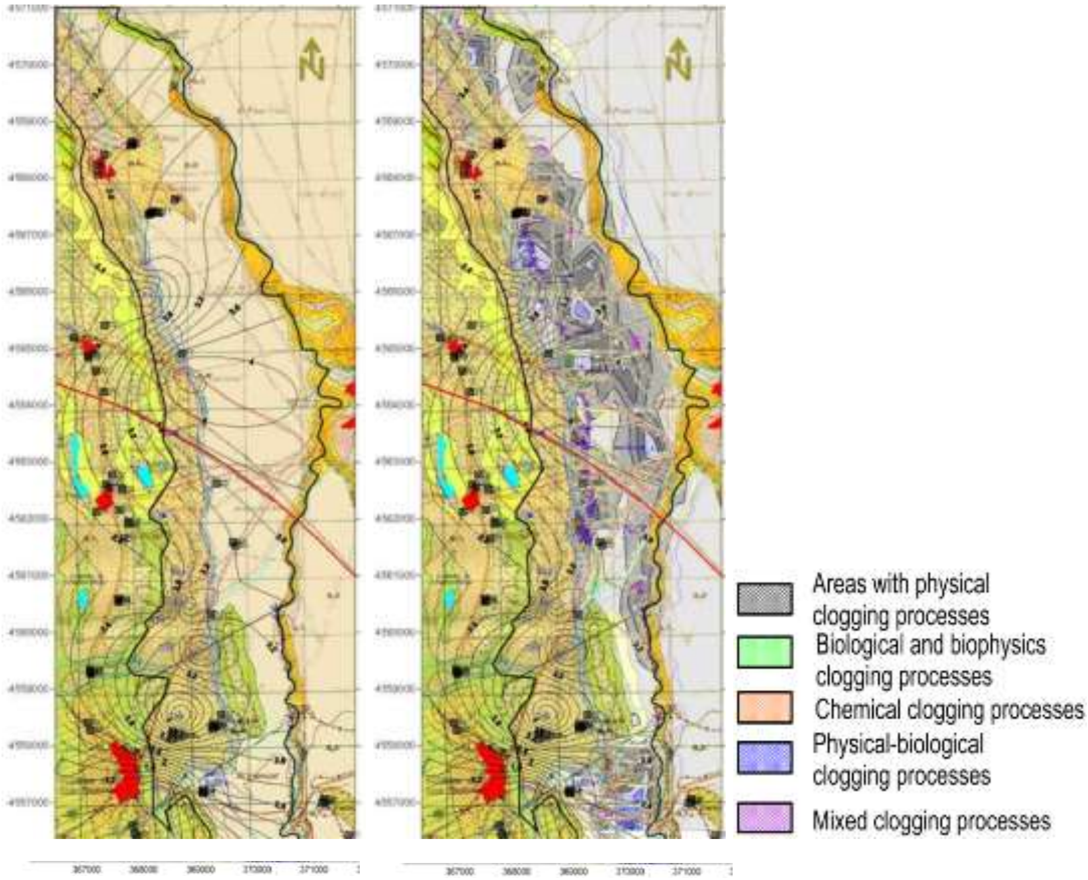
3-ISO-CHLORIDES



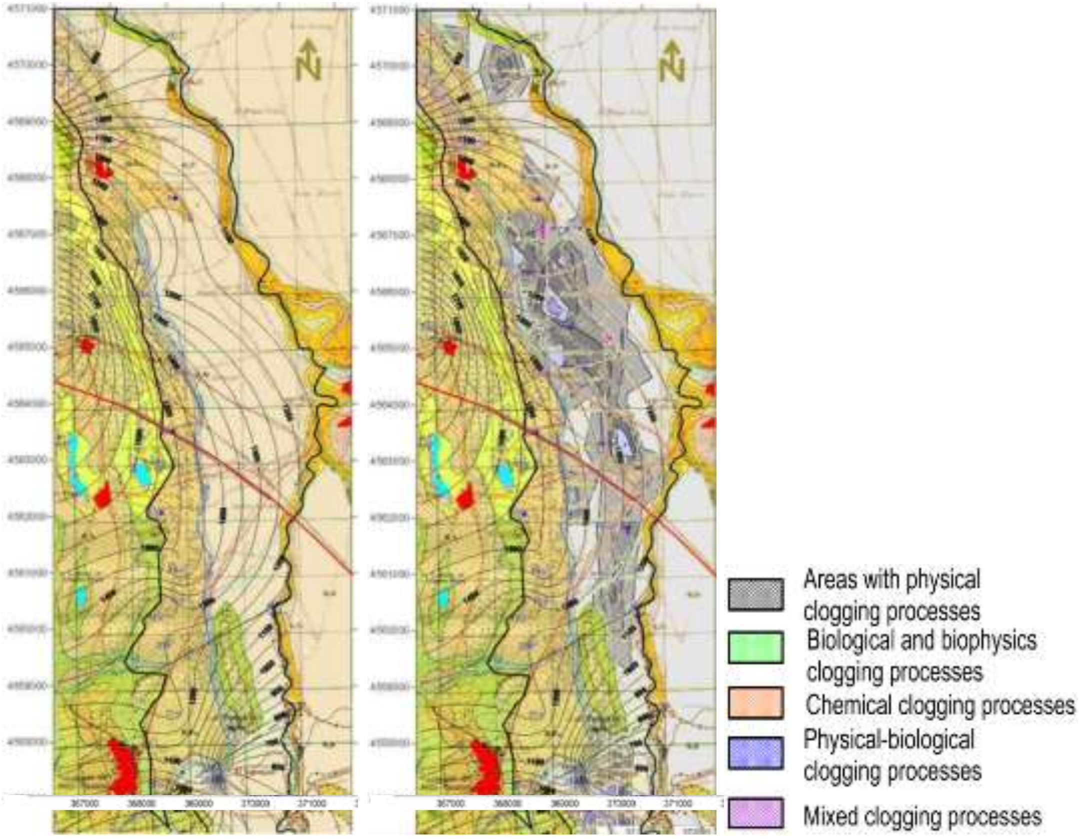
4-ISO-SODIUM+POTASSIUM



5-ISO-CALCIUM+MAGNESIUM



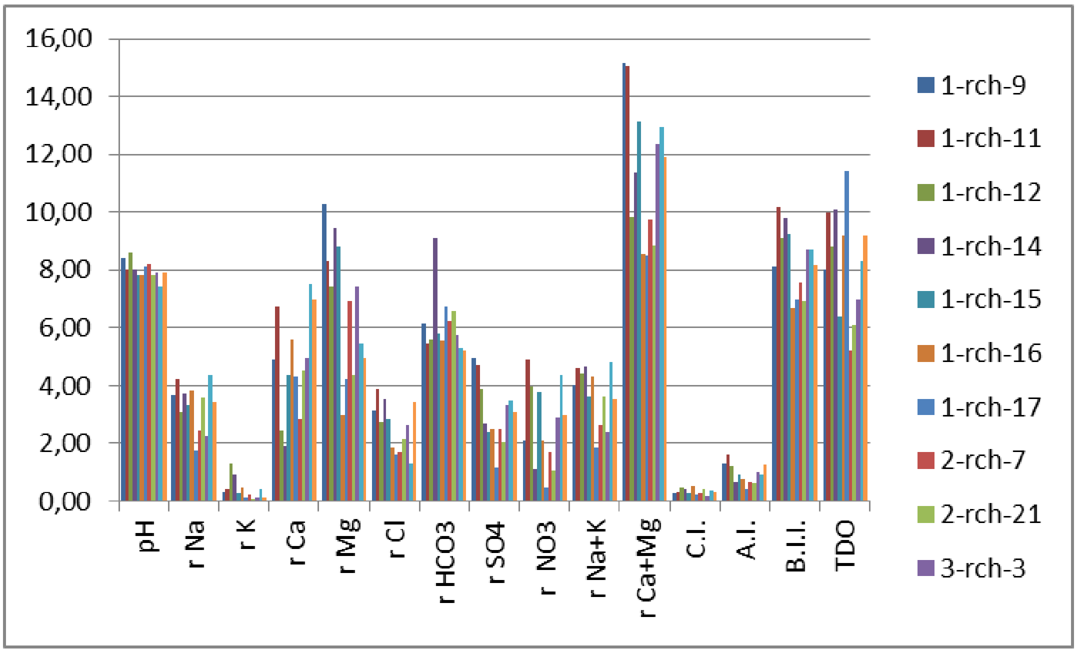
6-ISO-NITRATES

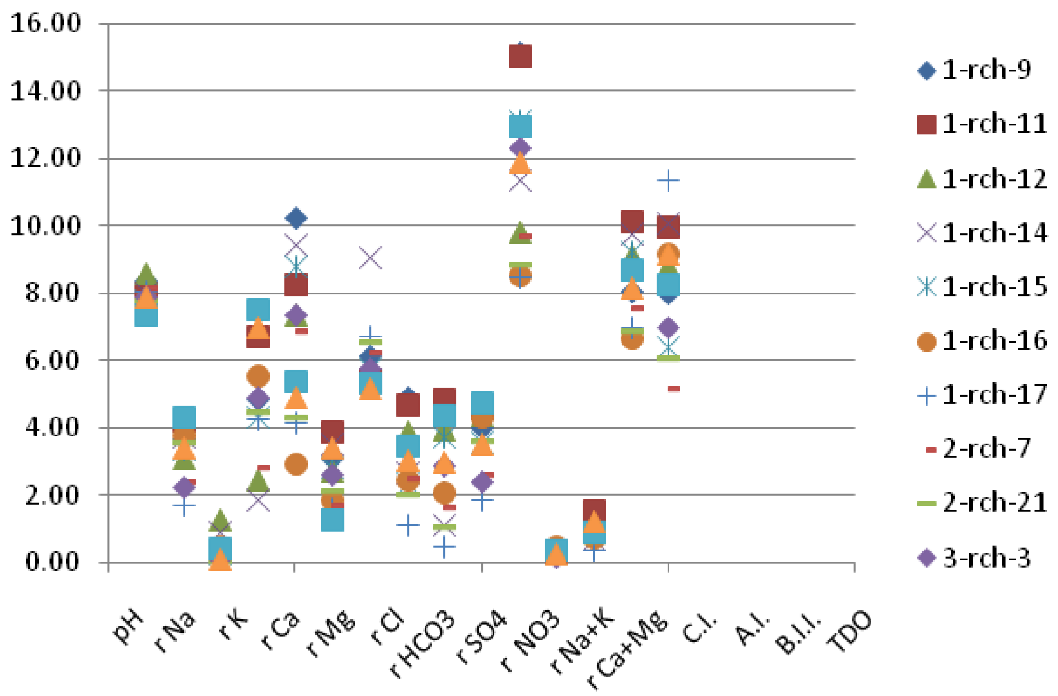


7-ISO-ELECTRICAL CONDUCTIVITY

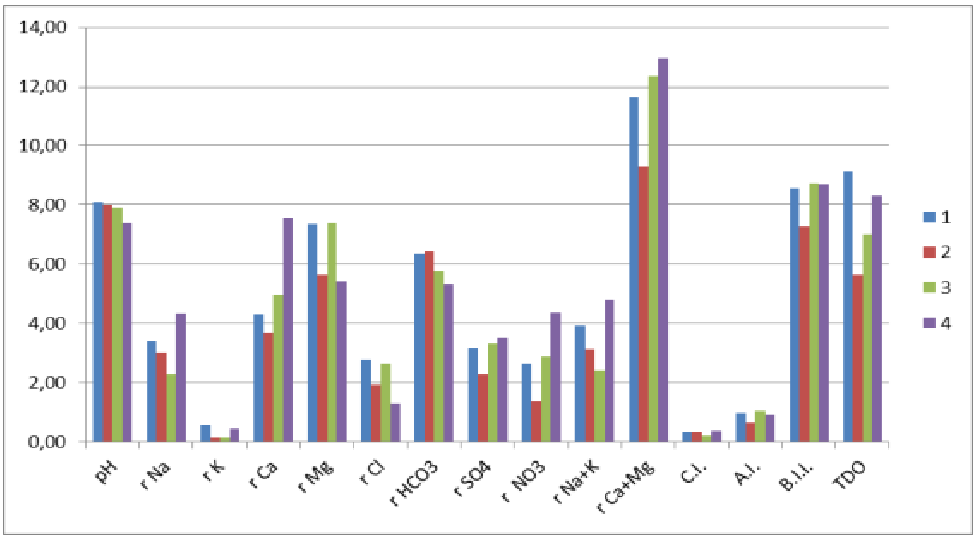
6.1.2 Multivariable Geo-statistical Analyses (MGA). Charting

Total values:





Mean values: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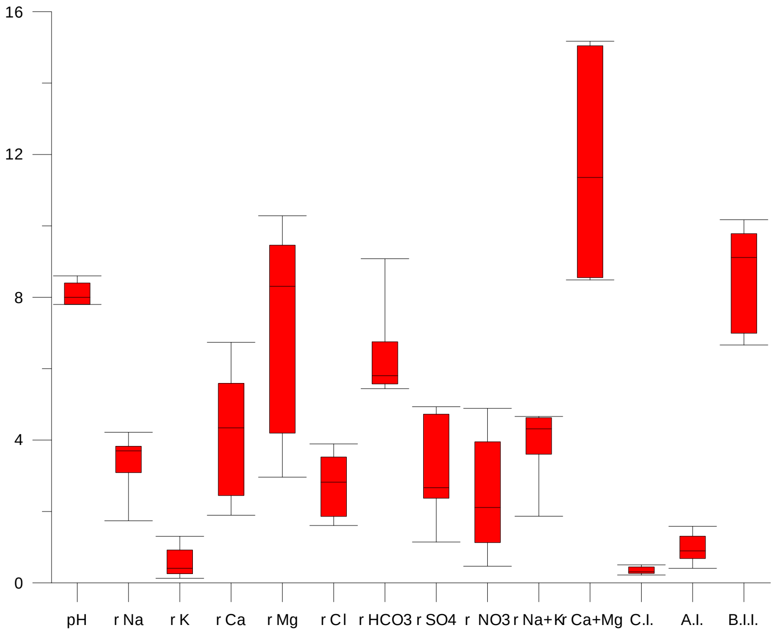
12,00
10,00
8,00
6,00
4,00
2,00
0,00
pH
r Na
r K
r Ca
r Mg
r Cl
r HCO3
r SO4
r NO3
r Na+K
r Ca+Mg
C.I.
A.I.
B.I.I.
TDO
1
2
3
4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12
8
4
0
pH
r Na
r K
r Ca
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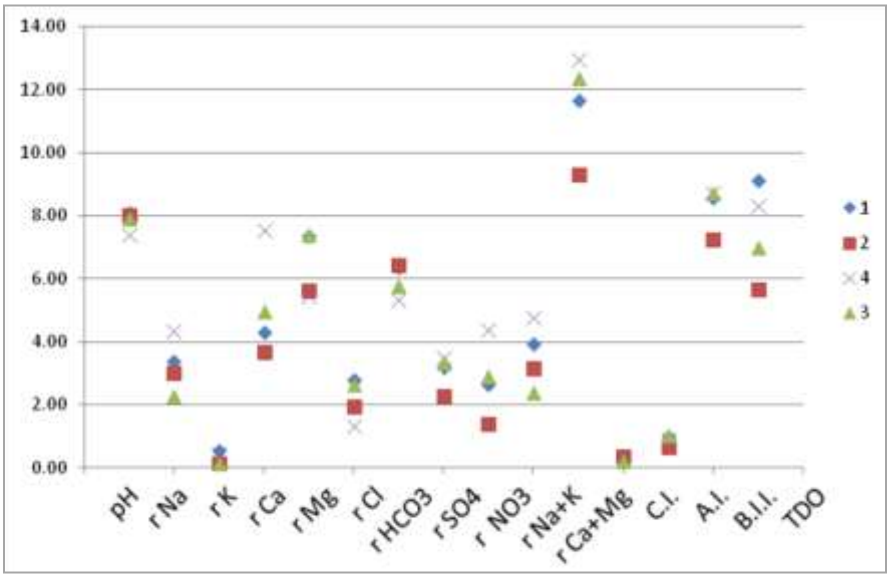
r HCO3
r SO4
r NO3
r Na+K
r Ca+Mg
C.I.
A.I.
B.I.I.


14.00
12.00
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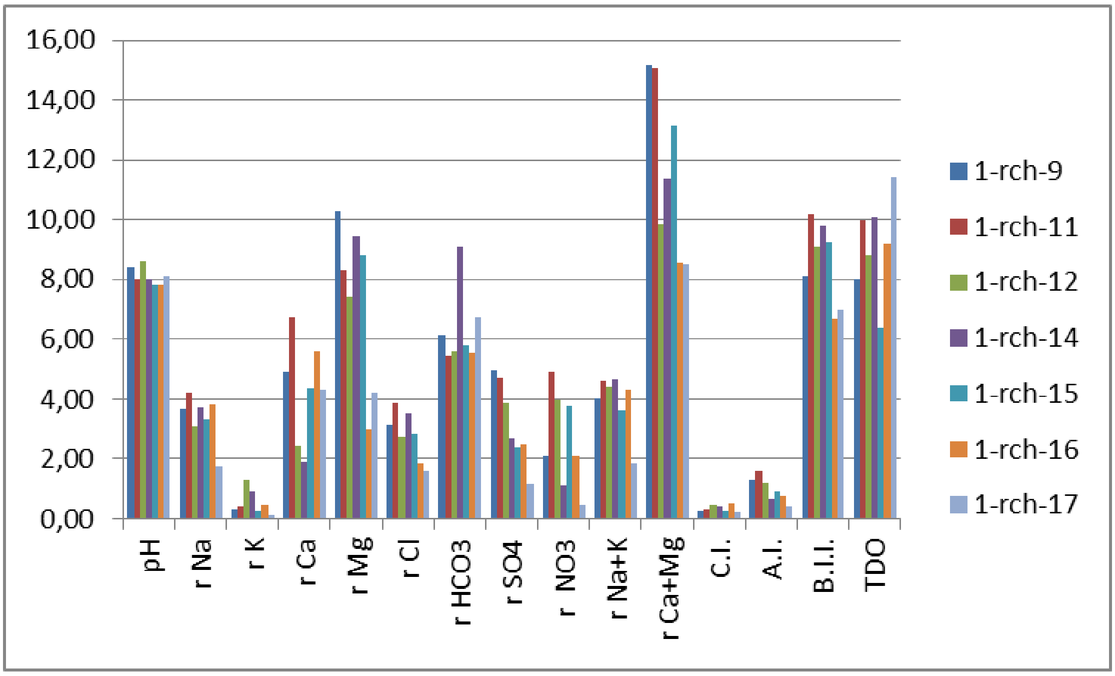
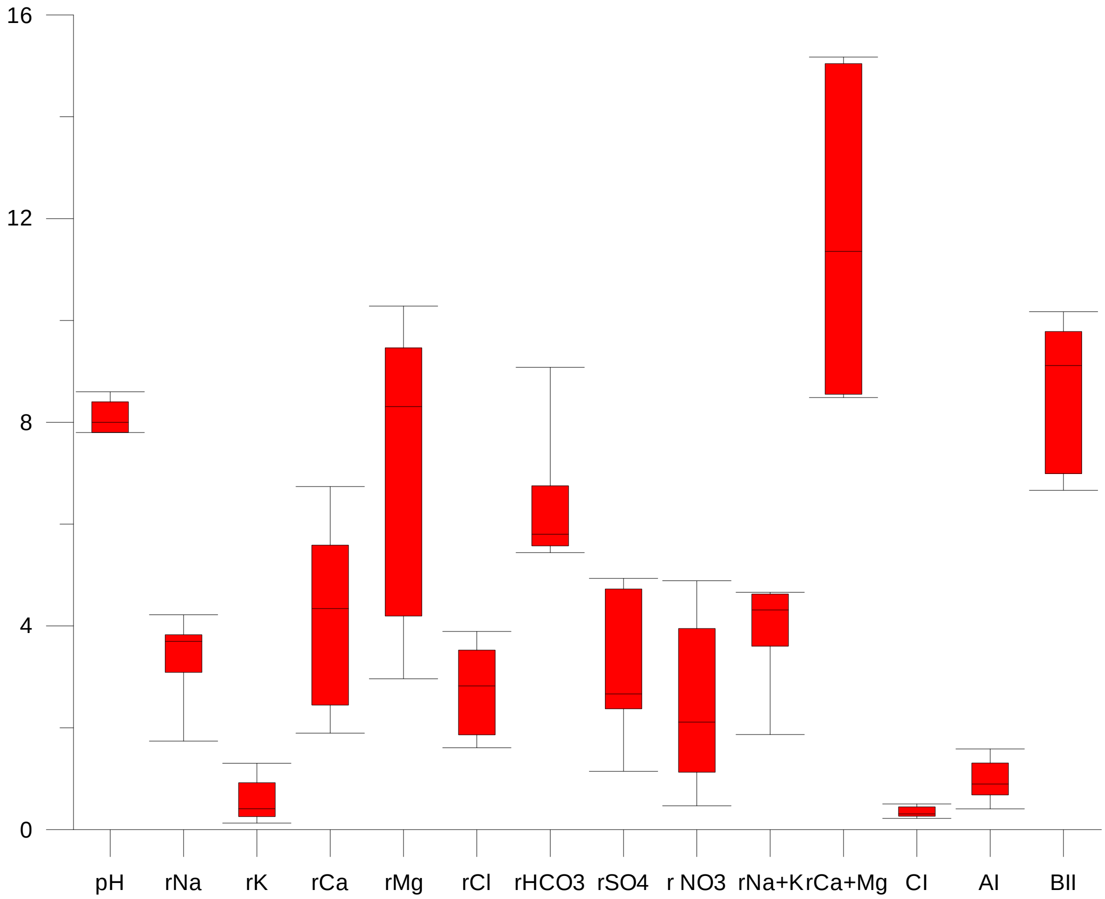
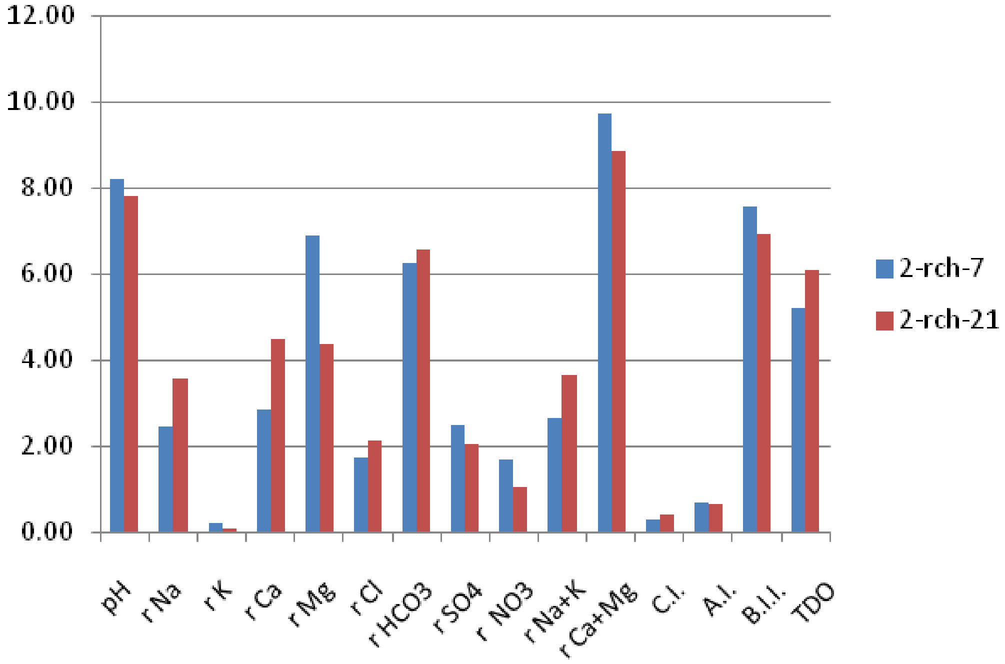
pH
r Na
r K
r Ca
r Mg
r Cl
r HCO3
r SO4
r NO3
r Na+K
r Ca+Mg
C.I.
A.I.
B.I.I.
TDO
1
2
4
3

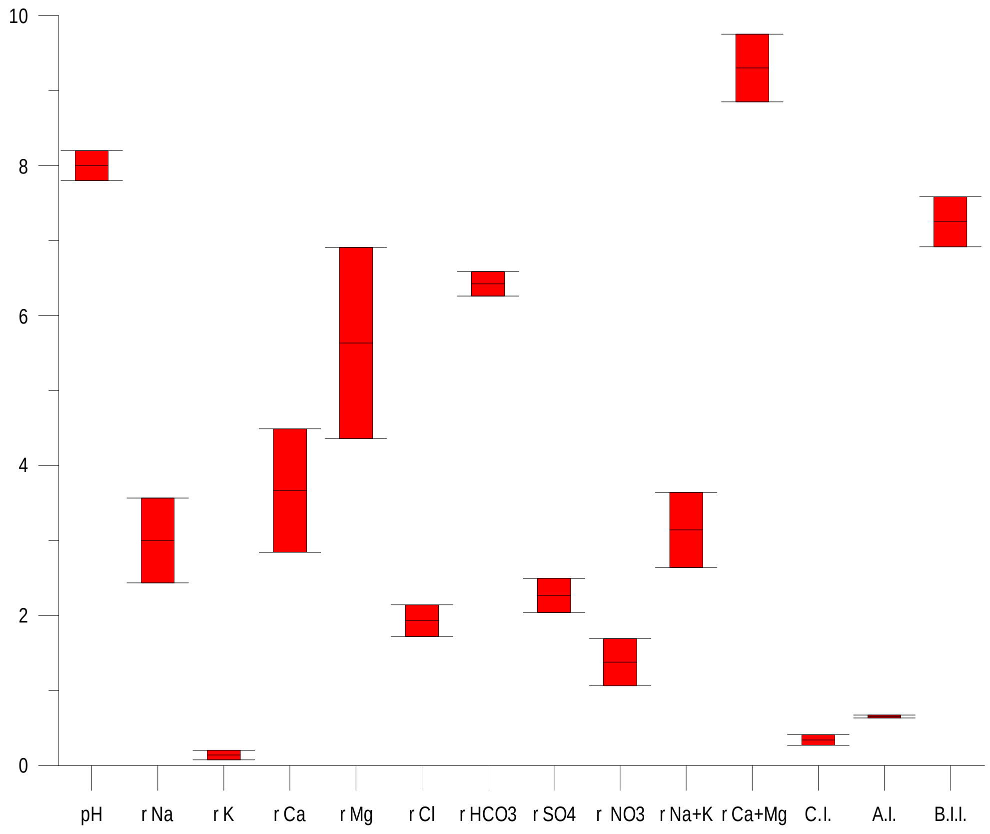
1-Areas with physical clogging processes:



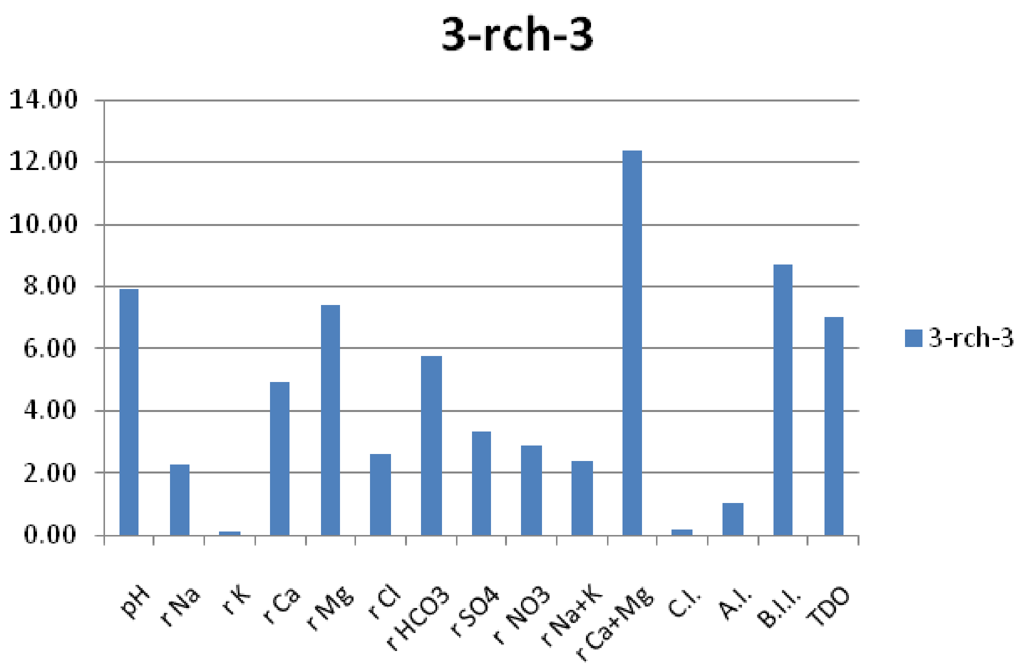


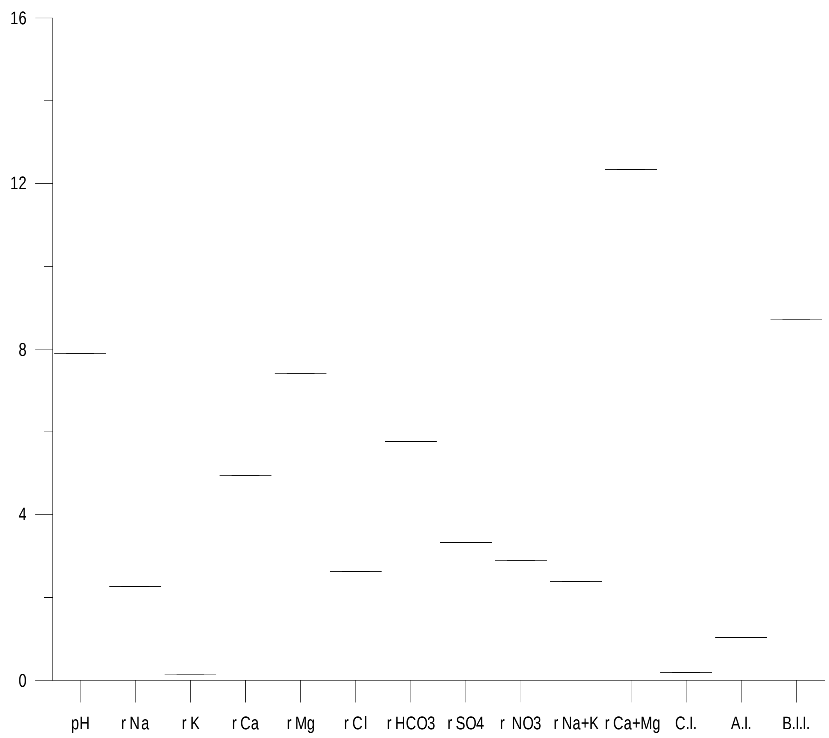
2-Biological and biophysics clogging processes:



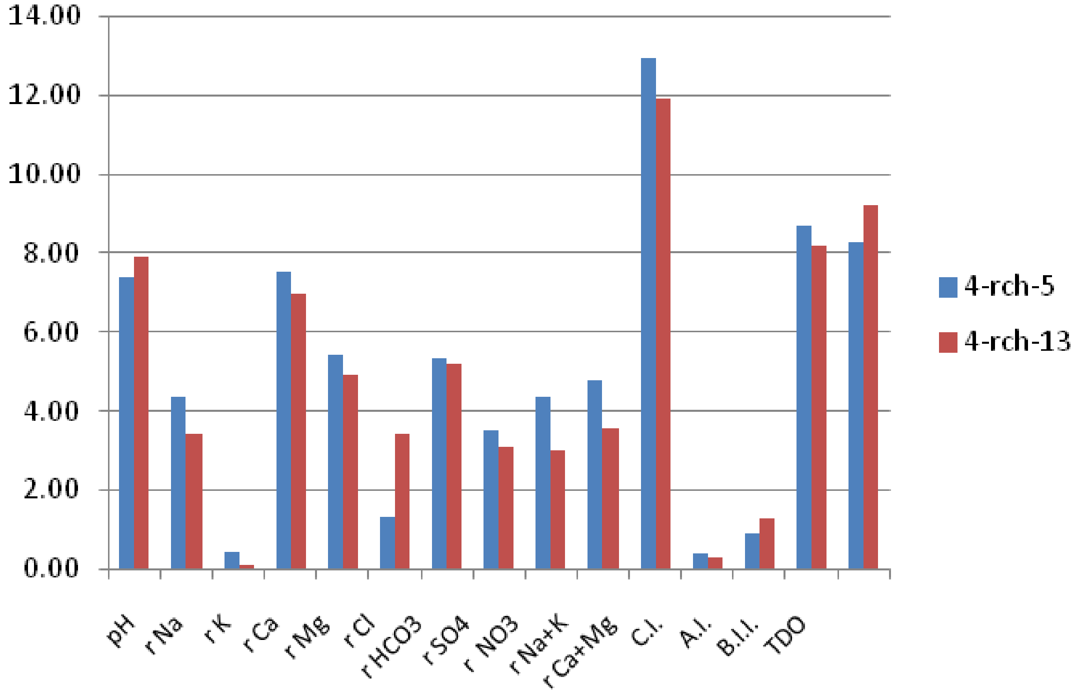


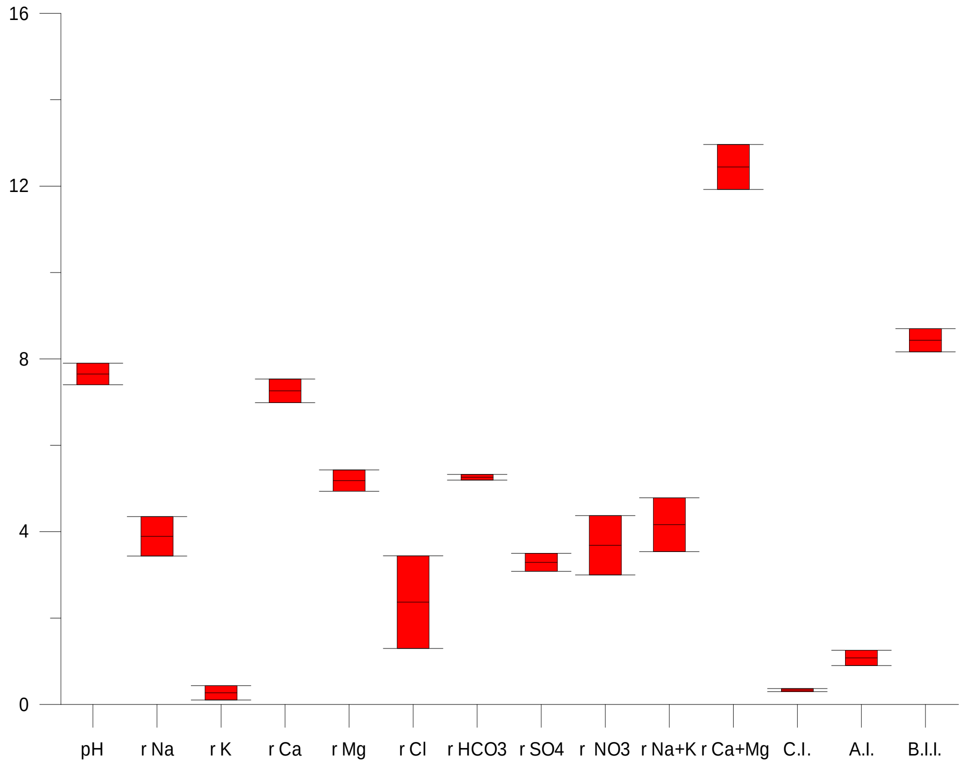
3-Chemical clogging processes:





4-Physical-biological clogging processes:





6.1.3 Profile columns

During this period we have been working on spatial distribution of the key processes and combinations thereof, the mapping for characterization of clogging types, as well as sampling collection for further characterization.

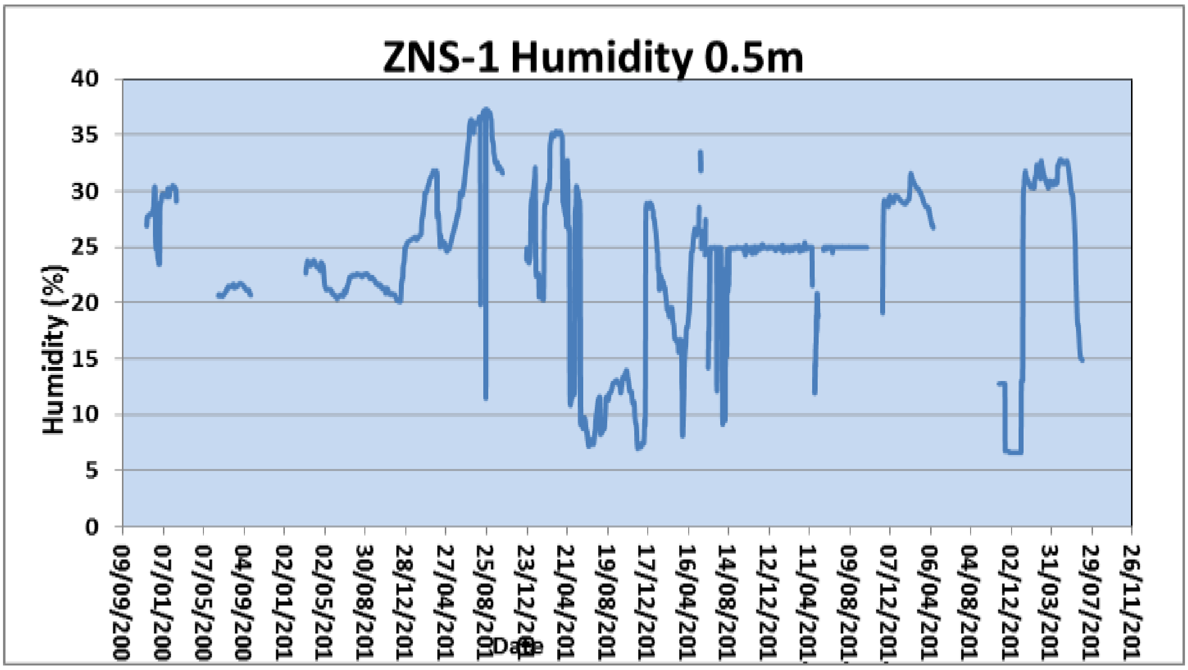
Samples of 2009 (up) and 2015 (below) so as to compare the clogging profile.

6.2 ANNEX II: Datasets collection from ZNS stations

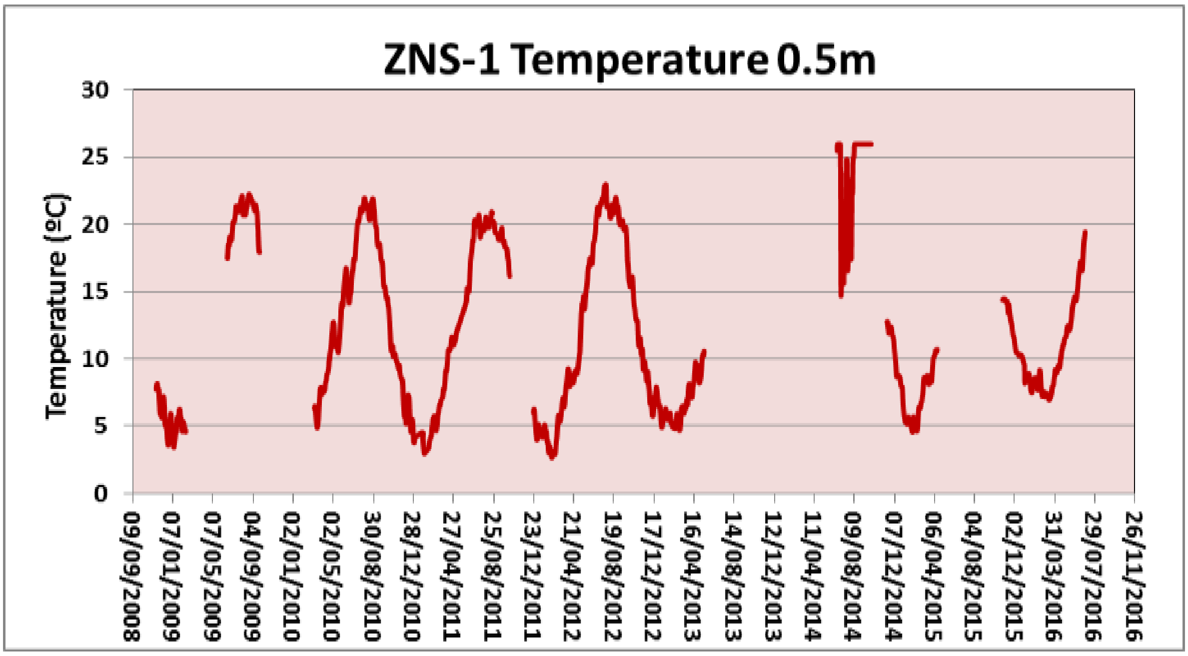
6.3.1 Santiuste basin ZNS 1 station

HUMIDIMETER 0.5m depth

HUMIDITY EVOLUTION: 18/11/2008 – 30/06/2016

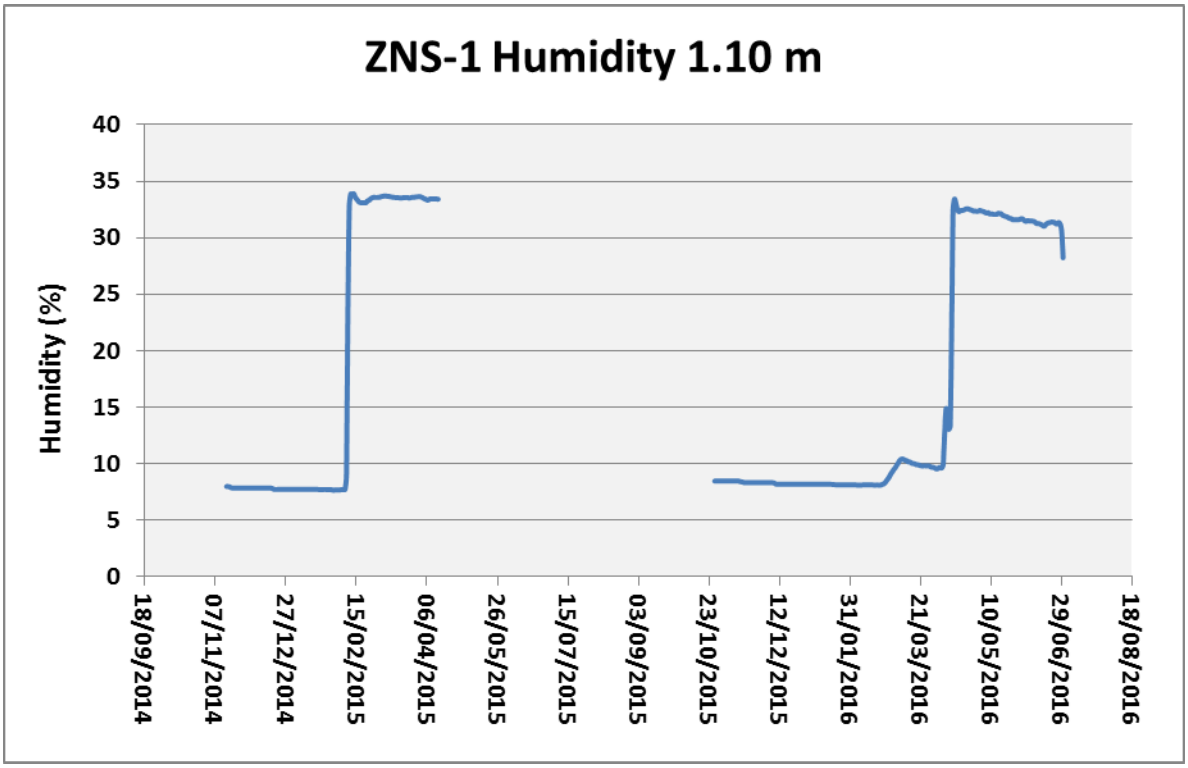


TEMPERATURE EVOLUTION: 18/11/2008 – 30/06/2016

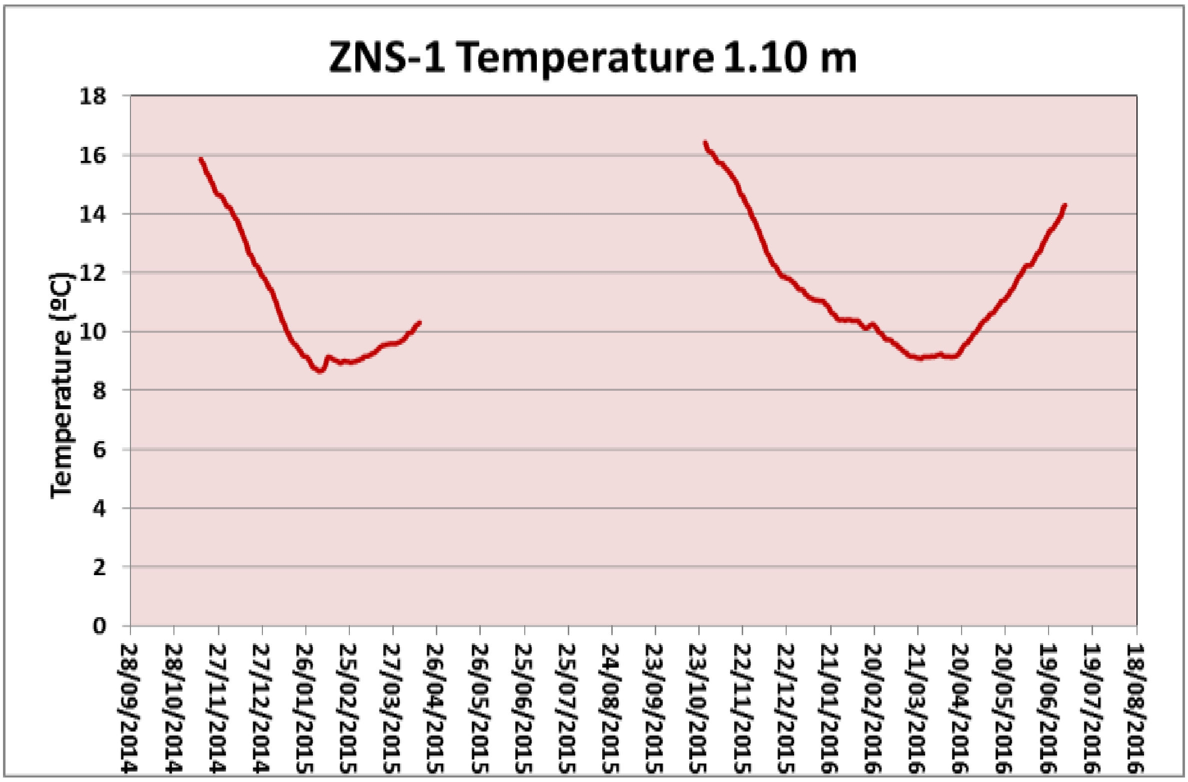


HUMIDIMETER 1.10m depth

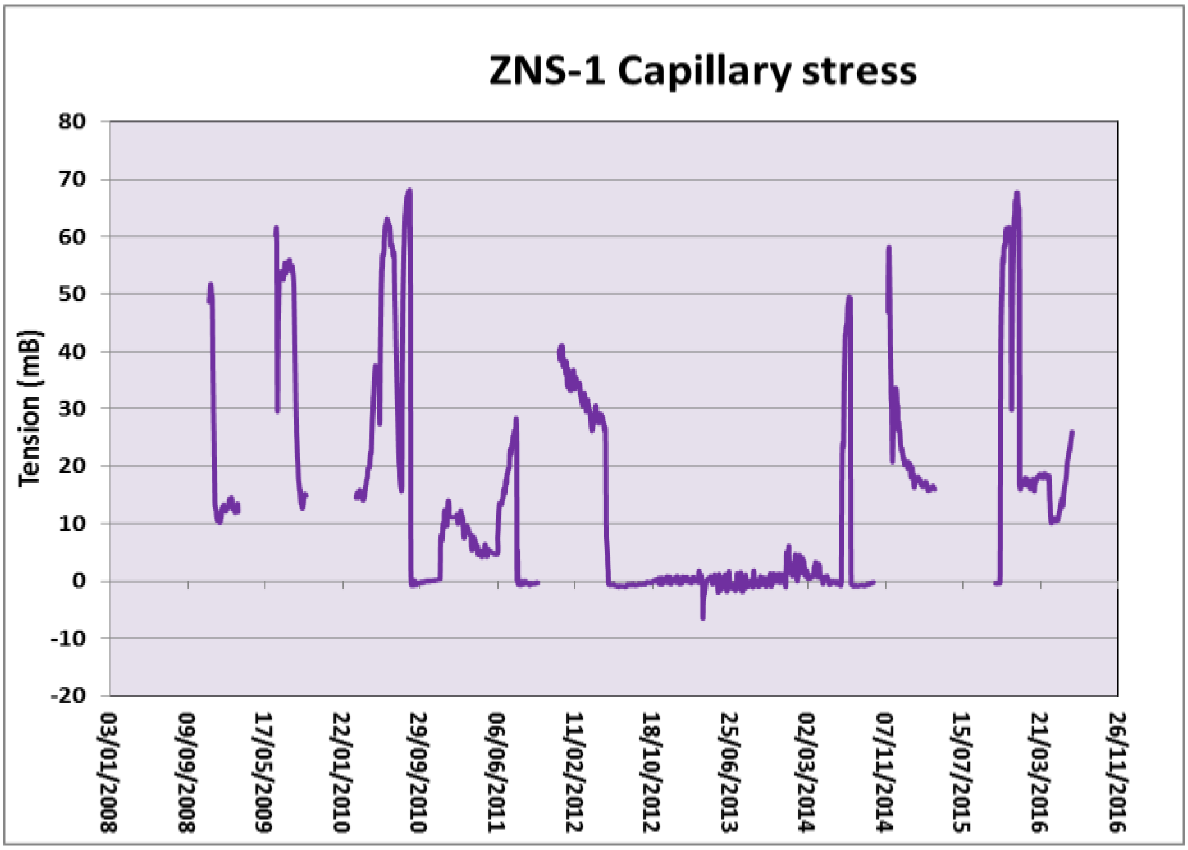
HUMIDITY EVOLUTION: 15/11/2014 – 30/06/2016

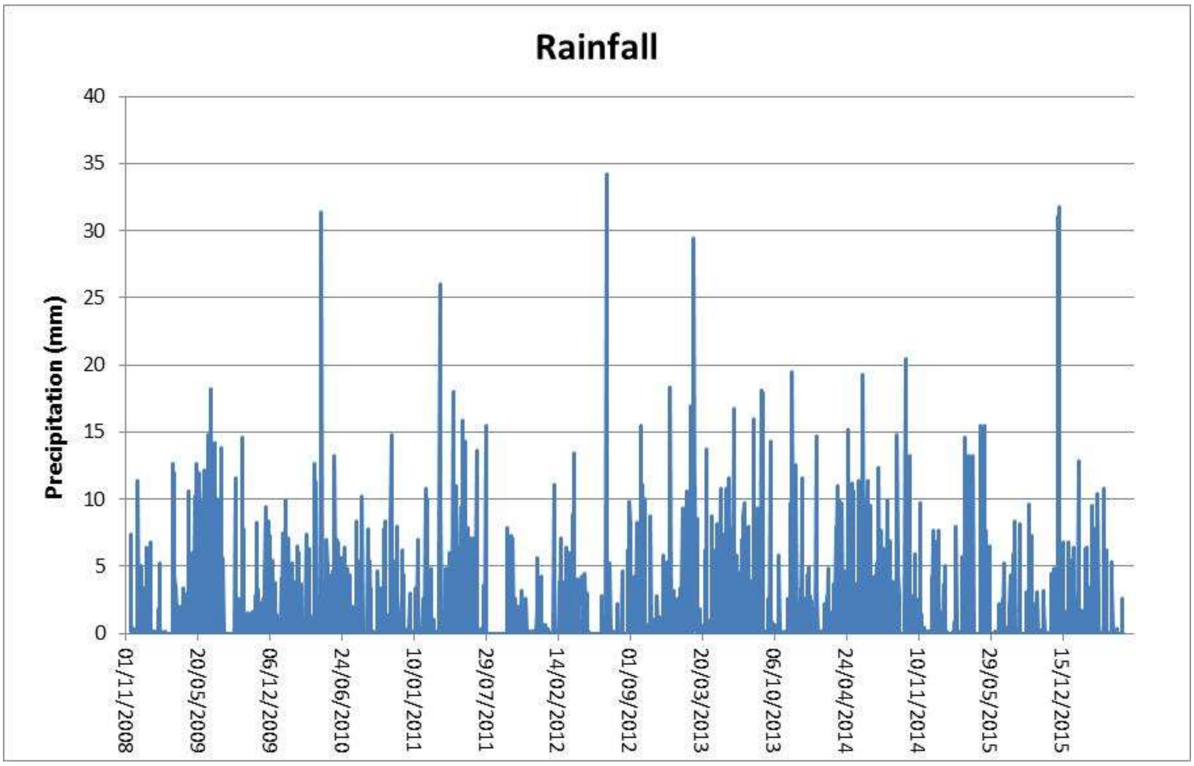


TEMPERATURE EVOLUTION: 15/11/2014 – 30/06/2016



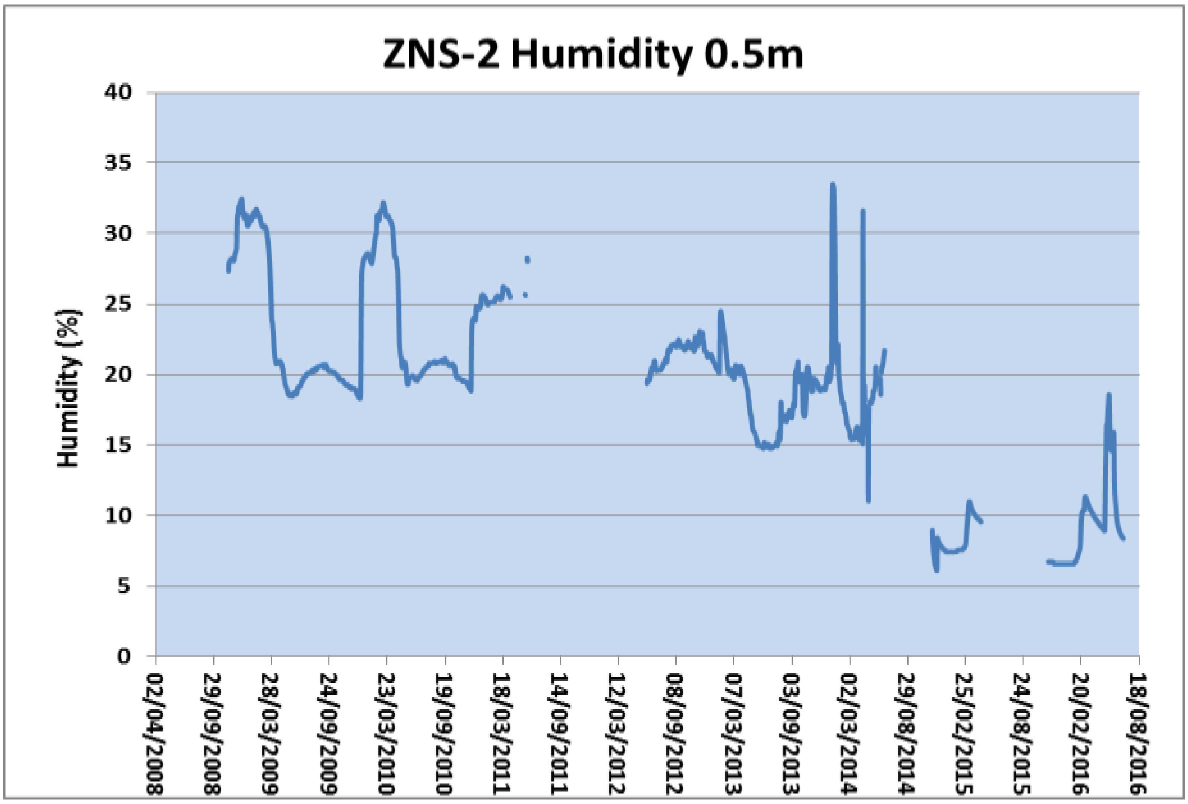
TENSIOMETER (1.20 m depth): 18/11/2008 – 30/06/2016



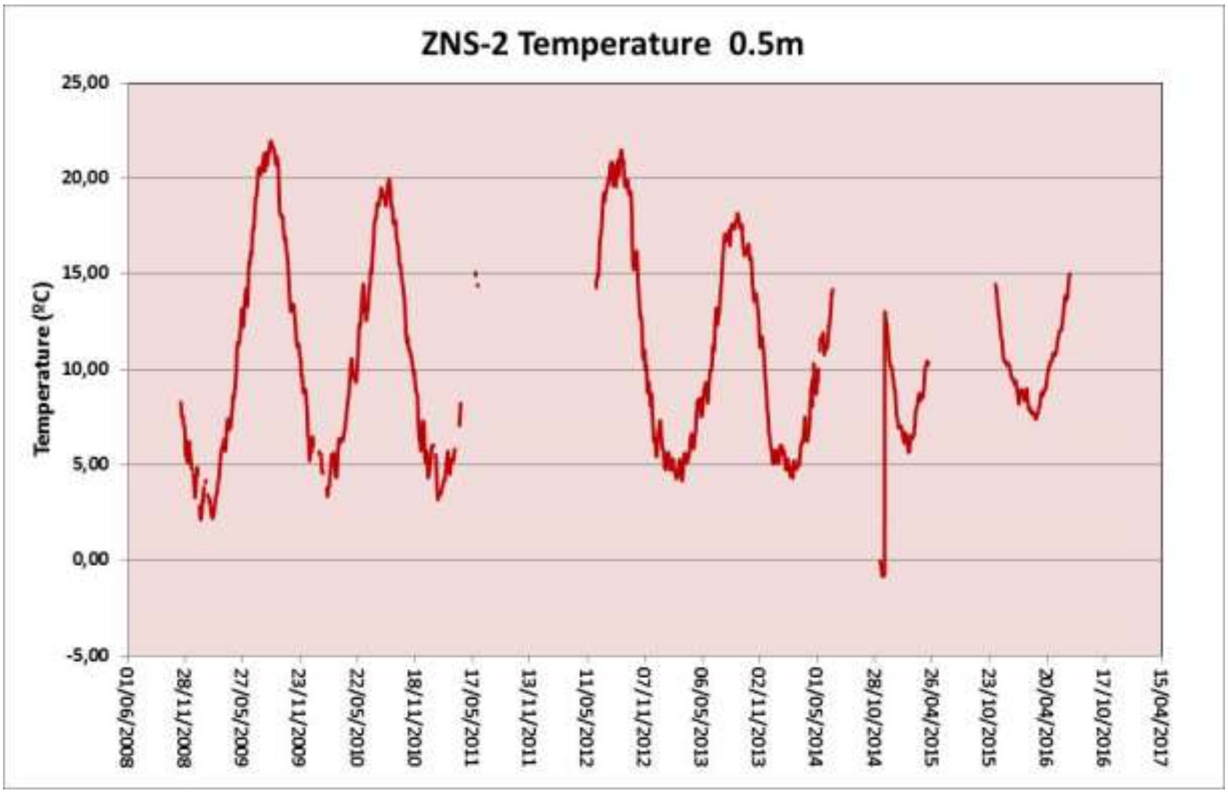


6.3.2 Santiuste basin ZNS 2 station

HUMIDIMETER 0.5m depth. 14/11/2008 – 30/06/2016

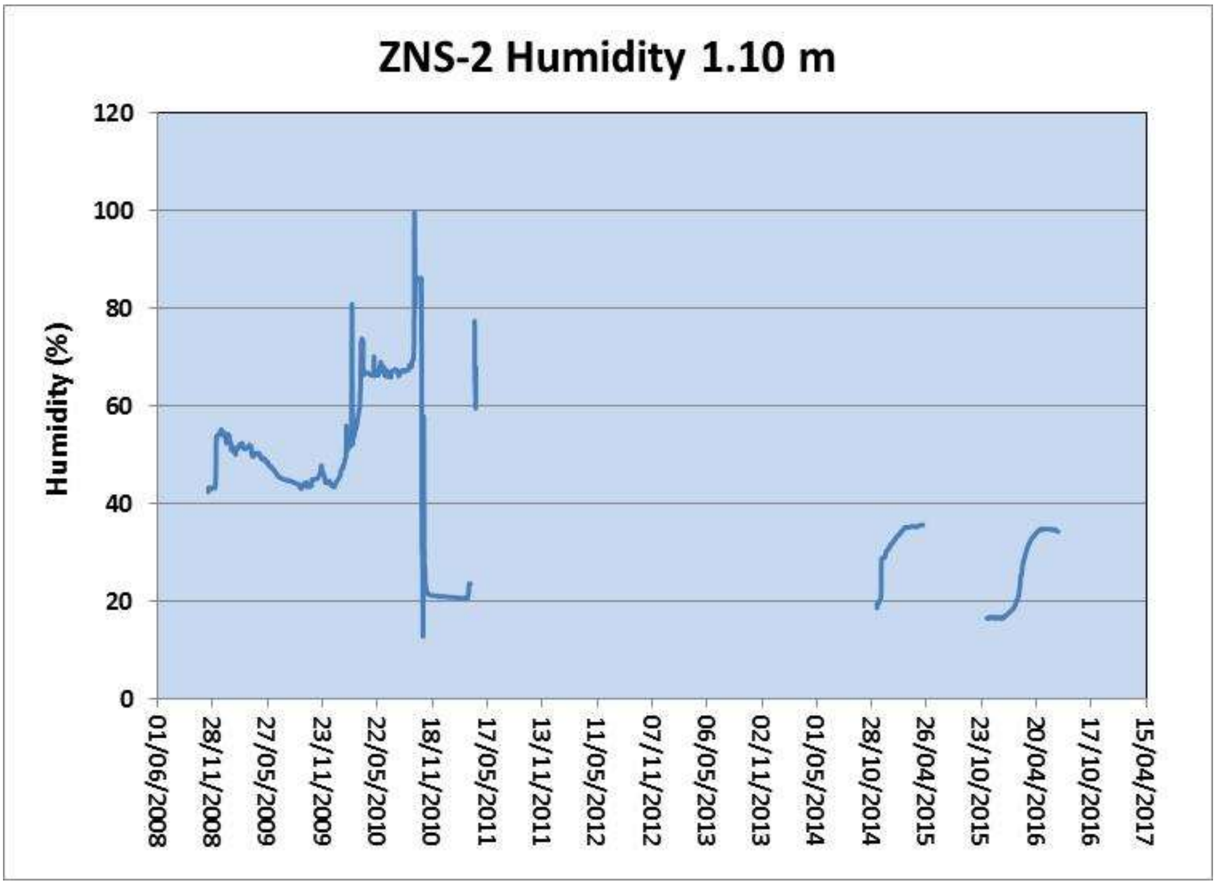


TEMPERATURE EVOLUTION: 14/11/2008 – 30/06/2016

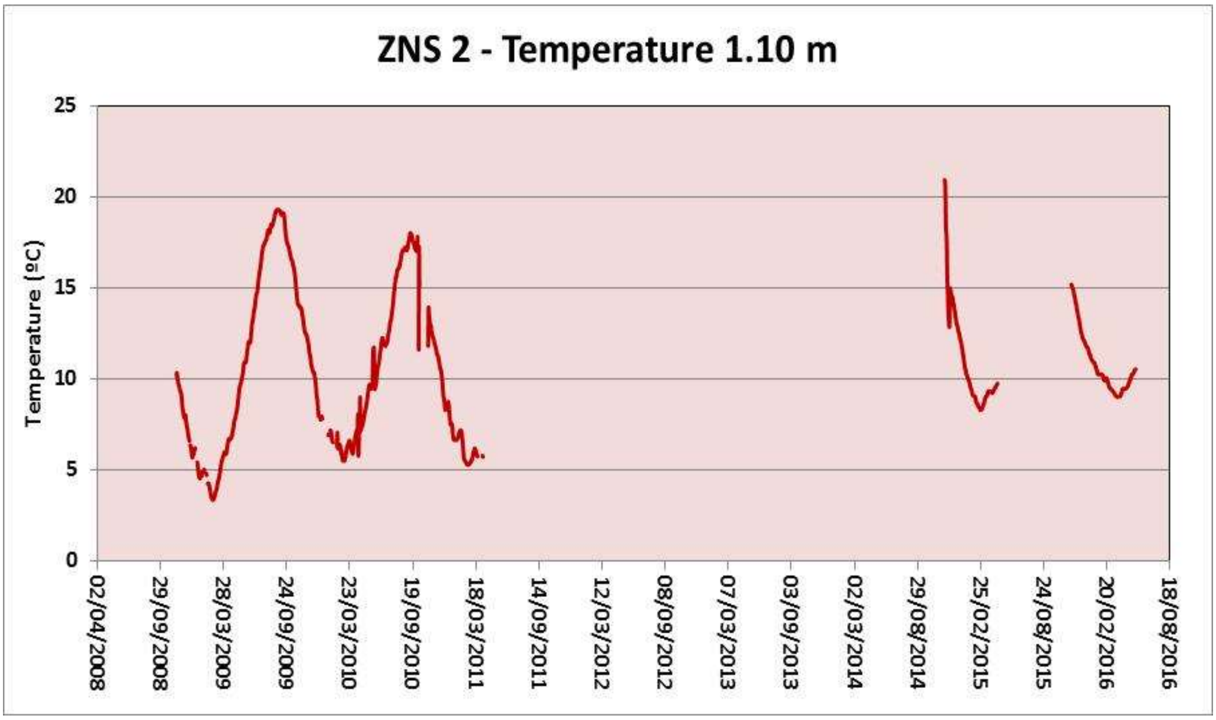


HUMIDIMETER 1.10m depth

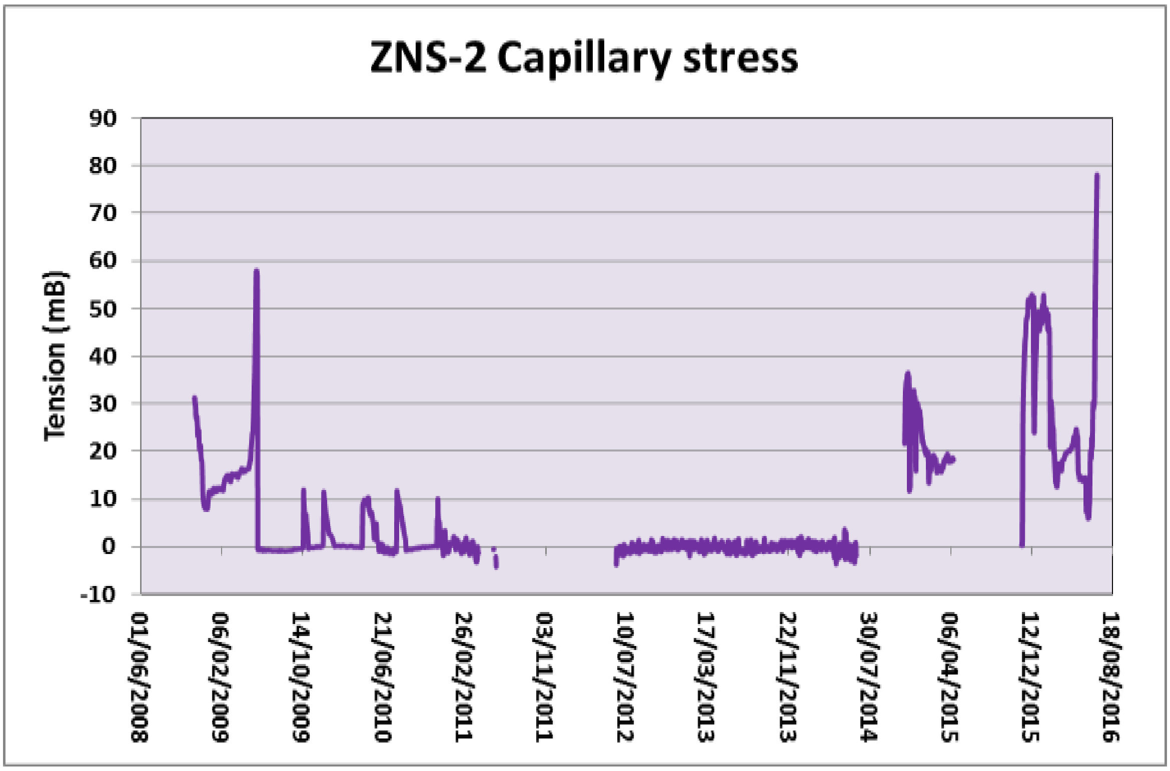
HUMIDITY EVOLUTION: 14/11/2008 – 30/06/2016



TEMPERATURE EVOLUTION: 14/11/2008 – 30/06/2016

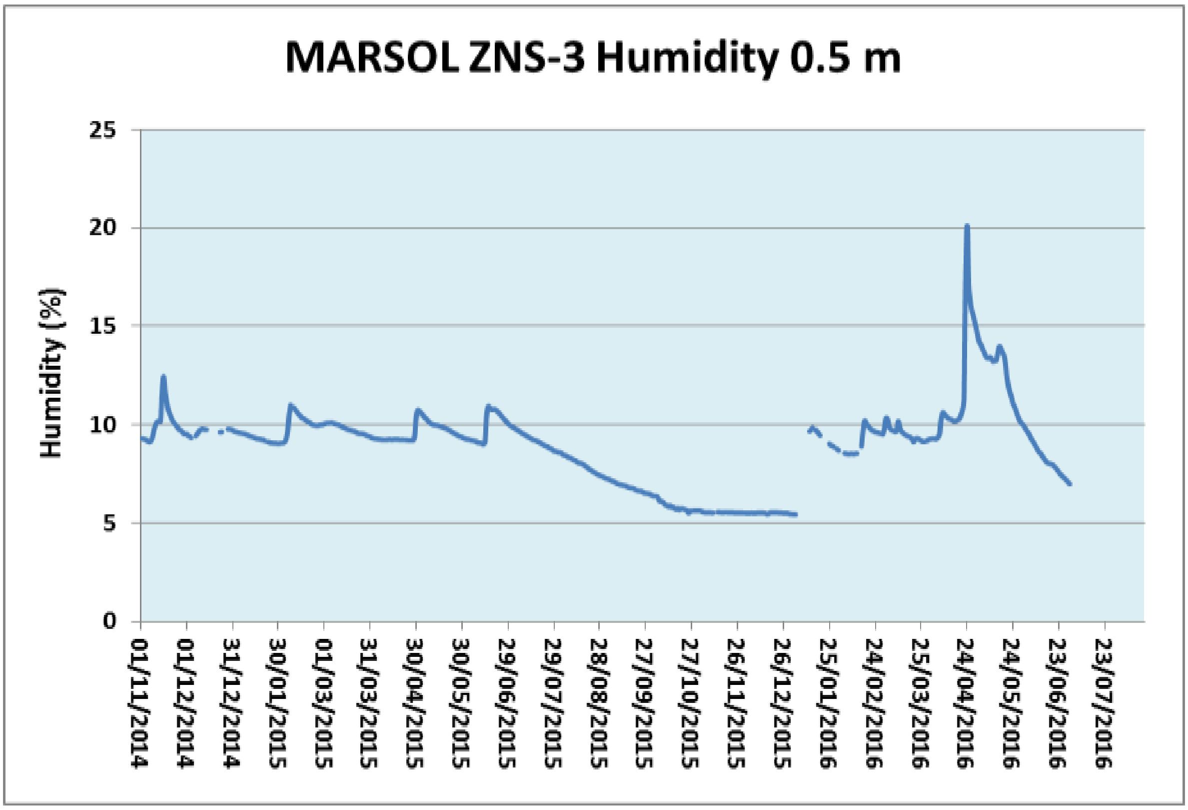


TENSIOMETER (1.20 m depth): 14/11/2008 – 30/06/2016

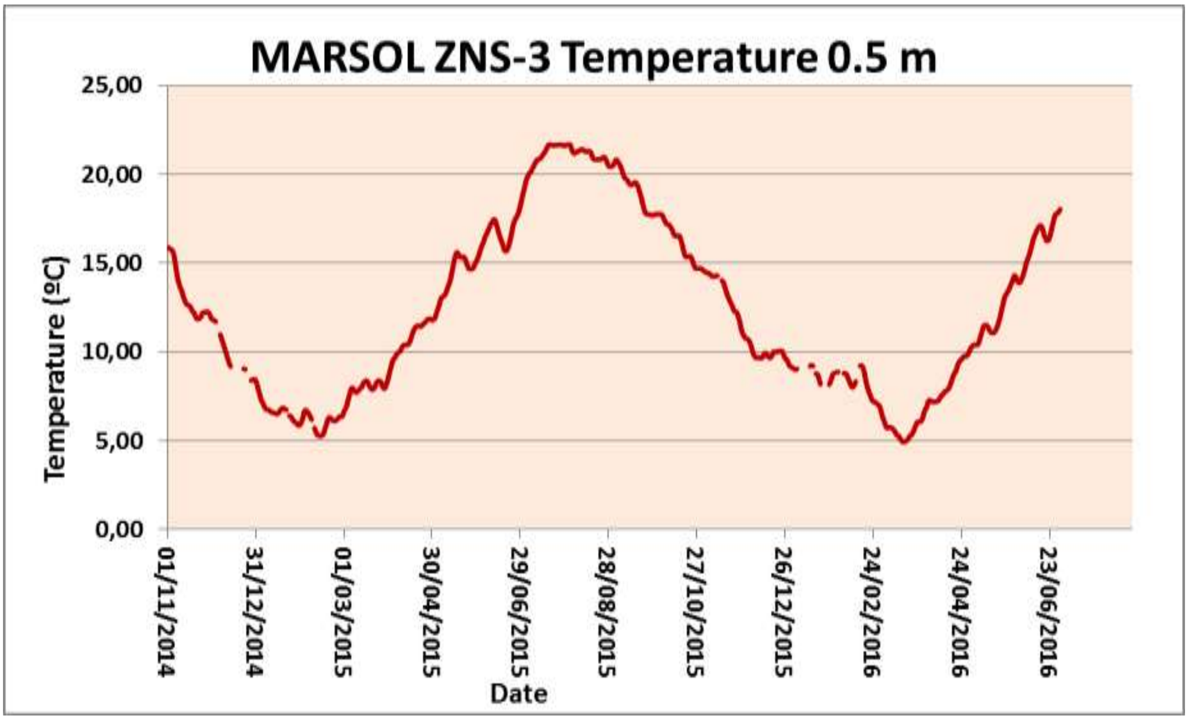


6.2.1 Carracillo council ZNS 3 station

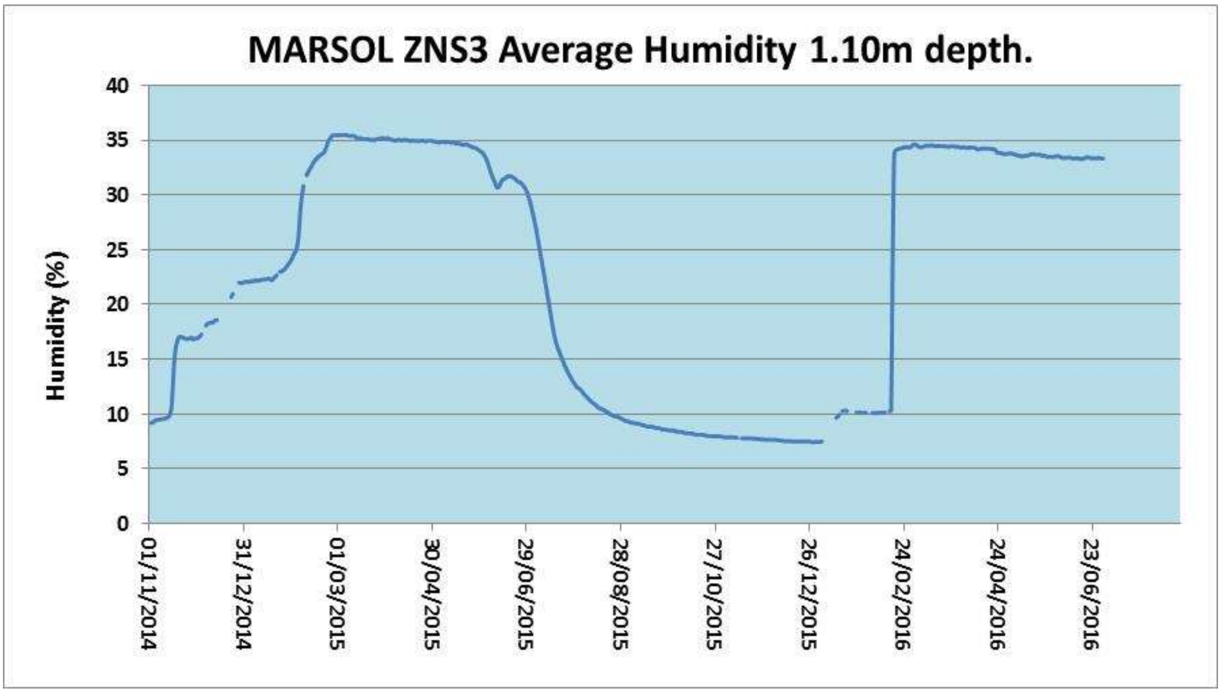
HUMIDIMETER 0.5m depth: HUMIDITY EVOLUTION: 2/11/2014 – 30/06/2016



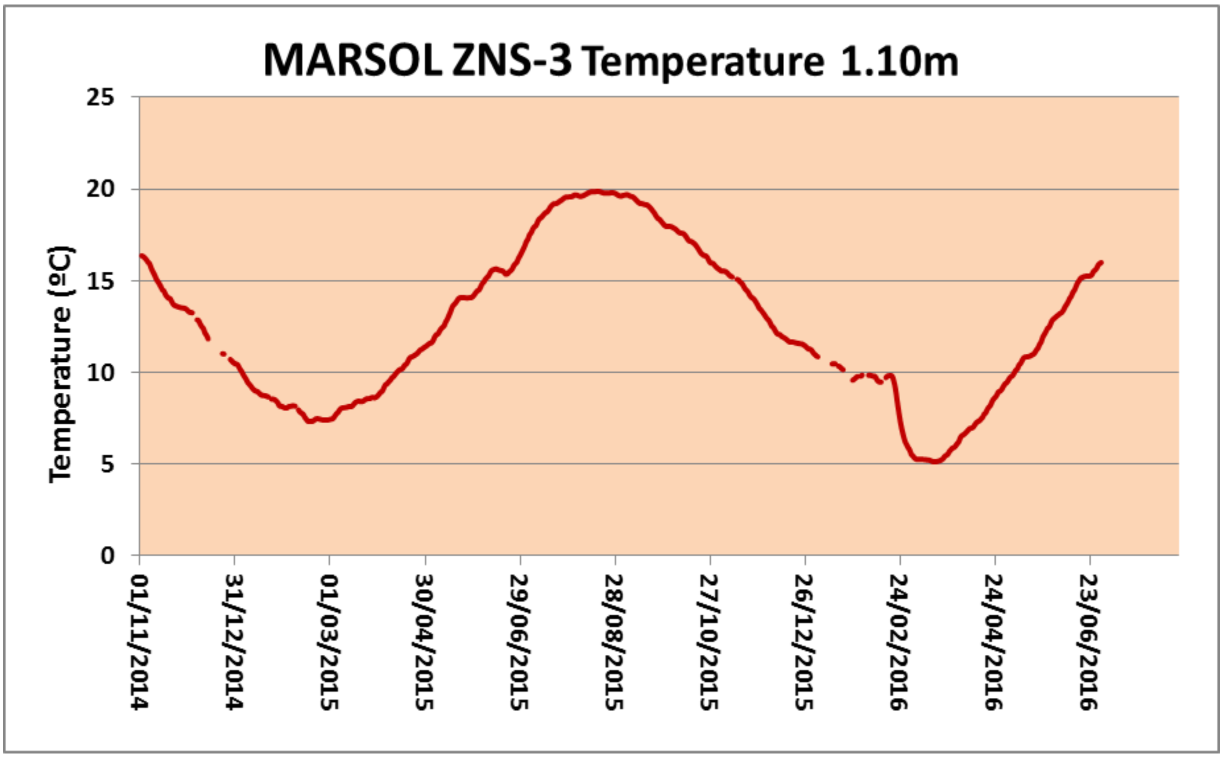
TEMPERATURE EVOLUTION: 2/11/2014 – 30/06/2016



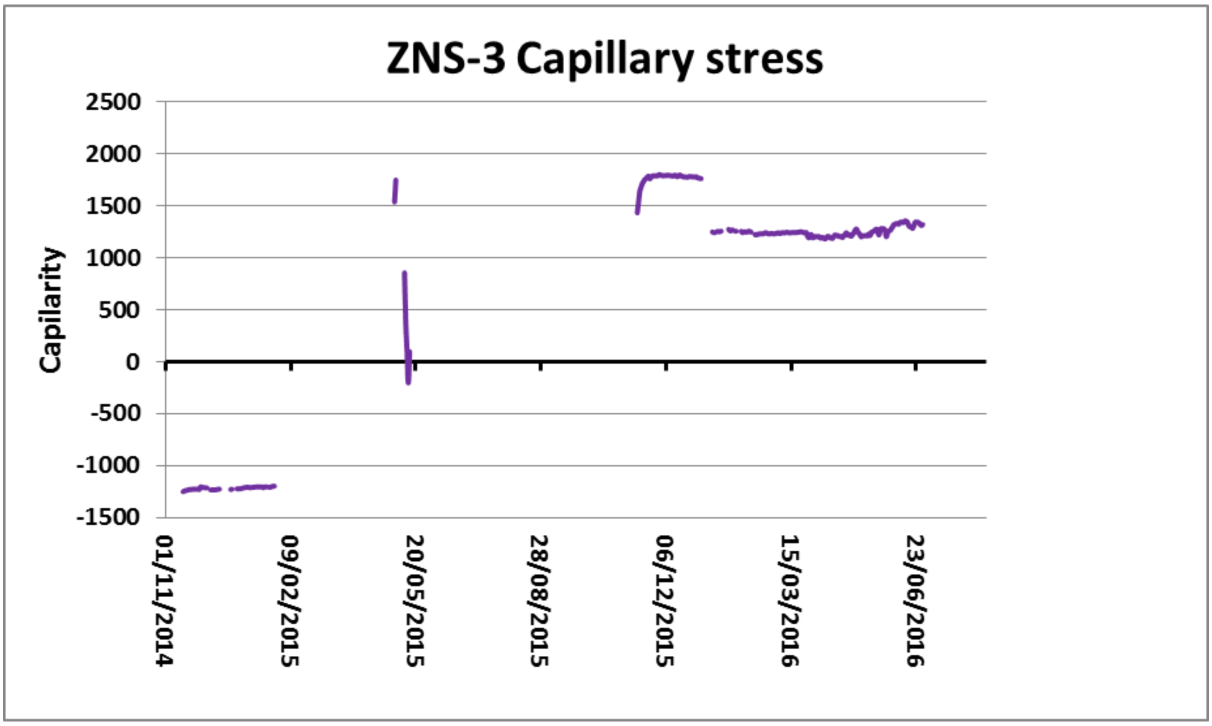
HUMIDIMETER 1.10m depth: HUMIDITY EVOLUTION: 2/11/2014 – 30/06/2016

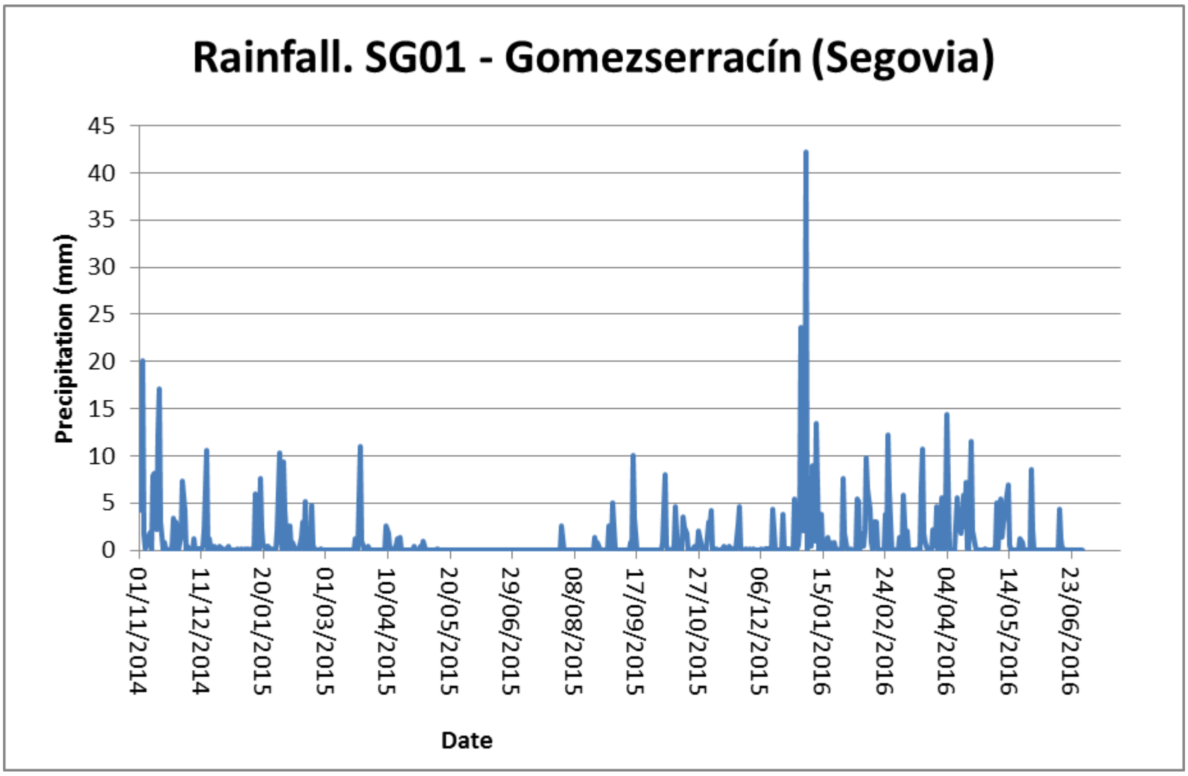


TERMOMETER 1.10m depth: TEMPERATURE EVOLUTION: 2/11/2014 – 30/06/2016

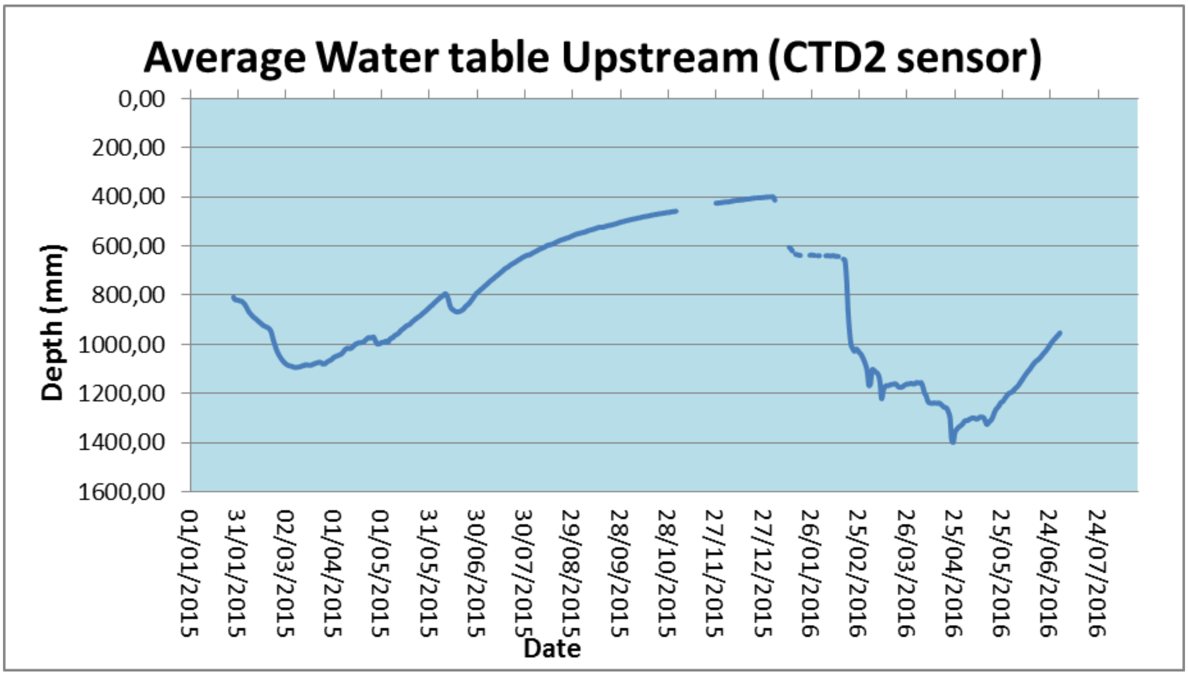


TENSIOMETER (1.50 m depth): 2/11/2014 – 30/06/2016

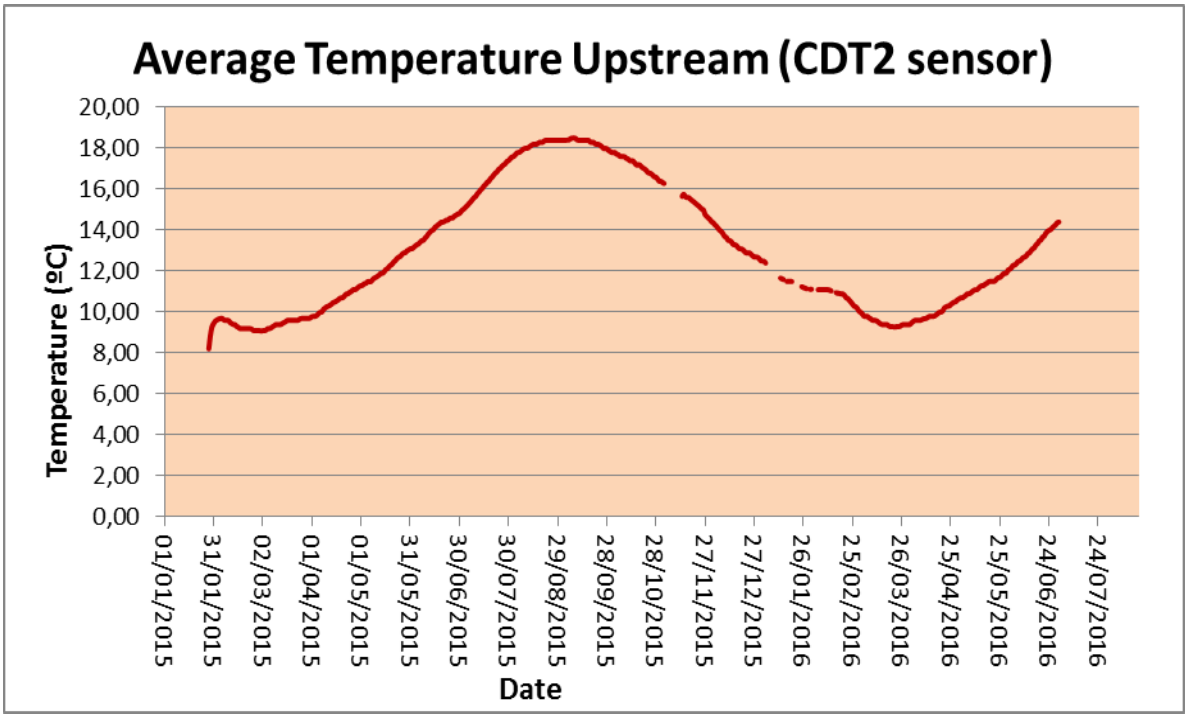




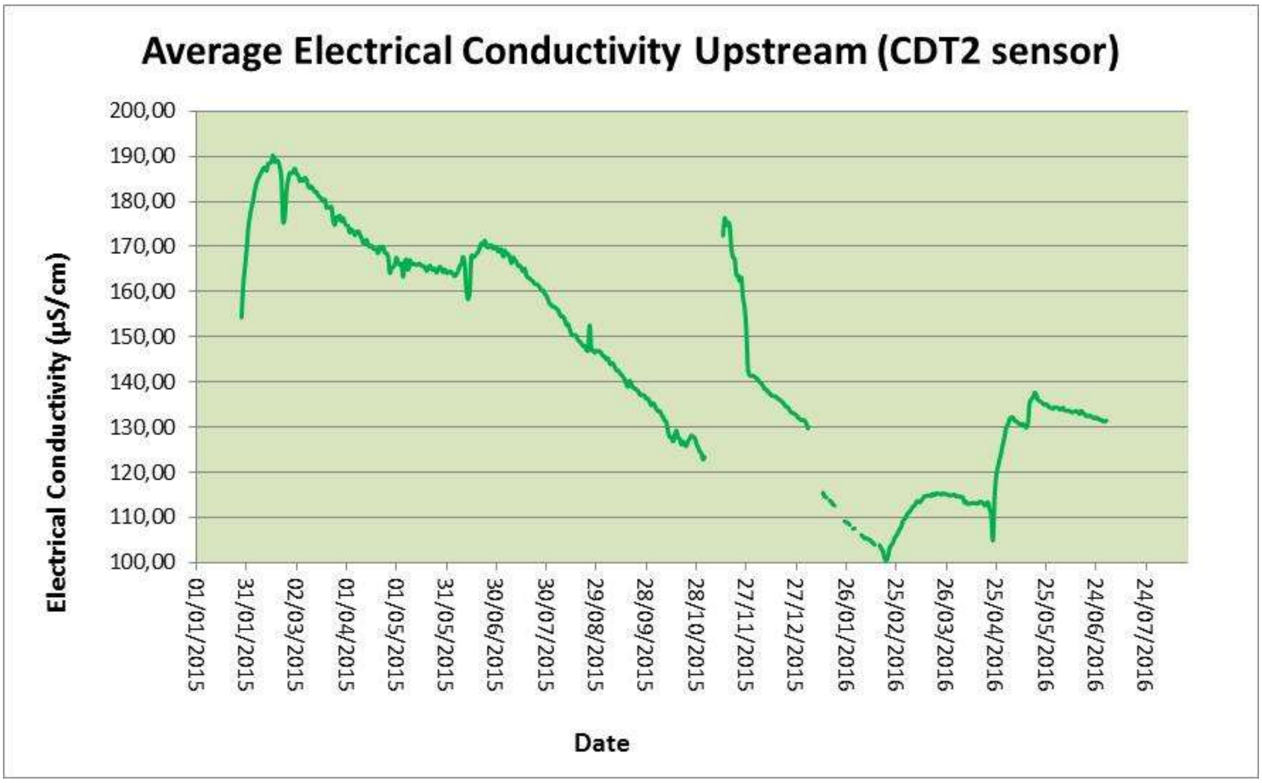
ZNS3: UPSTREAM CTD2 SENSOR: WATER TABLE EVOLUTION: 28/01/2015 – 30/06/2016



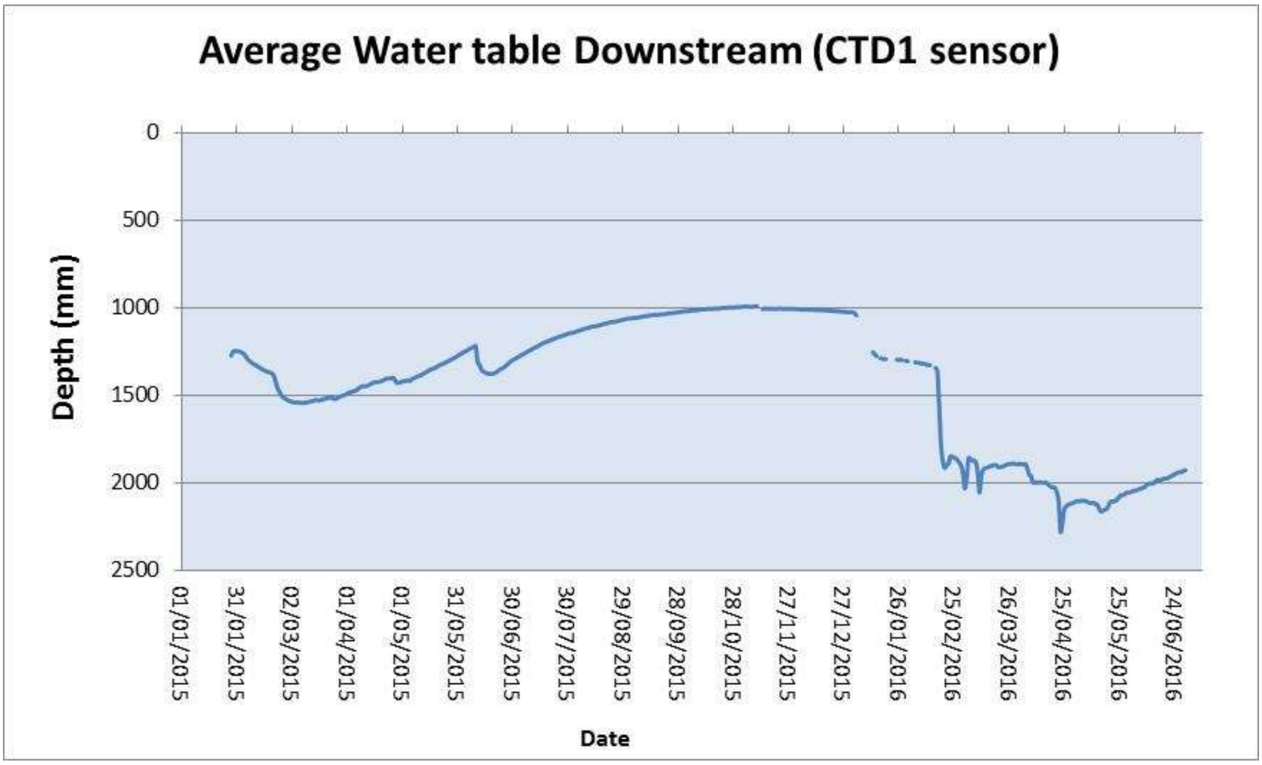
TEMPERATURE EVOLUTION: 28/01/2015 – 30/06/2016



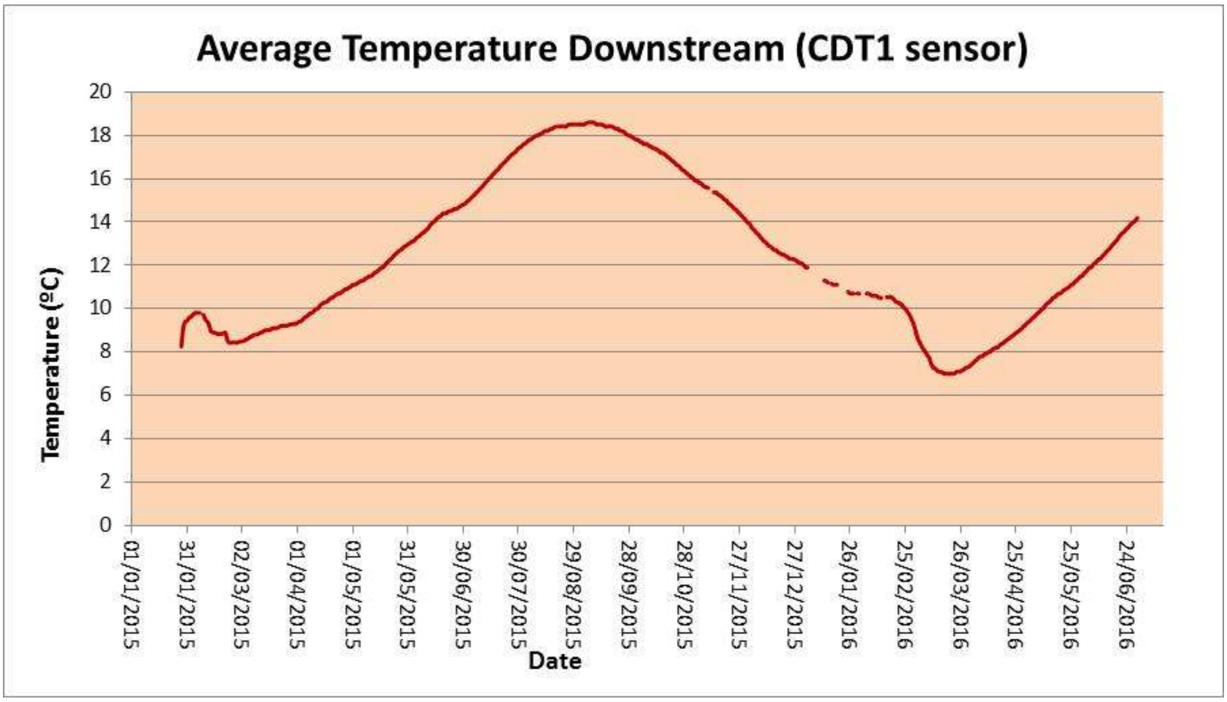
ELECTRICAL CONDUCTIVITY EVOLUTION: 28/01/2015 – 30/06/2016



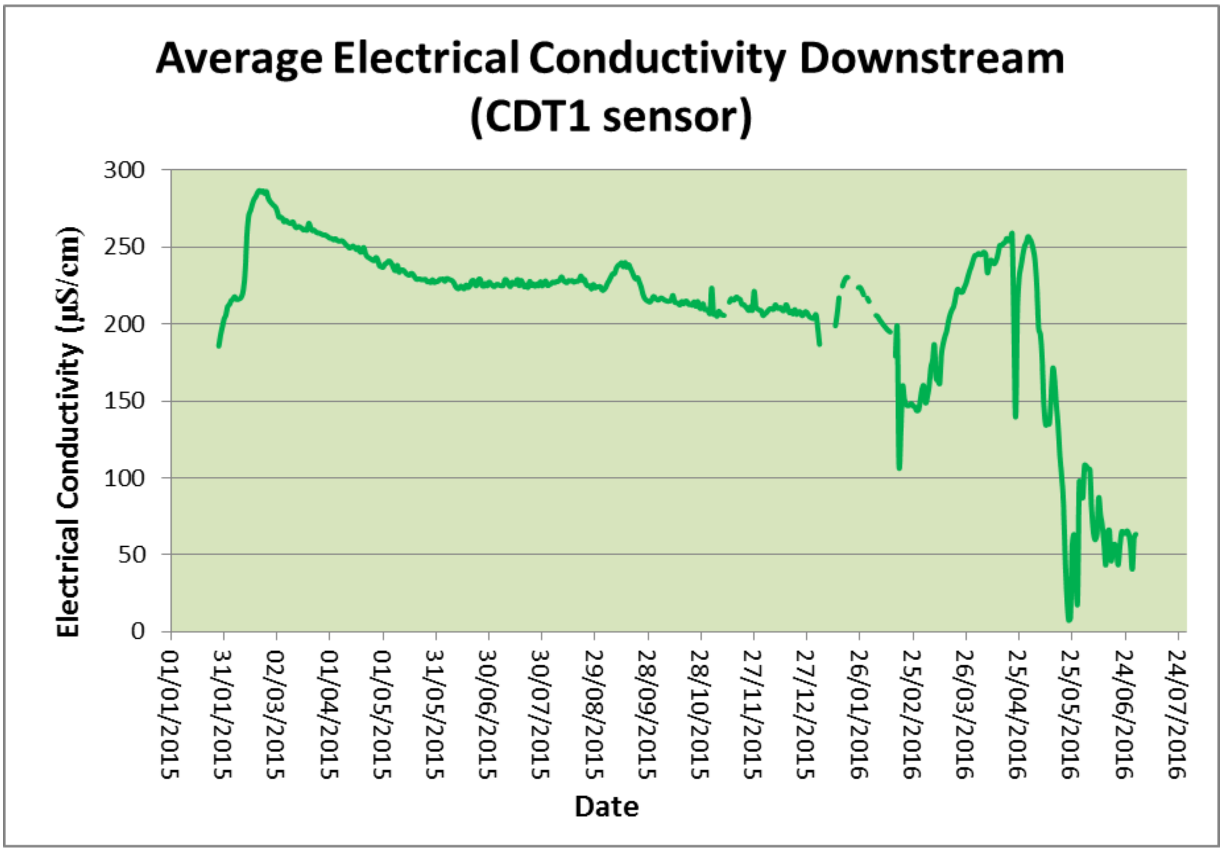
ZNS3: DOWNSTREAM CTD1 SENSOR: WATER TABLE EVOLUTION: 28/01/2015 – 30/06/2016



TEMPERATURE EVOLUTION: 28/01/2015 – 30/06/2016



ELECTRICAL CONDUCTIVITY EVOLUTION: 28/01/2015 – 30/06/2016

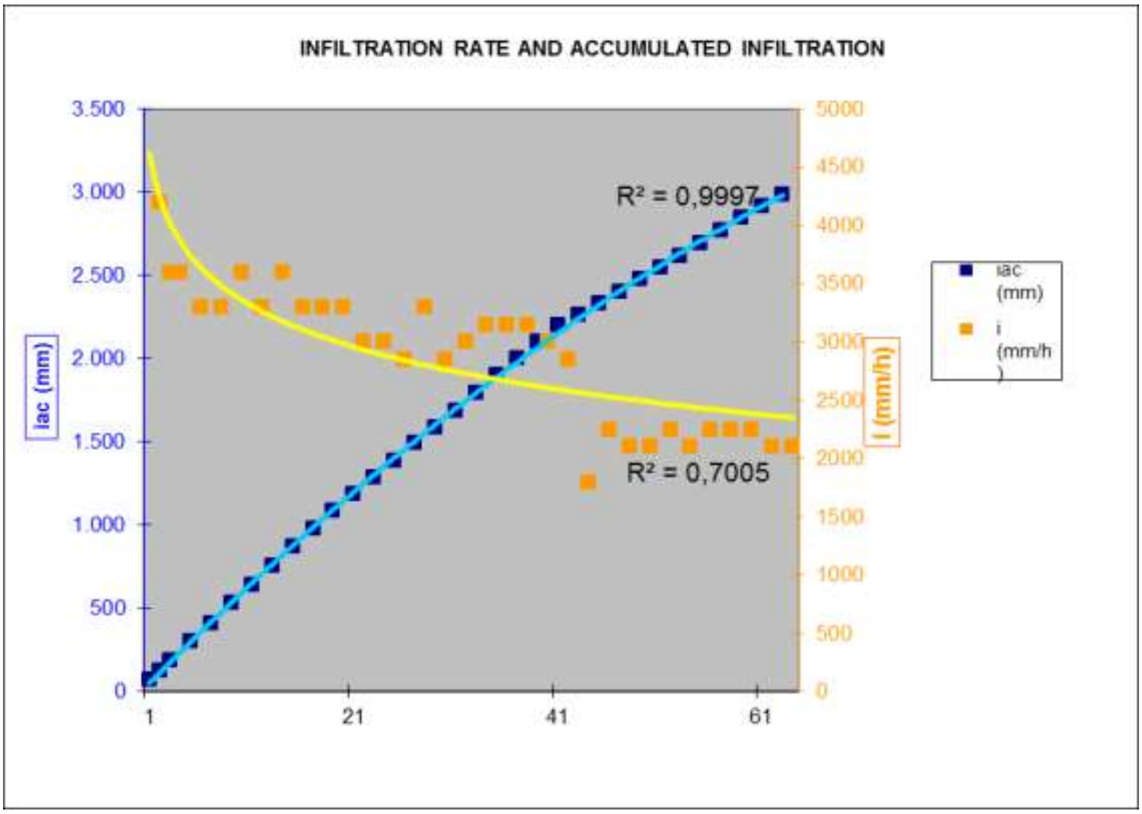


6.3 ANNEX III: Physical analyses. Infiltration tests results

6.3.1 Santiuste basin. Infiltration tests in the furrows at the bottom of Infiltration ponds results

AREA: ***Santiuste infiltration pond. Furrow width 40 cm***
DATE: 04/07/2016 HOUR: 11:30
Soil pit: sand

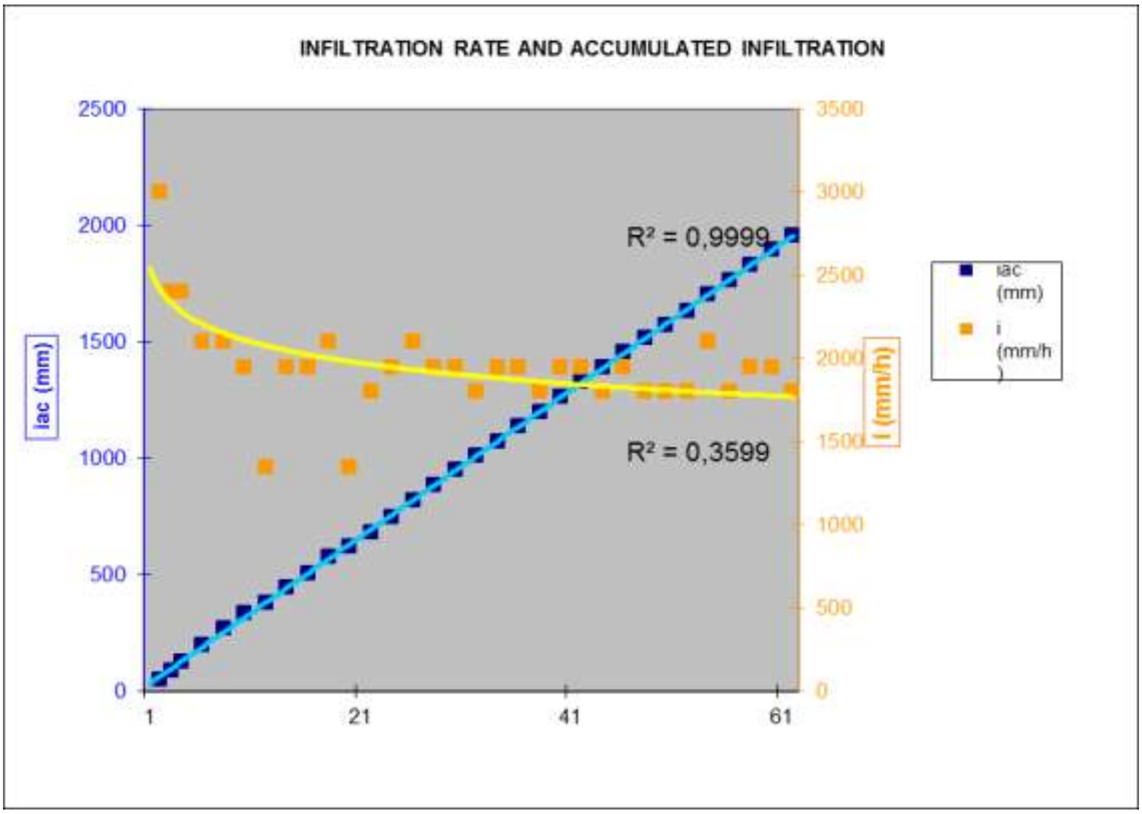
t(min)	h (cm)	i (mm)	iac (mm)	i (mm/h)
0	92,0	0	0	0
1	85-92	70	70	4.200
2	86-92	60	130	3.600
3	86-92	60	190	3.600
5	81-92	110	300	3.300
7	81-92	110	410	3.300
9	80-92	120	530	3.600
11	81-92	110	640	3.300
13	80-92	120	760	3.600
15	81-93	110	870	3.300
17	82-92	110	980	3.300
19	81-92	110	1.090	3.300
21	82-92	100	1.190	3.000
23	82-91,5	100	1.290	3.000
25	82-92	95	1.385	2.850
27	81,5-91	110	1.495	3.300
29	81,5-92	95	1.590	2.850
31	82-92	100	1.690	3.000
33	81,5-92	105	1.795	3.150
35	81,5-92	105	1.900	3.150
37	81,5-92	105	2.005	3.150
39	82-91	100	2.105	3.000
41	81,5-91	95	2.200	2.850
43	85-92	60	2.260	1.800
45	84,5-92	75	2.335	2.250
47	85-92	70	2.405	2.100
49	85-92	70	2.475	2.100
51	84,5-92	75	2.550	2.250
53	85-92	70	2.620	2.100
55	84,5-92	75	2.695	2.250
57	84-92,5	75	2.770	2.250
59	85-92	75	2.845	2.250
61	85-93	70	2.915	2.100
63	86	70	2.985	2.100



AREA: Santiuste infiltration pond. Furrow width 140 cm
DATE: 04/07/2016 HOUR: 13:30
Soil pit: sand

h (cm)	i (mm)	iac (mm)	i (mm/h)
93,0	0	0	0

88-93	50	50	3.000
89-94	40	90	2.400
90-93	40	130	2.400
86-93	70	200	2.100
86-93	70	270	2.100
86,5-92,5	65	335	1.950
88-93	45	380	1.350
86,5-92,5	65	445	1.950
86-93	65	510	1.950
86-92,5	70	580	2.100
88-93	45	625	1.350
87-93	60	685	1.800
86,5-93	65	750	1.950
86-93	70	820	2.100
86,5-93	65	885	1.950
86,5-93	65	950	1.950
87-93	60	1.010	1.800
86,5-93	65	1.075	1.950
86,5-93	65	1.140	1.950
87-93	60	1.200	1.800
86,5-93	65	1.265	1.950
86,5-93	65	1.330	1.950
87-93	60	1.390	1.800
86,5-93	65	1.455	1.950
87-93	60	1.515	1.800
87-93	60	1.575	1.800
87-93	60	1.635	1.800
86-93	70	1.705	2.100
87-93	60	1.765	1.800
86,5-93	65	1.830	1.950
86,5-93	65	1.895	1.950
87,0	60	1.955	1.800

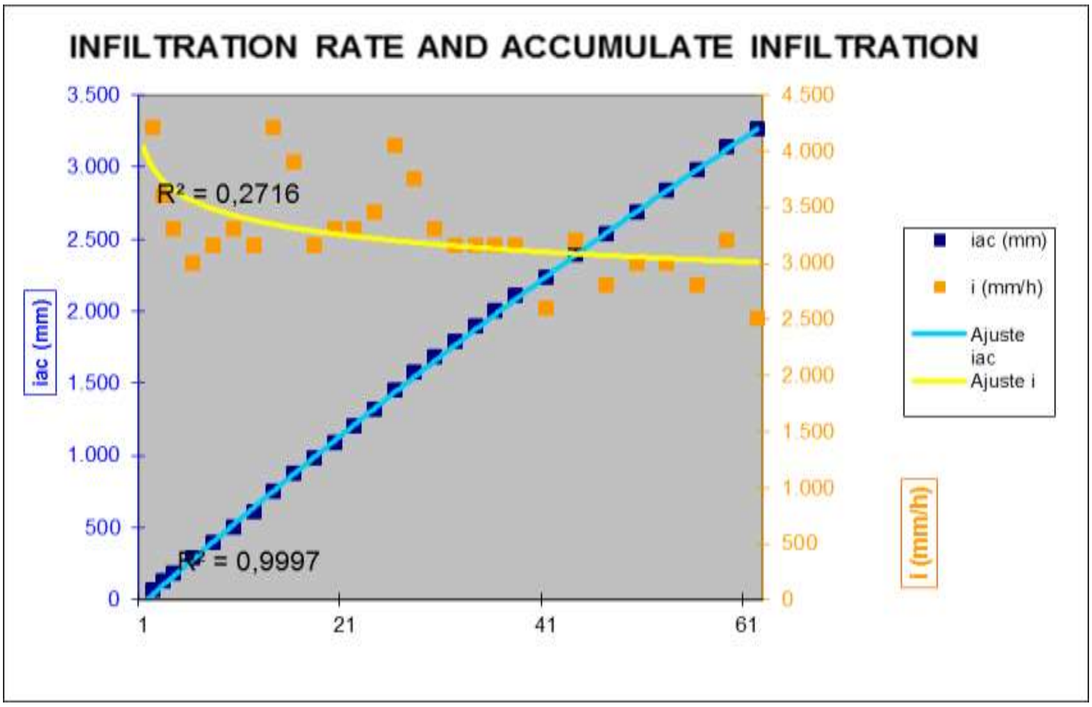


AREA: Santiuste infiltration pond. Furrow width 80 cm

DATE: 04/07/2016 HOUR: 17:00

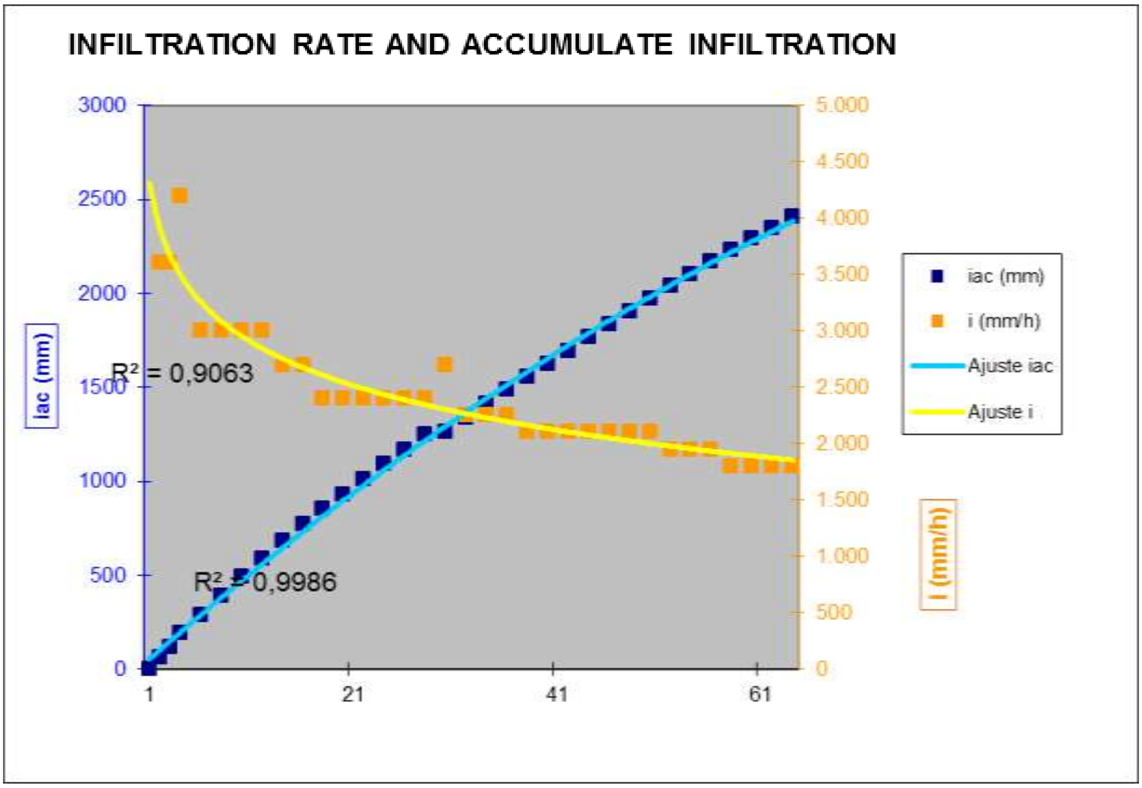
Soil pit: sand

t(min)	h (cm)	i (mm)	iac (mm)	i (mm/h)
0	97,0	0	0	0
1	90-97	70	70	4.200
2	91-97	60	130	3.600
3	91,5-97	55	185	3.300
5	87-97	100	285	3.000
7	86,5-97	105	390	3.150
9	86-97	110	500	3.300
11	86,5-97	105	605	3.150
13	83-97	140	745	4.200
15	84-97	130	875	3.900
17	86,5-97	105	980	3.150
19	86-97	110	1.090	3.300
21	86-97	110	1.200	3.300
23	85,5-97	115	1.315	3.450
25	83,5-97	135	1.450	4.050
27	84,5-97	125	1.575	3.750
29	86-97	110	1.685	3.300
31	86-97	105	1.790	3.150
33	86,5-97	105	1.895	3.150
35	86,5-97	105	2.000	3.150
37	86,5-97	105	2.105	3.150
40	84-97	130	2.235	2.600
43	81-97	160	2.395	3.200
46	83-97	140	2.535	2.800
49	82-97	150	2.685	3.000
52	82-97	150	2.835	3.000
55	83-97	140	2.975	2.800
58	81-97	160	3.135	3.200
61	84,5	125	3.260	2.500


INFILTRATION RATE AND ACCUMULATE INFILTRATION
3.500
3.000
2.500
2.000
1.500
1.000
500
0
4.500
4.000
3.500
3.000
2.500
2.000
1.500
1.000
500
0
1
21
41
61
R² = 0,2716
R² = 0,9997
iac (mm)
i (mm/h)
iac (mm)
i (mm/h)
Ajuste iac
Ajuste i

AREA: Santiuste infiltration pond. No furrow
DATE: 04/07/2016 HOUR: 18:30
Soil pit: Not available due to electrical storm conditions

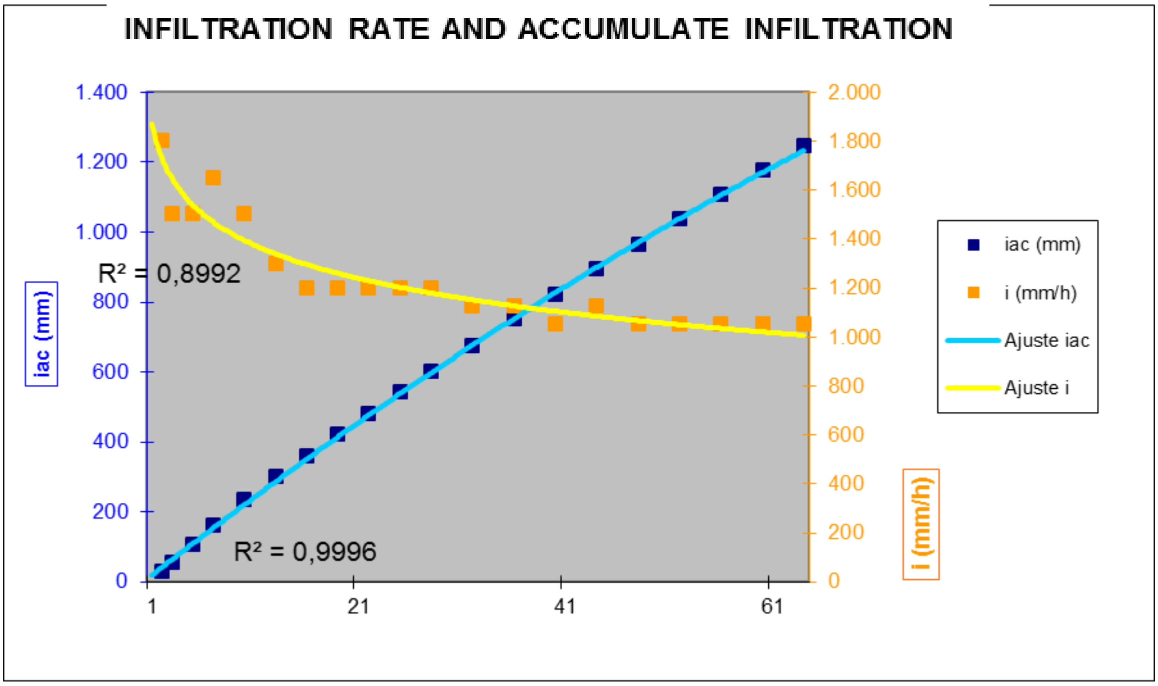
t(min)	h (cm)	i (mm)	iac (mm)	i (mm/h)
0	92,0	0	0	0
1	86-92	60	60	3.600
2	86-92	60	120	3.600
3	85-92	70	190	4.200
5	82-92	100	290	3.000
7	82-92	100	390	3.000
9	82-92	100	490	3.000
11	82-92	100	590	3.000
13	83-92	90	680	2.700
15	83-92	90	770	2.700
17	84-92	80	850	2.400
19	84-92	80	930	2.400
21	84-92	80	1.010	2.400
23	84-92	80	1.090	2.400
25	84-92	80	1.170	2.400
27	84-92	80	1.250	2.400
29	84,5-92	75	1.260	2.700
31	84,5-92	75	1.335	2.250
33	84,5-92	75	1.410	2.250
35	84,5-92	75	1.485	2.250
37	85-92	70	1.555	2.100
39	85-92	70	1.625	2.100
41	85-92	70	1.695	2.100
43	85-92	70	1.765	2.100
45	85-92	70	1.835	2.100
47	85-92	70	1.905	2.100
49	85-92	70	1.975	2.100
51	85,5-92	65	2.040	1.950
53	85,5-92	65	2.105	1.950
55	85,5-92	65	2.170	1.950
57	86-92	60	2.230	1.800
59	86-92	60	2.290	1.800
61	86-92	60	2.350	1.800
63	86-92	60	2.410	1.800


INFILTRATION RATE AND ACCUMULATE INFILTRATION
iac (mm)
i (mm/h)
iac (mm)
i (mm/h)
Ajuste iac
Ajuste i
R² = 0,9063
R² = 0,9986
3000
2500
2000
1500
1000
500
0
5.000
4.500
4.000
3.500
3.000
2.500
2.000
1.500
1.000
500
0
1
21
41
61

6.3.2 Carracillo Council. Changes in the infiltration rate in ponds with and without vegetation

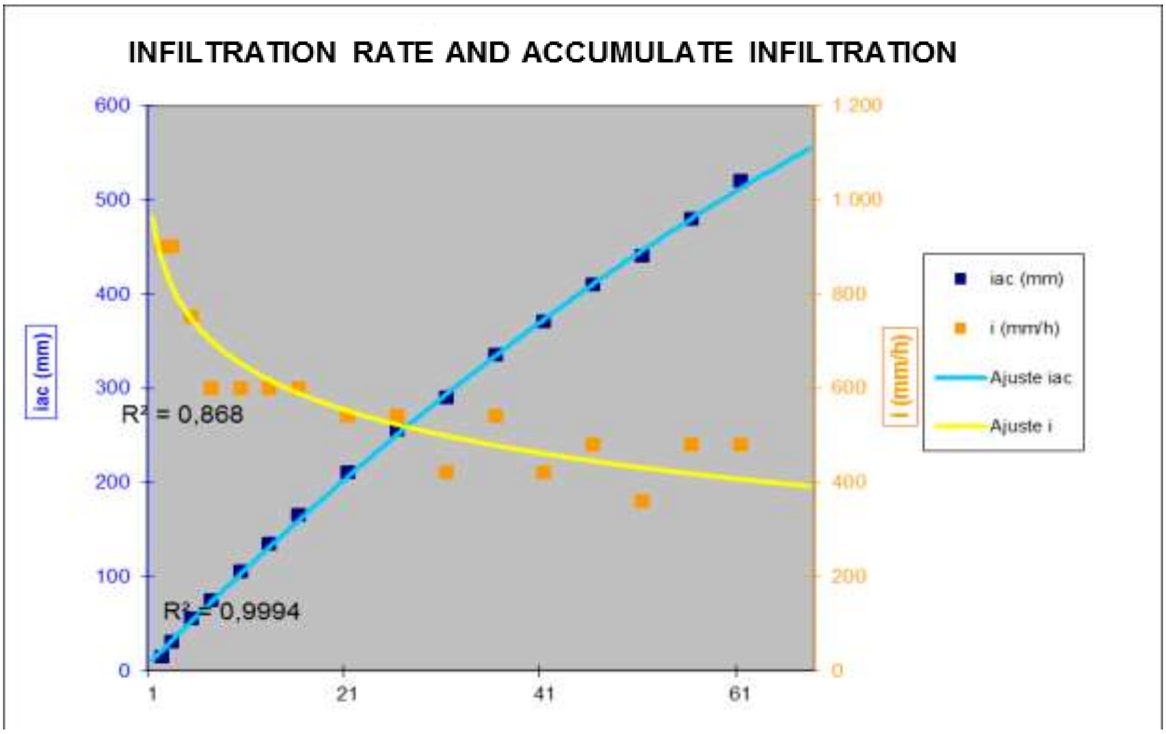
AREA: Carracillo with vegetation
DATE: 05/07/2016
Soil pit: sand

t(min)	h (cm)	i (mm)	iac (mm)	i (mm/h)
0	95,0	0	0	0
1	92-95	30	30	1.800
2	92,5-95	25	55	1.500
4	90-95,5	50	105	1.500
6	90-95,5	55	160	1.650
9	88-95,5	75	235	1.500
12	89-95	65	300	1.300
15	89-95	60	360	1.200
18	89-95	60	420	1.200
21	89-95	60	480	1.200
24	89-95	60	540	1.200
27	89-95	60	600	1.200
31	87,5-95	75	675	1.125
35	87,5-95	75	750	1.125
39	88-95	70	820	1.050
43	87,5-95	75	895	1.125
47	88-95	70	965	1.050
51	88-95	70	1.035	1.050
55	88-95	70	1.105	1.050
59	88-95	70	1.175	1.050
63	88-95	70	1.245	1.050
67	88,0	70	1.315	1.050


INFILTRATION RATE AND ACCUMULATE INFILTRATION
iac (mm)
i (mm/h)
R² = 0,8992
R² = 0,9996
1.400
1.200
1.000
800
600
400
200
0
2.000
1.800
1.600
1.400
1.200
1.000
800
600
400
200
0
1
21
41
61
iac (mm)
i (mm/h)
Ajuste iac
Ajuste i

AREA: Carracillo without vegetation
DATE: 05/07/2016
Soil pit: sand

t(min)	h (cm)	i (mm)	iac (mm)	i (mm/h)
0	95,0	0	0	0
1	93,5-95	15	15	900
2	93,5-95	15	30	900
4	92,5-95	25	55	750
6	93-95	20	75	600
9	92-95	30	105	600
12	92-95	30	135	600
15	92-95	30	165	600
20	90,5-95	45	210	540
25	90,5	45	255	540
30	87-95	35	290	420
35	90,5	45	335	540
40	87-95	35	370	420
45	91,0	40	410	480
50	88-95	30	440	360
55	91,0	40	480	480
60	87,0	40	520	480



6.4 ANNEX IV: Chemical and biological analyses of the clogging samples

The samples collected and analysed have been:

(**SCE a**: Santiuste Canal Este before WWTP; **SCE d**: Santiuste Canal Este after WWTP; **SH**: Canal Sanchón; **HS1-b**: Humedal artificial Sanchón 1b)

6.4.1 Water analyses

PHYSICAL AND CHEMICAL PARAMETERS (WATER SAMPLES)

1. TOTAL DISSOLVED SOLIDS

SAMPLE	TDS (mg/L)
SCE-a	156
SCE-d	173
SH	161
HS1-b	265

2. pH and 3. CONDUCTIVITY

SAMPLE	pH	Conductivity (µS/cm)
SCE-a	7.37	184
SCE-d	7.07	386
SH	7.53	178
HS1-b	6.7	182

4. CHEMICAL OXYGEN DEMAND (COD), 5. BIOCHEMICAL OXYGEN DEMAND (BOD5) and 6. TOTAL ORGANIC CARBON (COT)

SAMPLE	COD (mgO_2/L)	BOD_5 (mgO_2/L)	TOC (mg/L)
SCE-a	108 ± 1	77 ± 4	72.0 ± 0.7
SCE-d	101 ± 3	48 ± 9	86 ± 2
SH	109 ± 1	34 ± 2	46.7 ± 0.3
HS1-b	188.3 ± 0.2	54 ± 5	50 ± 1

7. METALS

Metal	**Symbol**	**SH**	**HS1-b**	**SCE-a**	**SCE-d**
Silver	Ag	< LD	< LD	< LD	< LD
Aluminium	Al	0.009	0.006	0.005	0.007
Arsenic	As	< LD	< LD	< LD	< LD
Gold	Au	< LD	< LD	< LD	< LD
Boron	B	< LD	< LD	< LD	< LD
Barium	Ba	0.026	0.034	0.025	0.049
Beryllium	Be	< LD	< LD	< LD	< LD
Bismuth	Bi	< LD	< LD	< LD	< LD
Calcium	Ca	18.602	19.789	18.040	26.034
Cadmium	Cd	< LD	0.000	< LD	< LD
Cobalt	Co	< LD	< LD	< LD	< LD
Metal	**Symbol**	**SH**	**HS1-b**	**SCE-a**	**SCE-d**
Chromo	Cr	0.012	0.003	0.002	< LD

Cupper	Cu	0.002	0.001	0.001	0.002
Iron	Fe	0.099	0.021	0.085	0.013
Mercury	Hg	< LD	< LD	< LD	< LD
Potassium	K	2.637	2.477	8.485	14.272
Lanthanum	La	< LD	< LD	< LD	< LD
Lithium	Li	0.001	0.000	< LD	0.027
Magnesium	Mg	5.855	6.023	5.283	13.362
Manganese	Mn	0.001	0.000	0.001	0.001
Molybdenum	Mo	< LD	< LD	< LD	< LD
Sodium	Na	17.226	17.223	16.396	39.974
Nickel	Ni	< LD	< LD	< LD	< LD
Phosphorus	P	0.175	0.428	0.190	1.686
Lead	Pb	< LD	< LD	< LD	< LD
Palladio	Pd	< LD	< LD	< LD	< LD
Platinum	Pt	< LD	< LD	< LD	< LD
Rubidium	Rib	0.169	0.154	0.162	0.172
Sulphur	S	0.469	0.263	0.387	6.052
Antimony	Sb	< LD	< LD	< LD	< LD
Scandium	SC	< LD	0.000	0.000	0.000
Selenium	Se	< LD	< LD	< LD	< LD
Silicon	Si	3.828	4.056	3.717	7.953
Tin	Sn	< LD	< LD	< LD	< LD
Strontium	Sr	0.082	0.084	0.065	0.271
Tellurium	Te	< LD	< LD	< LD	< LD
Titanium	Ti	< LD	< LD	< LD	< LD
Thallium	Tl	< LD	< LD	< LD	< LD
Vanadium	V	0.002	0.000	0.001	0.003
Wolfram	W	0.010	< LD	0.021	0.007
Zinc	Zn	0.026	0.042	0.029	0.035
Zirconium	Zr	< LD	< LD	< LD	< LD

8.NUTRIENTS

SAMPLE	Total Nitrogen (µgN·L^{-1})	Total Phosphorus (µgP·L^{-1})	Nitrate (µgN·L^{-1})	Nitrite (µgN·L^{-1})	Ammonium (µgN·L^{-1})	Phosphate (µgL^{-1} P)	K (mgL^{-1})
SCEa	776	107	0.00	0.40	19	82.3	1.03
SCEd	7053	1738	520	0.00	5990	1270	18.78
SH	813	195	142	1.45	37	174	2.21
HS1b	2511	459	21	0.56	1650	320	2.80

6.4.2 Clogging analyses

BIOLOGICAL PARAMETERS IN THE CLOGGING SAMPLES

1.-DNA ANALYSES AT THE FIRST STAGE OF BACTERIAL SPECIES SPECIFIC IDENTIFICATION

SAMPLE	DNA pg/ul	READS
SCE-a	1793,40	237627
SCE-d	2055,00	119128
SH	2362,80	191613
HS1-b	5032,80	207230

6.5 ANNEX V: SAT-MAR studies

6.5.1 Annex V-1: Experimental tests on "treatment in itinere". Triplet schemes

ANNEX V-1-A: SAMPLE POINTS LOCATION MAPS IN SANTIUSTE (A) AND EL CARRACILLO (B) AND TABLES WITH THE EXACT POSITION AND THE CAMPAIGNS PERFORMED.

(a)

(b)

TRIPLET	STATION	X	Y	Unstable parameters 2009	Unstable parameters 2015	Unstable parameters 2016	Biochemical analysis 2015
SANTIUSTE	**EV1-Heading**	370033	4557315	X	X		
	EV1-East canal heading	369945	4557786		X		
	EV-2 Canal pre WWTP	369972	4558275	X	X		X
	WWTP water	369983	4558153		X		X
	WWTP-canal mixture	369985	4558184		X		
	EV-2b	369750	4559248		X		
	EV-3	369674	4560291	X	X		
	EV-3b (Canal)	369733	4560915		X		
	EV3b (AW 2A)	369733	4560915		X		X
	EV-4	369624	4562556	X	X		X
	EV-5	369541	4563188	X	X		
	EV-6	369361	4564552	X	X		
	EV-7	368809	4566014	X			
CARRACILLO	**Infiltration pond**	391778	4571068		X	X	
	Canal	391743	4571122		X	X	
	Artificial Wetland inlet	391679	4571191		X	X	
	Artificial Wetland outlet	391625	4571374		X	X	
	Infiltration field	391506	4571374		X	X	

ANNEX V-1-B: WINTER (2009, 2015) AND SPRING (2015) DATA FROM 7 MAIN STATIONS. UNSTABLE PARAMETERS DETERMINED

B1: Analyses results of the main Biochemical parameters determined at Santiuste (2009):

STATION	pH	ORP (mV)	DO (ppm)	EC (ms/cm)	TDS [ppm]	Salinity (PSU)	Turbidity (NTU)	Tª (ºC)
EV-1 Heading	6.33	22.4	10.2	253	134	N/A	-	7.2
EV-2 East canal pre WWTP	7.1	-16.1	9.7	232	116	0.11	-	7.85
EV-3 Sanchón	6.01	-17.7	6.5	271	137	0.13	-	6.73
EV-4	6.9	-20.9	7.7	280	144	0.14	-	6.13
EV-5	7.02	-21.3	7.1	344	177	0.17	-	6.76
EV-6	7.04	-12.7	8.8	178	141	0.14	-	7.56
EV-7	7.01	-8.9	4.8	438	223	0.22	-	7.54

B2: Analyses results of 19 selected Biochemical parameters (2015):

Santiuste Basin 2015 water samples analysis. In situ water unstable parameters mean values from three campaigns (Multiparameter HANNA HI 9829).

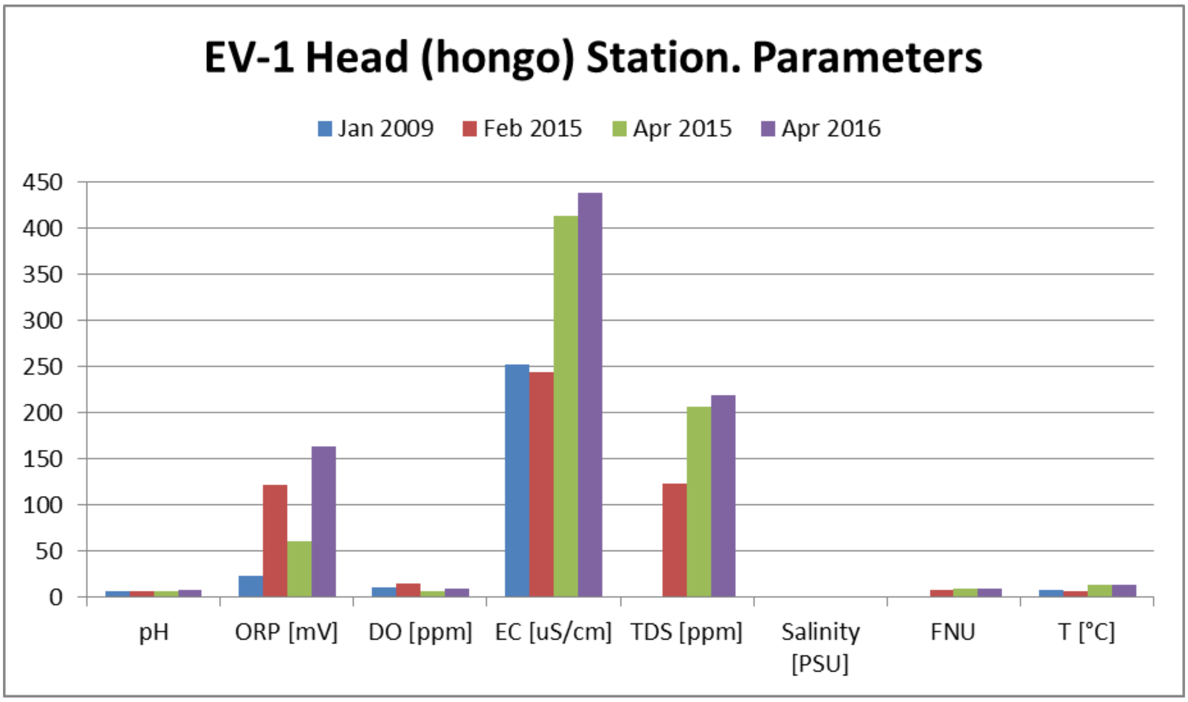
STATION	pH	ORP [mV]	DO [ppm]	EC [µS/cm]	TDS [ppm]	Salinity [PSU]	Turbidity (NTU)	T [°C]
EV1-Heading	6.99	90.60	10.57	323.00	170.00	0.19	8.33	9.04
EV1-East canal heading	7.68	163.67	9.10	318.33	161.33	0.18	6.47	9.08
EV-2 Canal pre WWTP	7.96	173.80	6.56	286.67	143.33	0.15	8.87	9.34
WWTP water	7.85	76.23	5.83	809.33	377.67	0.49	7.23	9.59
WWTP -canal mixture	7.66	110.80	4.68	534.33	264.00	0.31	5.28	9.65
EV-2b	7.95	116.07	4.73	274.33	151.67	0.16	10.03	9.43
EV-3 Sanchón	7.98	152.40	3.98	291.00	150.67	0.18	10.90	9.58
EV-3b	8.38	126.70	4.73	388.00	183.50	0.21	38.85	11.34
Artificial Wetland (2A)	8.13	134.40	4.70	845.00	397.00	0.50	13.20	12.72
EV-4	8.22	154.23	4.44	332.33	165.67	0.16	5.00	10.14
EV-5	8.23	143.23	4.71	321.00	163.67	0.17	6.14	10.11
EV-6	8.24	159.63	4.61	324.33	168.00	0.17	10.29	10.26

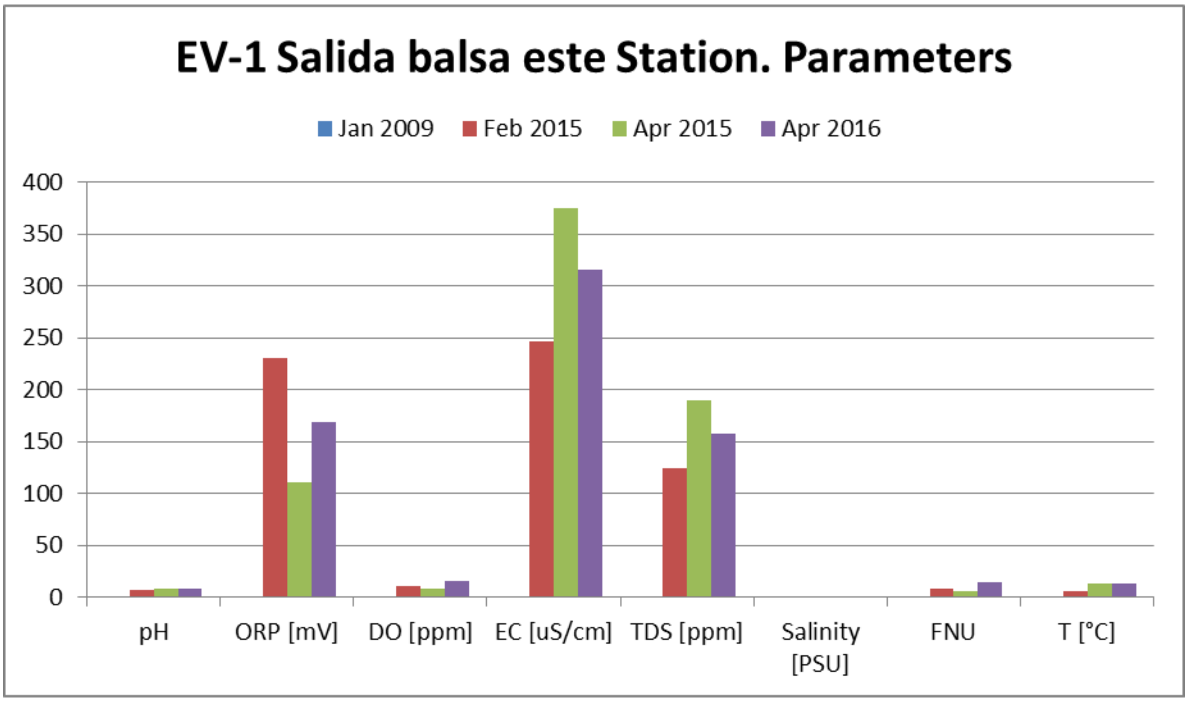
STATION	Turbidity NTU	NO_3^- mg/l	K mg/l	Cl- mg/l	SO_4^{2-}mg/l	COD mg/l	Na mg/l
EV-2 Canal before WWTP	9.12	1.6	1.59	21.5	5.68	7.7	14
EV-2 WWTP	49.8	11.3	29	58.7	12.7	21	69.5
EV-3 Artificial Wetland	8.55	1.18	2.69	23.2	6.34	9.6	16.1
EV-4 canal after AW	6.02	1.13	2.8	24	6.61	7.5	16.5

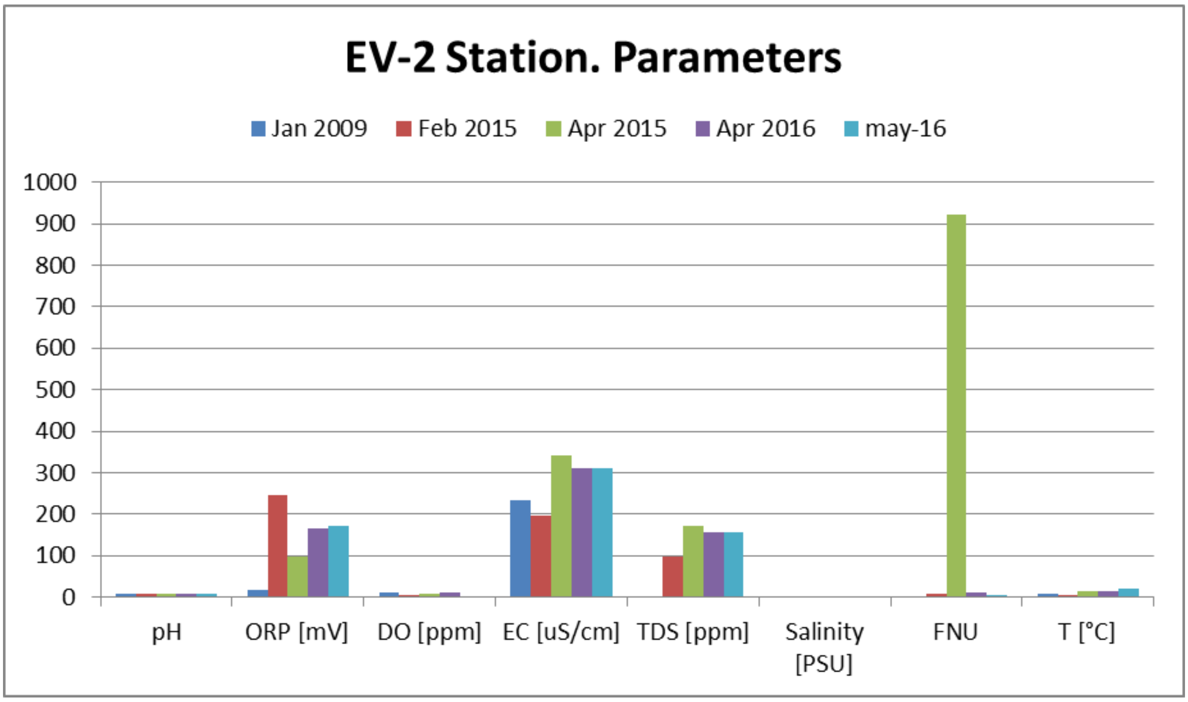
STATION	Mg mg/l	Ca mg/l	PO_4^{3-} mg/l	P mg/l	Alcalinity mmol/l	Caffeine µg/l
EV-2 Canal before WWTP	3.59	14.2	0.174	0.057	0.503	0.15
EV-2 WWTP	14.9	32.9	3.324	1.084	1.43	8.4
EV-3 Artificial Wetland	4.13	15.6	0.226	0.074	0.558	0.25
EV-4 canal after AW	4.34	16.2	0.26	0.085	0.581	0.24

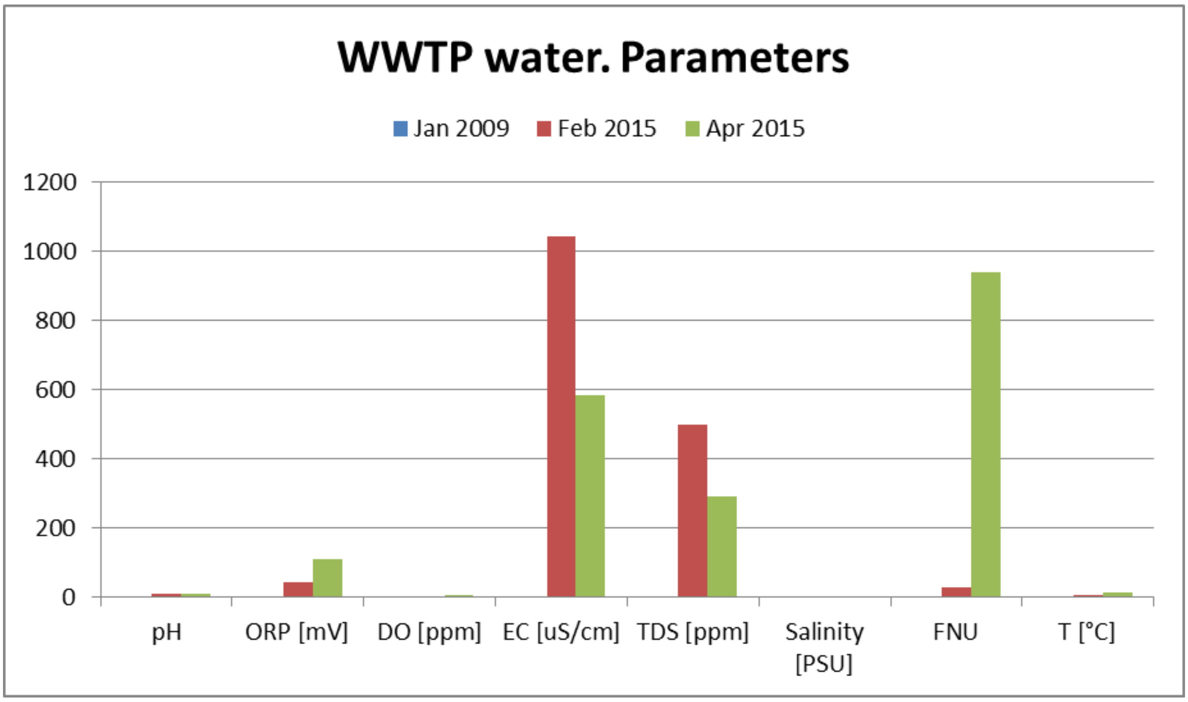
STATION	ºdH	$NH4^+$ mg/l	Fe mg/l	Cu mg/l	As mg/l	Conductivity mS/cm
EV-2 Canal before WWTP	2.82	0.038	0.089	0.019	0.0017	0.18
EV-2 WWTP	8.02	5.4	0.056	0.014	0.0066	0.734
EV-3 Artificial Wetland	3.13	0.1	0.082	0.016	0.0022	0.206
EV-4 canal after AW	3.26	0.11	0.093	0.006	0.0023	0.212

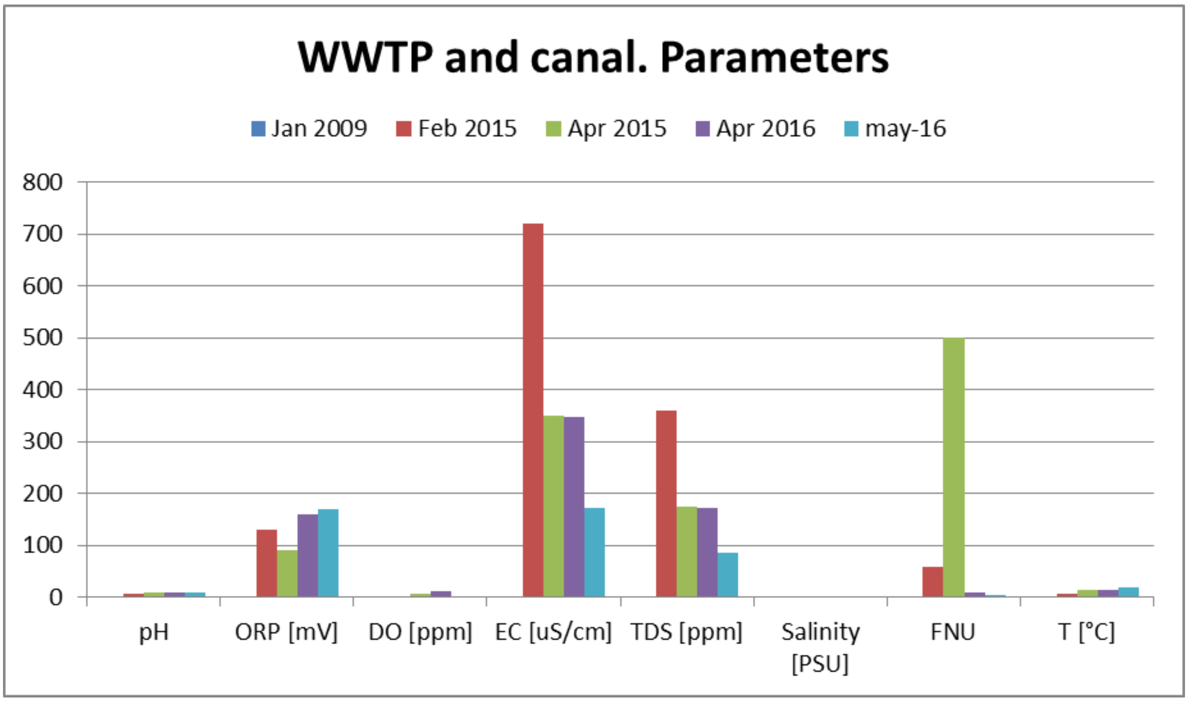
B3: Charting for the chemical determinations collected:

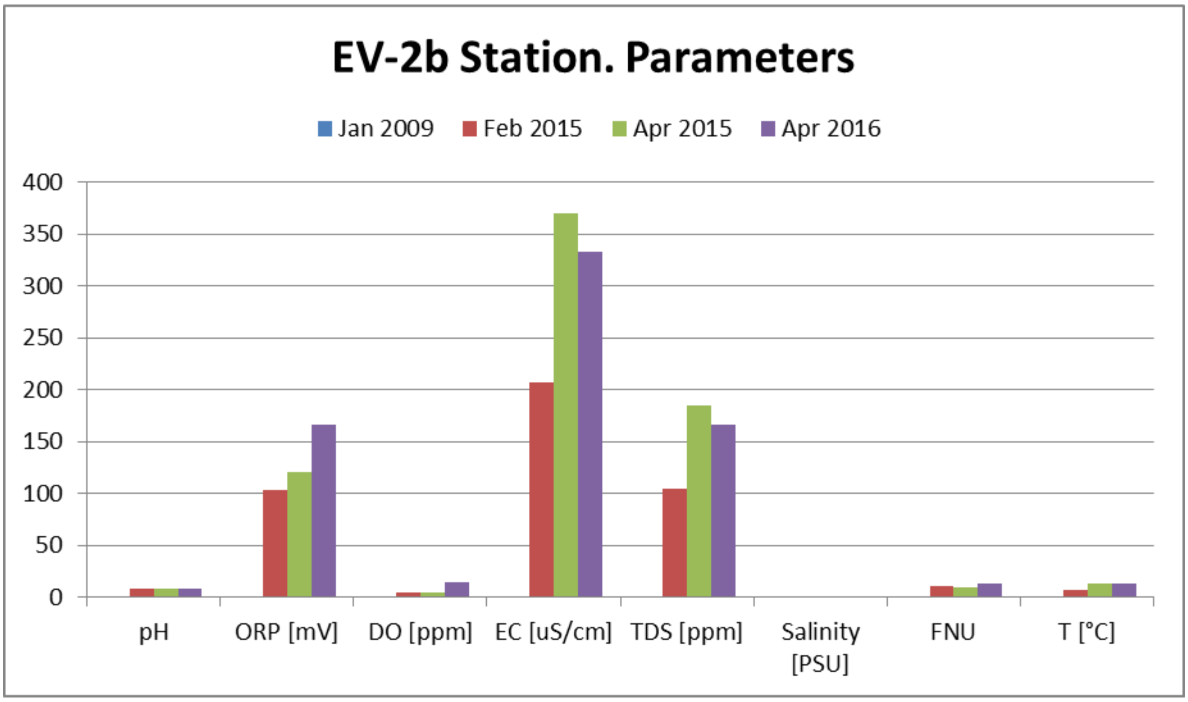


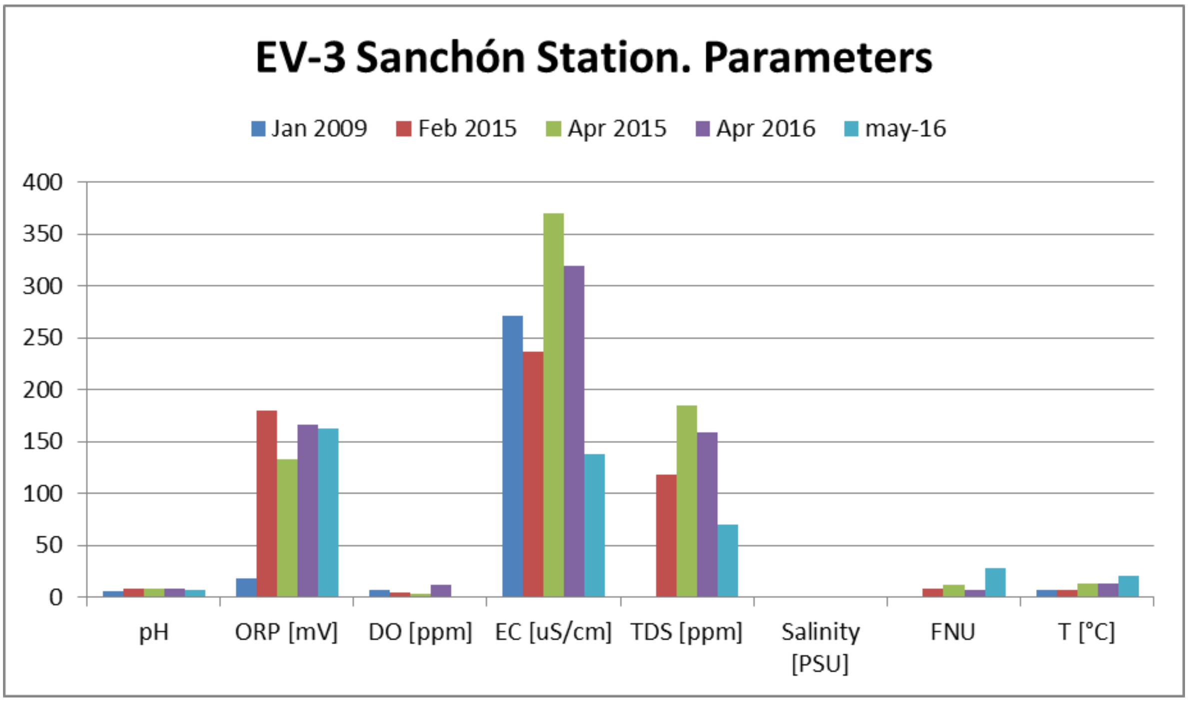


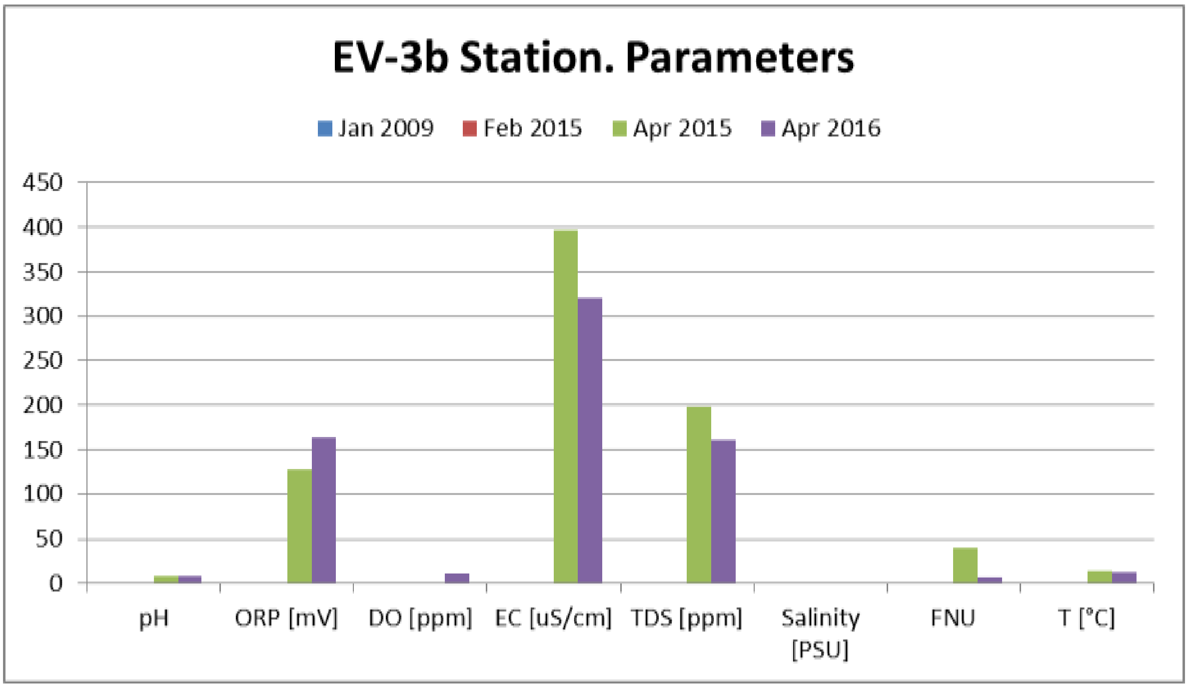

EV-2 Station. Parameters
Jan 2009
Feb 2015
Apr 2015
Apr 2016
may-16
1000
900
800
700
600
500
400
300
200
100
0
pH
ORP [mV]
DO [ppm]
EC [uS/cm]
TDS [ppm]
Salinity [PSU]
FNU
T [°C]

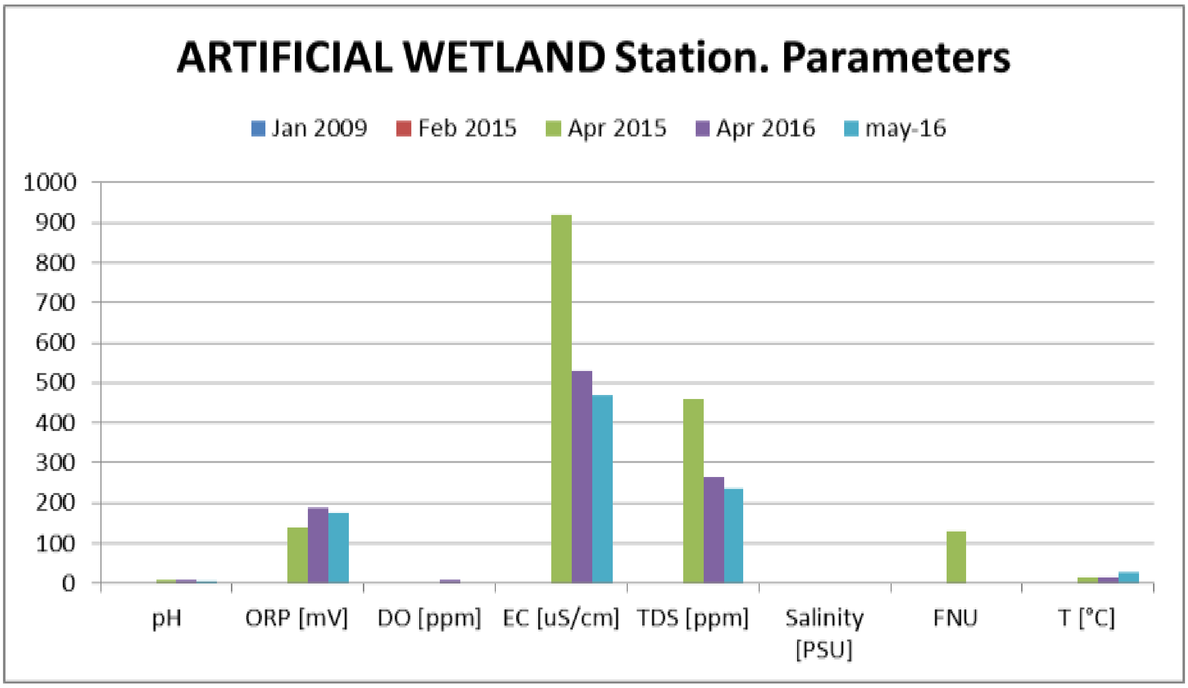

WWTP water. Parameters
Jan 2009
Feb 2015
Apr 2015
1200
1000
800
600
400
200
0
pH
ORP [mV]
DO [ppm]
EC [uS/cm]
TDS [ppm]
Salinity [PSU]
FNU
T [°C]

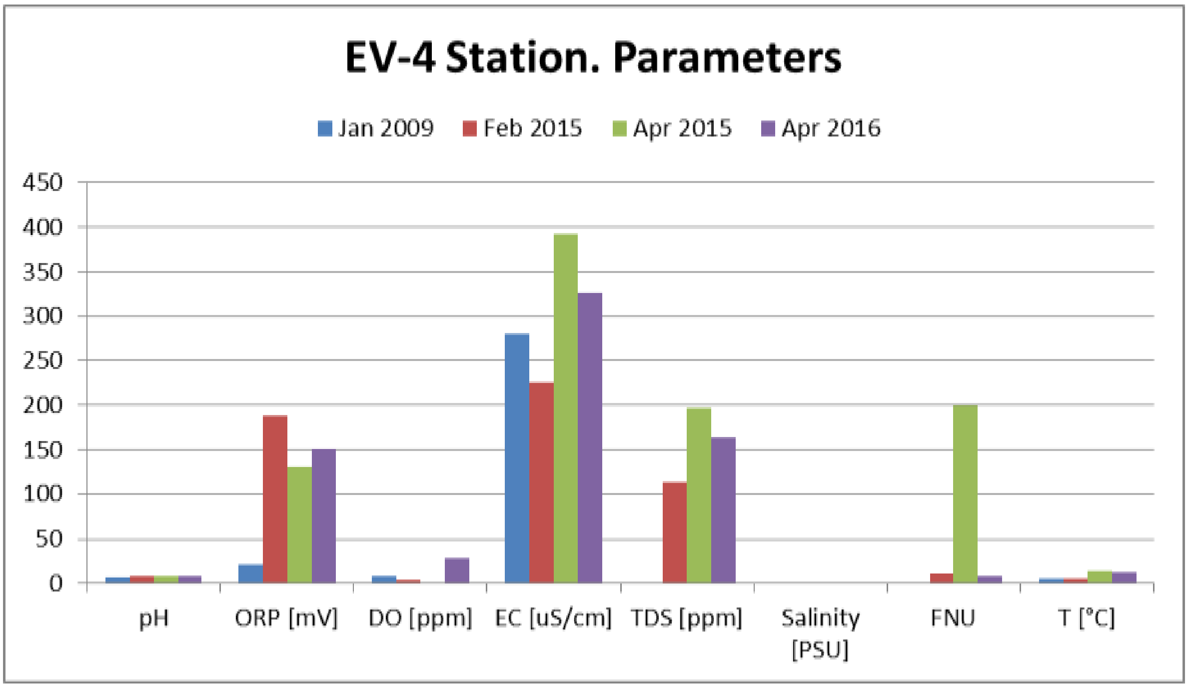

WWTP and canal. Parameters
Jan 2009
Feb 2015
Apr 2015
Apr 2016
may-16
800
700
600
500
400
300
200
100
0
pH
ORP [mV]
DO [ppm]
EC [uS/cm]
TDS [ppm]
Salinity [PSU]
FNU
T [°C]

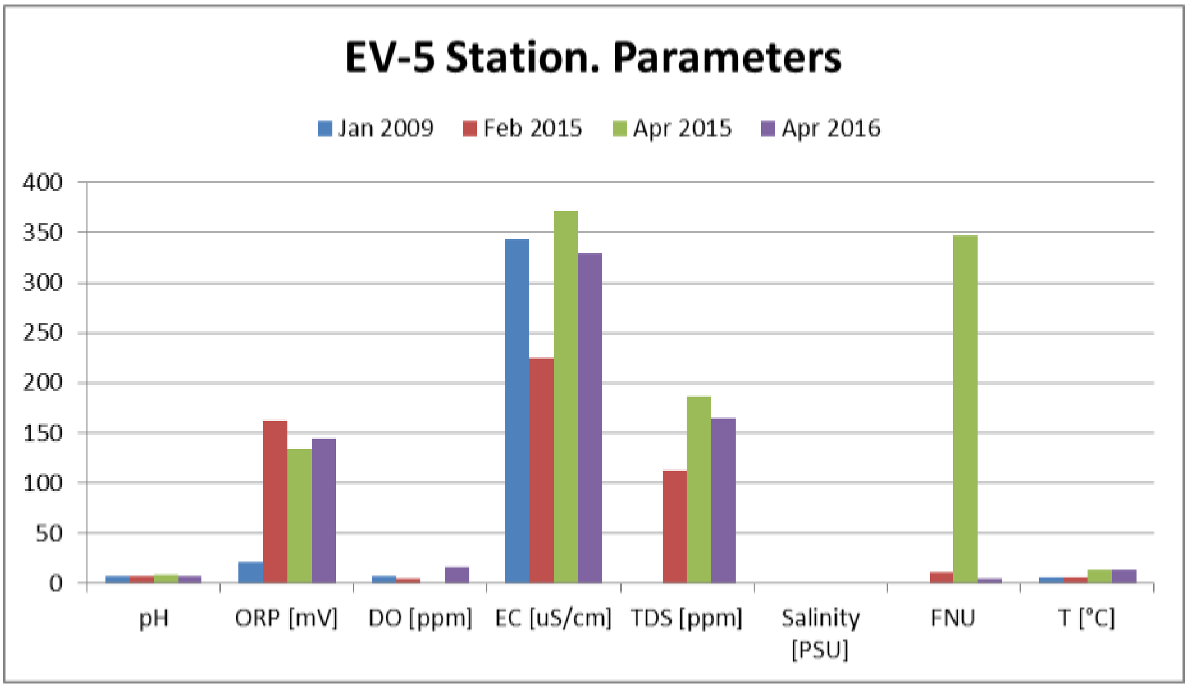

EV-2b Station. Parameters
Jan 2009
Feb 2015
Apr 2015
Apr 2016
400
350
300
250
200
150
100
50
0
pH
ORP [mV]
DO [ppm]
EC [uS/cm]
TDS [ppm]
Salinity [PSU]
FNU
T [°C]

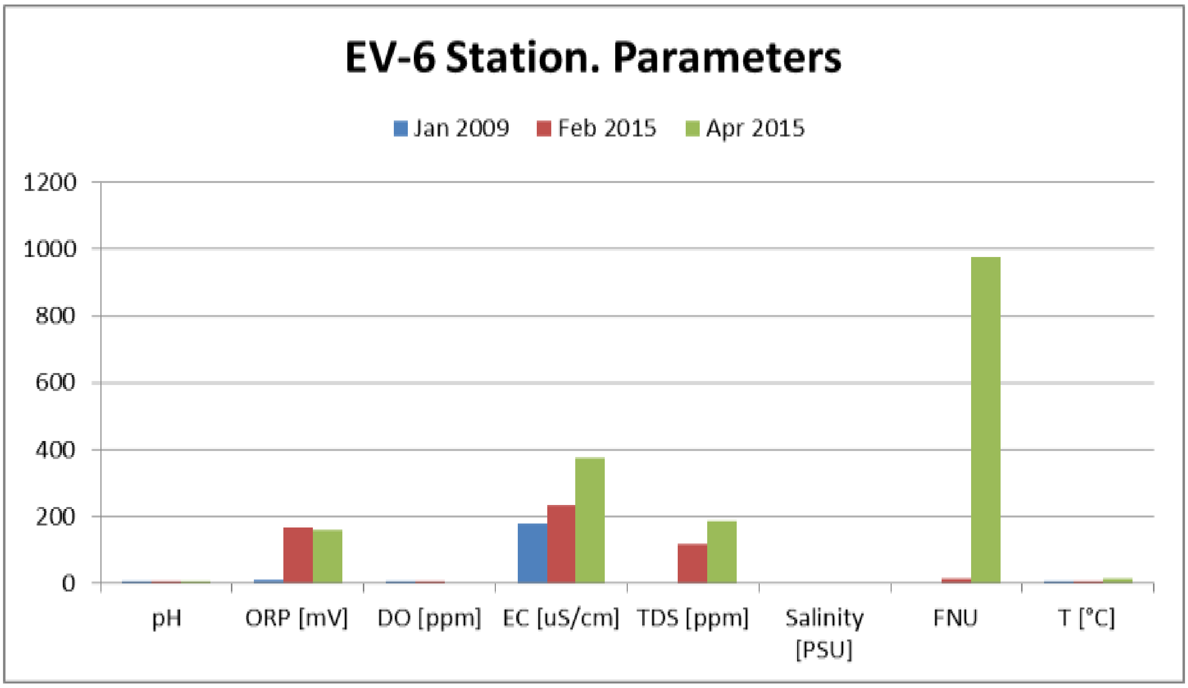

EV-3 Sanchón Station. Parameters
Jan 2009
Feb 2015
Apr 2015
Apr 2016
may-16
400
350
300
250
200
150
100
50
0
pH
ORP [mV]
DO [ppm]
EC [uS/cm]
TDS [ppm]
Salinity [PSU]
FNU
T [°C]

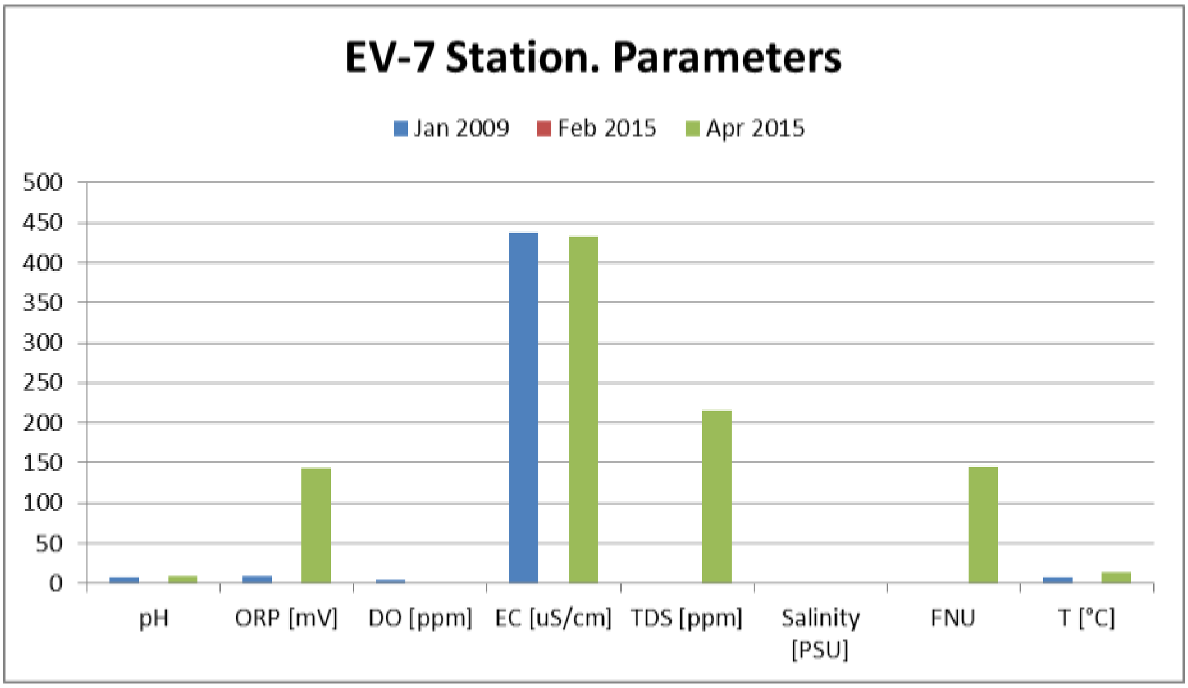

EV-3b Station. Parameters
Jan 2009
Feb 2015
Apr 2015
Apr 2016
450
400
350
300
250
200
150
100
50
0
pH
ORP [mV]
DO [ppm]
EC [uS/cm]
TDS [ppm]
Salinity [PSU]
FNU
T [°C]

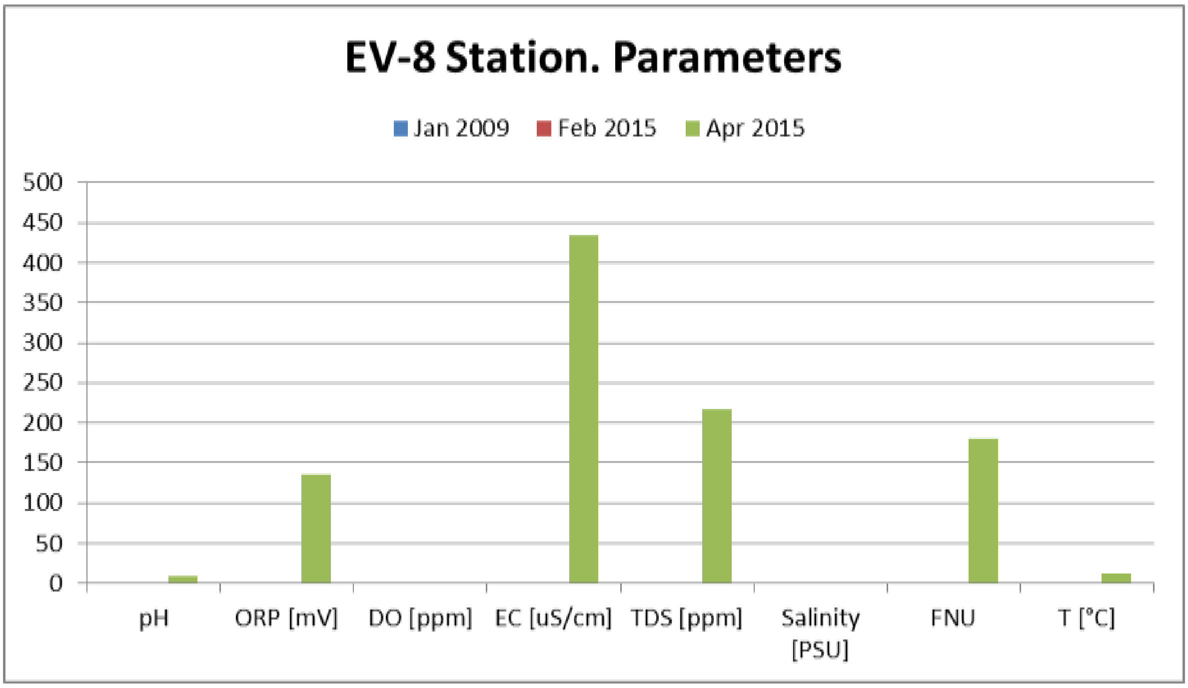

ARTIFICIAL WETLAND Station. Parameters
Jan 2009
Feb 2015
Apr 2015
Apr 2016
may-16
1000
900
800
700
600
500
400
300
200
100
0
pH
ORP [mV]
DO [ppm]
EC [uS/cm]
TDS [ppm]
Salinity [PSU]
FNU
T [°C]

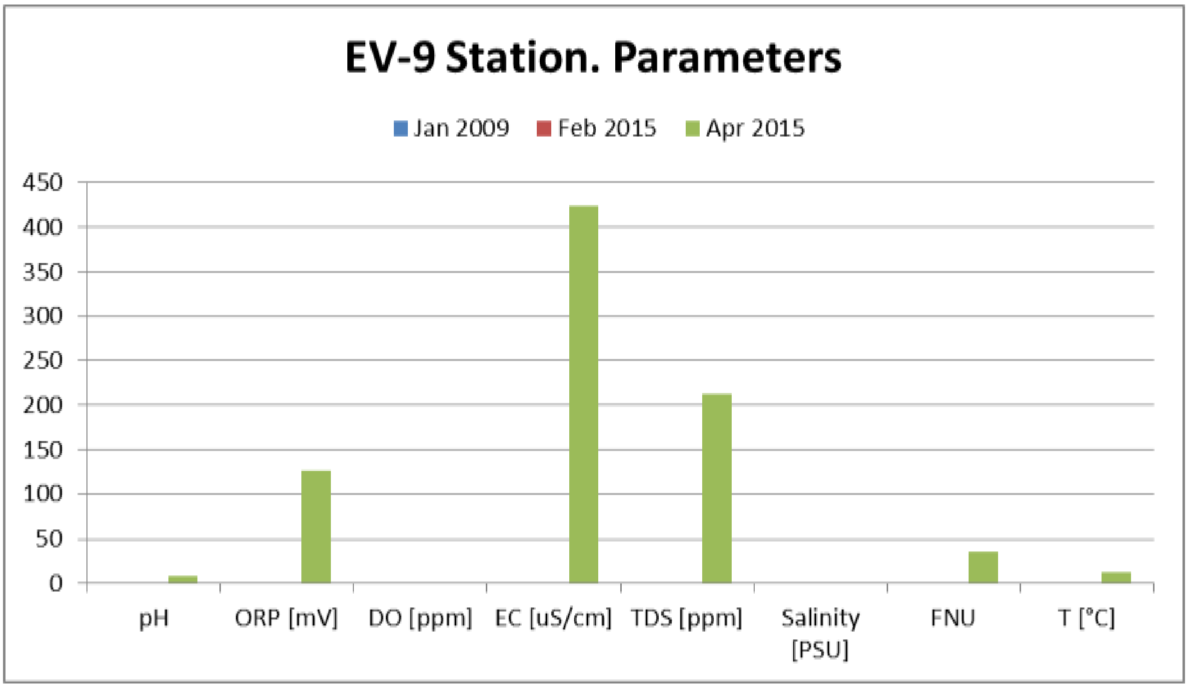

EV-4 Station. Parameters
Jan 2009
Feb 2015
Apr 2015
Apr 2016
450
400
350
300
250
200
150
100
50
0
pH
ORP [mV]
DO [ppm]
EC [uS/cm]
TDS [ppm]
Salinity [PSU]
FNU
T [°C]

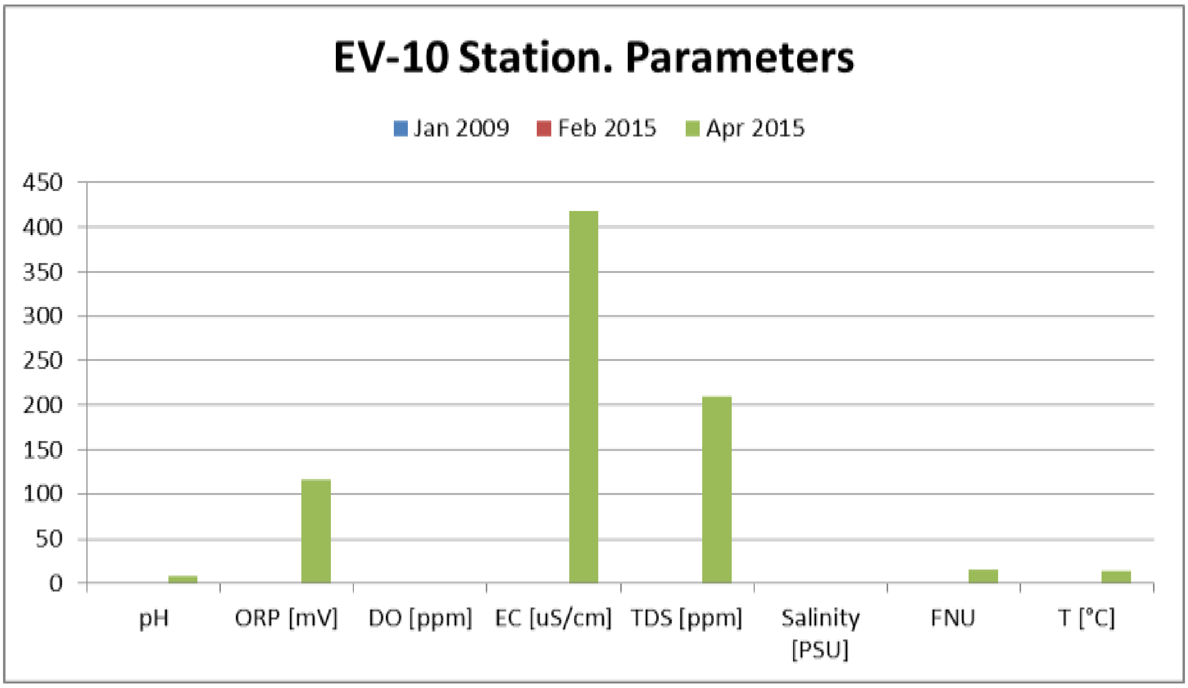

EV-5 Station. Parameters
Jan 2009
Feb 2015
Apr 2015
Apr 2016
400
350
300
250
200
150
100
50
0
pH
ORP [mV]
DO [ppm]
EC [uS/cm]
TDS [ppm]
Salinity [PSU]
FNU
T [°C]


EV-6 Station. Parameters
Jan 2009
Feb 2015
Apr 2015
1200
1000
800
600
400
200
0
pH
ORP [mV]
DO [ppm]
EC [uS/cm]
TDS [ppm]
Salinity [PSU]
FNU
T [°C]

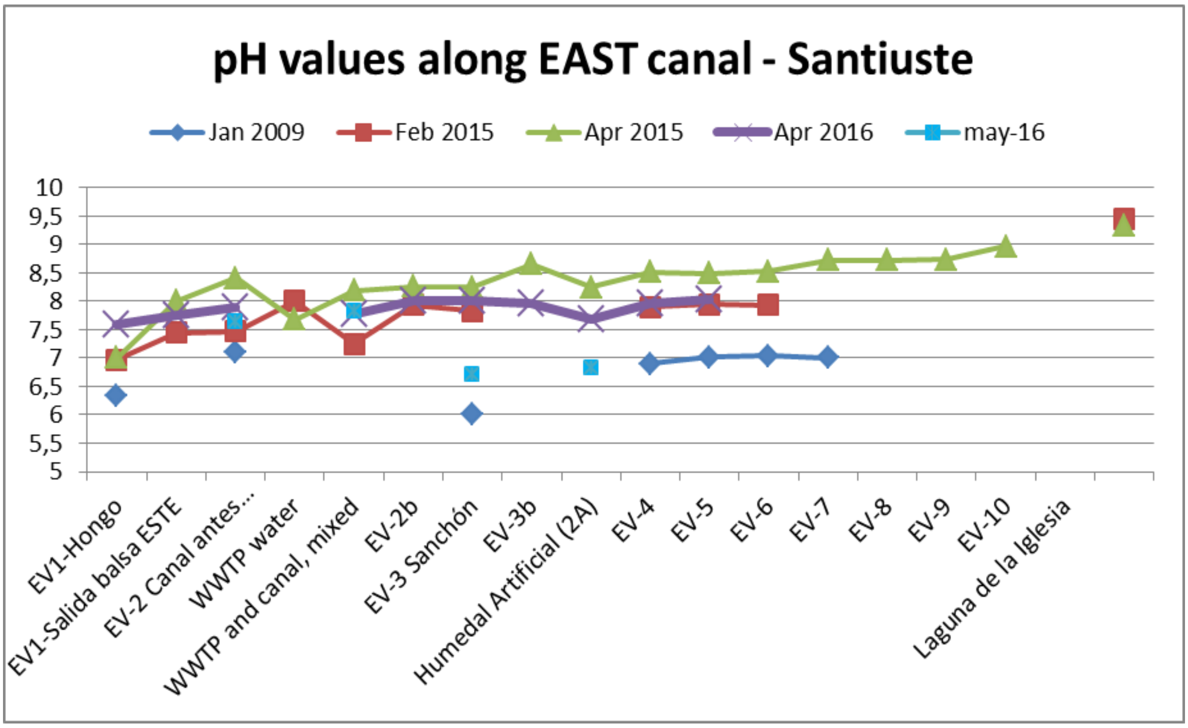

EV-7 Station. Parameters
Jan 2009
Feb 2015
Apr 2015
500
450
400
350
300
250
200
150
100
50
0
pH
ORP [mV]
DO [ppm]
EC [uS/cm]
TDS [ppm]
Salinity [PSU]
FNU
T [°C]

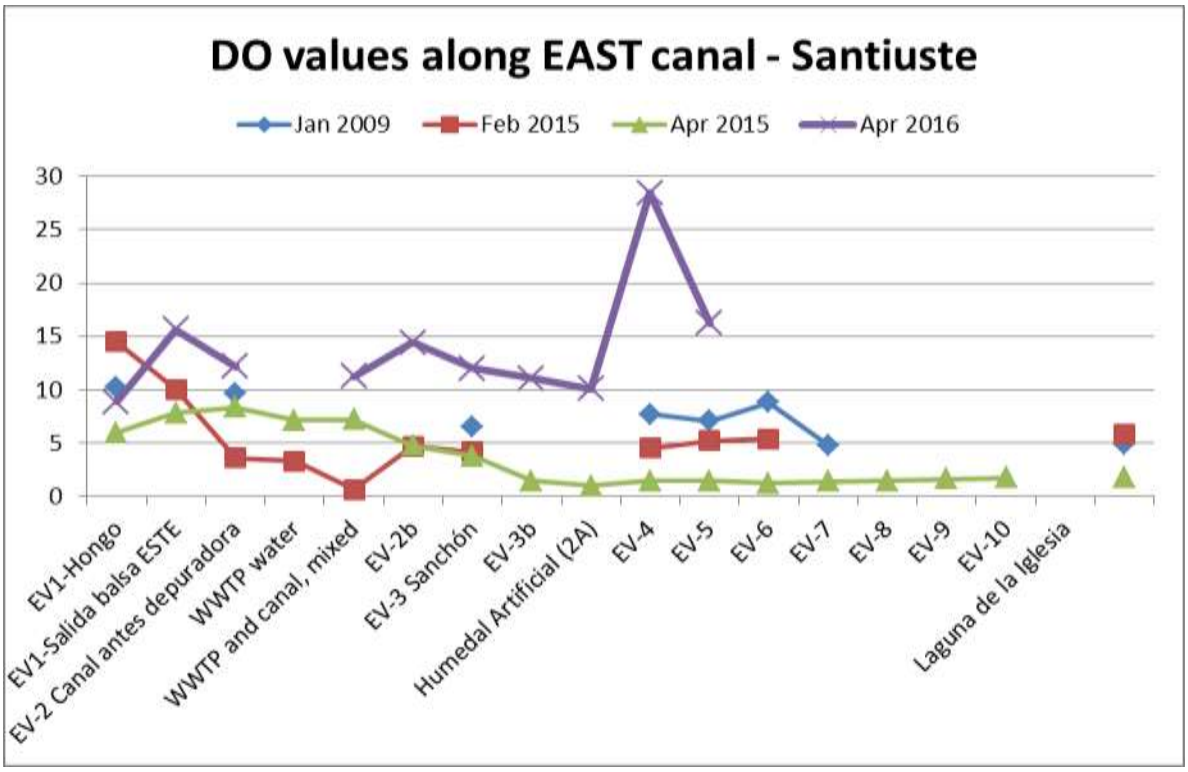

EV-8 Station. Parameters
Jan 2009
Feb 2015
Apr 2015
500
450
400
350
300
250
200
150
100
50
0
pH
ORP [mV]
DO [ppm]
EC [uS/cm]
TDS [ppm]
Salinity [PSU]
FNU
T [°C]

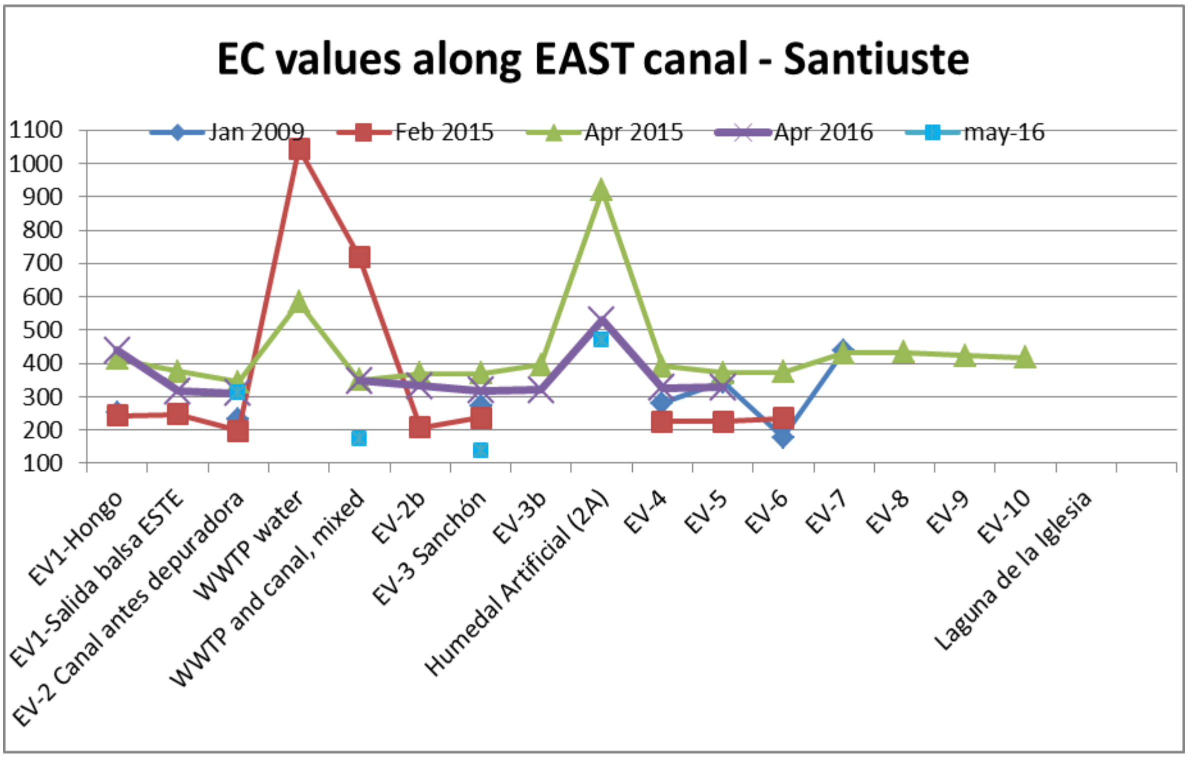

EV-9 Station. Parameters
Jan 2009
Feb 2015
Apr 2015
450
400
350
300
250
200
150
100
50
0
pH
ORP [mV]
DO [ppm]
EC [uS/cm]
TDS [ppm]
Salinity [PSU]
FNU
T [°C]

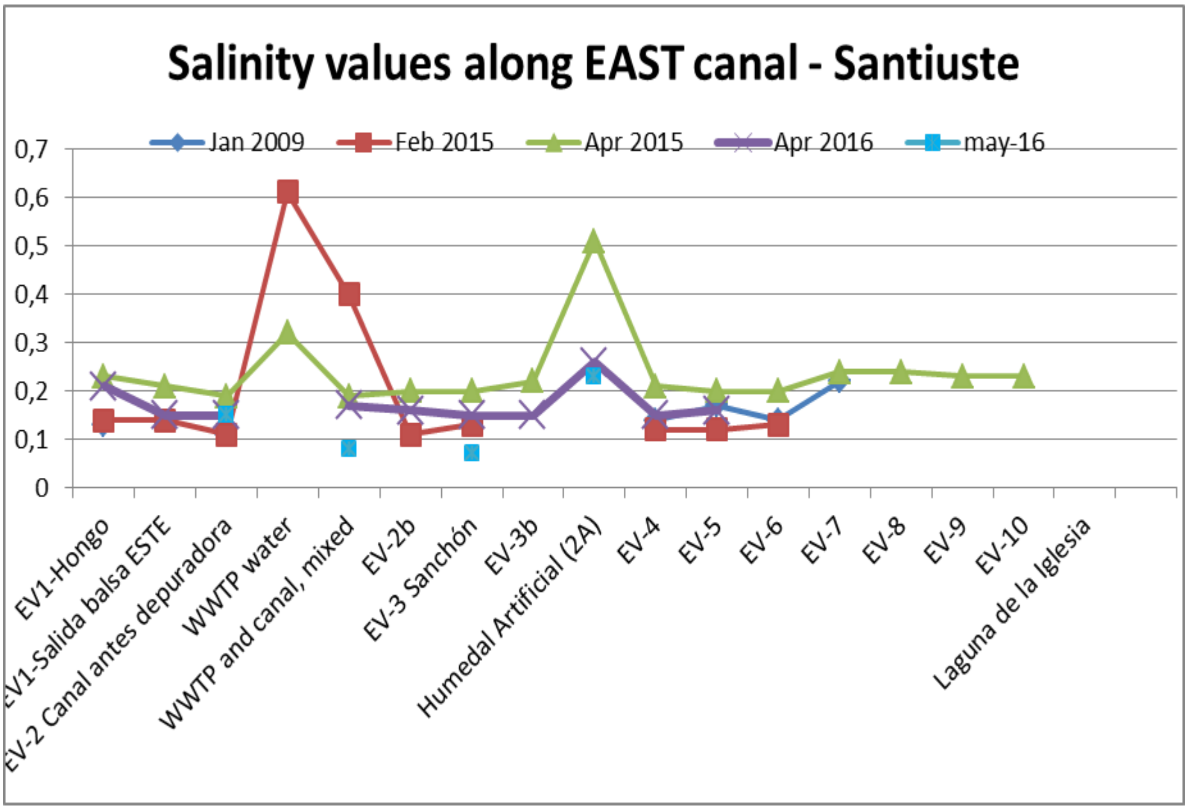

EV-10 Station. Parameters
Jan 2009
Feb 2015
Apr 2015
450
400
350
300
250
200
150
100
50
0
pH
ORP [mV]
DO [ppm]
EC [uS/cm]
TDS [ppm]
Salinity [PSU]
FNU
T [°C]

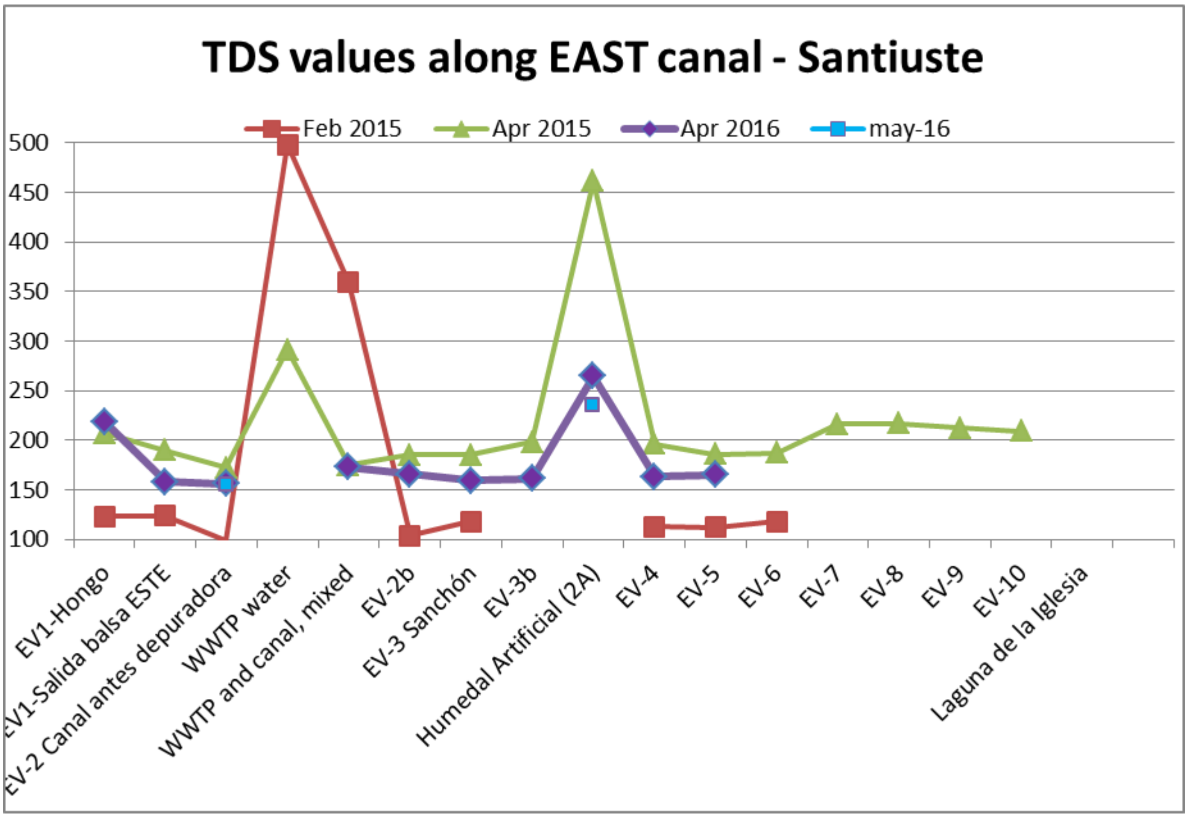
B4: Charting for the chemical determinations evolution along the *triplet*:

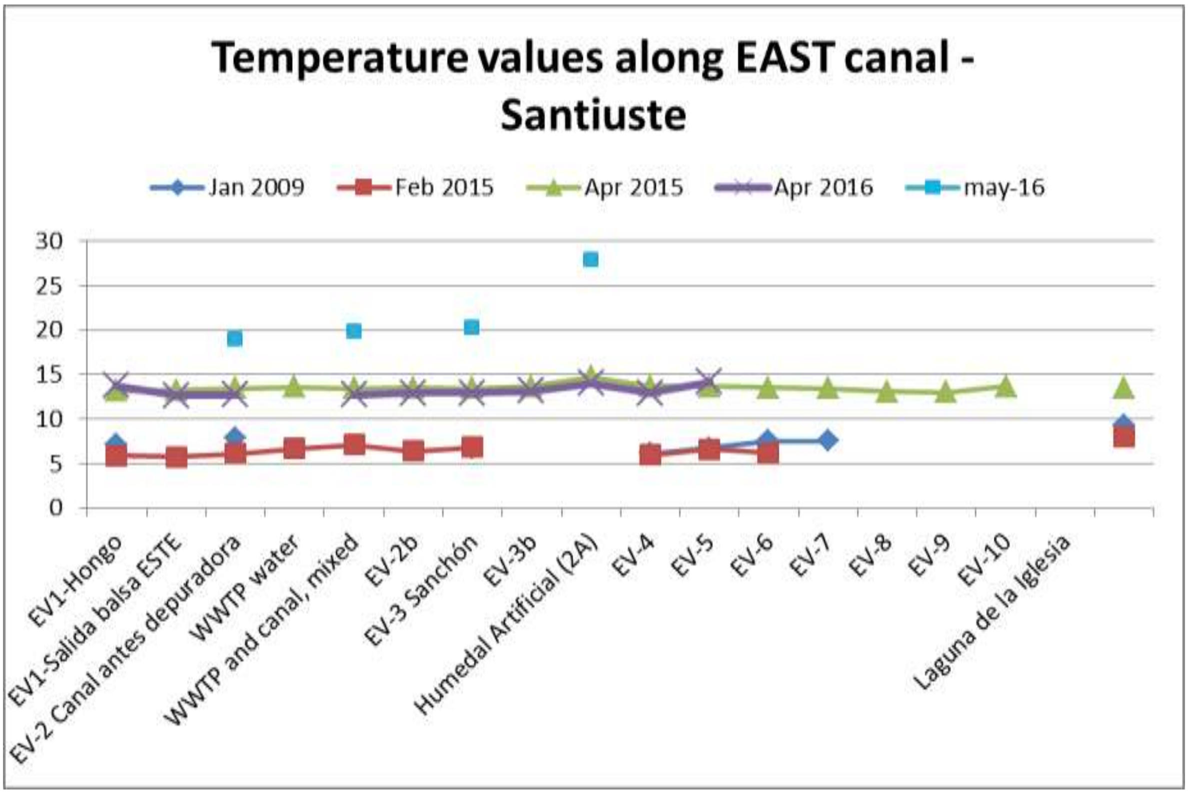





EC values along EAST canal - Santiuste
Jan 2009
Feb 2015
Apr 2015
Apr 2016
may-16
1100
1000
900
800
700
600
500
400
300
200
100
EV1-Hongo
EV1-Salida balsa ESTE
EV-2 Canal antes depuradora
WWTP water
WWTP and canal, mixed
EV-2b
EV-3 Sanchón
EV-3b
Humedal Artificial (2A)
EV-4
EV-5
EV-6
EV-7
EV-8
EV-9
EV-10
Laguna de la Iglesia


Salinity values along EAST canal - Santiuste
Jan 2009
Feb 2015
Apr 2015
Apr 2016
may-16
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
EV1-Hongo
EV1-Salida balsa ESTE
EV-2 Canal antes depuradora
WWTP water
WWTP and canal, mixed
EV-2b
EV-3 Sanchón
EV-3b
Humedal Artificial (2A)
EV-4
EV-5
EV-6
EV-7
EV-8
EV-9
EV-10
Laguna de la Iglesia


TDS values along EAST canal - Santiuste
Feb 2015
Apr 2015
Apr 2016
may-16
500
450
400
350
300
250
200
150
100
EV1-Hongo
EV1-Salida balsa ESTE
EV-2 Canal antes depuradora
WWTP water
WWTP and canal, mixed
EV-2b
EV-3 Sanchón
EV-3b
Humedal Artificial (2A)
EV-4
EV-5
EV-6
EV-7
EV-8
EV-9
EV-10
Laguna de la Iglesia


Temperature values along EAST canal - Santiuste
Jan 2009
Feb 2015
Apr 2015
Apr 2016
may-16
30
25
20
15
10
5
0
EV1-Hongo
EV1-Salida balsa ESTE
EV-2 Canal antes depuradora
WWTP water
WWTP and canal, mixed
EV-2b
EV-3 Sanchón
EV-3b
Humedal Artificial (2A)
EV-4
EV-5
EV-6
EV-7
EV-8
EV-9
EV-10
Laguna de la Iglesia

6.5.2 Annex V-2: Santiuste basin. Chemical characterization of the system for 2015 Feb 17th (111 parameters)

Conductivity

Turbidity

Ammonia

Nitrite

Chloride

Nitrate

Sulphate

DOC

Iron, dissolved

Potassium

Cupper

Magnesium

Manganese

Sodium

Nickel

Phosphate. total

Phosphor. gesamt

Cadmium

Calcium

Total Hardness

Sum earth alkali elements

Arsenic, dissolved

Lead, dissolved

Zinc, dissolved

Chemical Oxygen Demand

Biological Oxygen Demand

Filterable Solids

2-Bromo-biPh

2.2´.4.4´.6.6´-Hexabromo-biPh

2.2´.4´.5-Tetrabromo-biPh

2.2´.4.5.5´-Pentabromo-biPh

2.3´.5-Tribromo-biPh

2.4-Dibromo-biPh

BDE 100

BDE 153

BDE 183

BDE 28

BDE 47

BDE 77

BDE 99

BDE-Sum

BDE154

Bisphenol A

4-Nonylphenol. Isomer mixture

4-tert.-Octylphenol

Atrazine

Caffeine

DEET

Hexachlorbutadiene (HCBd)

Parathion-methyl

Chloramphenicol

Chlortetracyclin

Clarithromycine

Dehydrato-Erythromycin

Doxicycline

Erythromycin

Oxytetracycline

Roxithromycine

Sulfadiazine

Sulfadimidine

Sulfamethoxazole

Tetracycline

Trimethoprim

Atenolol

Betaxolol

Bisoprolol

Metoprolol

Pindolol

Propanolol

Sotalol

Acetylsalicyl acid

Bezafibrate

Clofibric acid

Diclofenac

Fenoprofen

Gemfibrozil

Ibuprofen

Indometacine

Ketoprofen

Naproxen

Carbamazepine

Diazepam

Etofibrate

Fenofibrate

Pentoxifylline

Phenacetin

Phenazone

beta-Sitosterol

Estradiol

Estriol

Estrone

Mestranol

16a-Hydroxyestrone

17a-Ethinylestradiol

Amidotrizoic acid

Iodipamide

Iohexol

Iomeprol

Iopamidol

Iopromide

Iothalamic acid

Ioxaglinic acid

Ioxithalamic acid

EDTA

Tris (2-chloroethyl)phosphate

Tris (1-chlor-2-propyl) phosphate

Tris (1.3-dichlor-2-propyl) phosphate

TMDD

Acesulfame

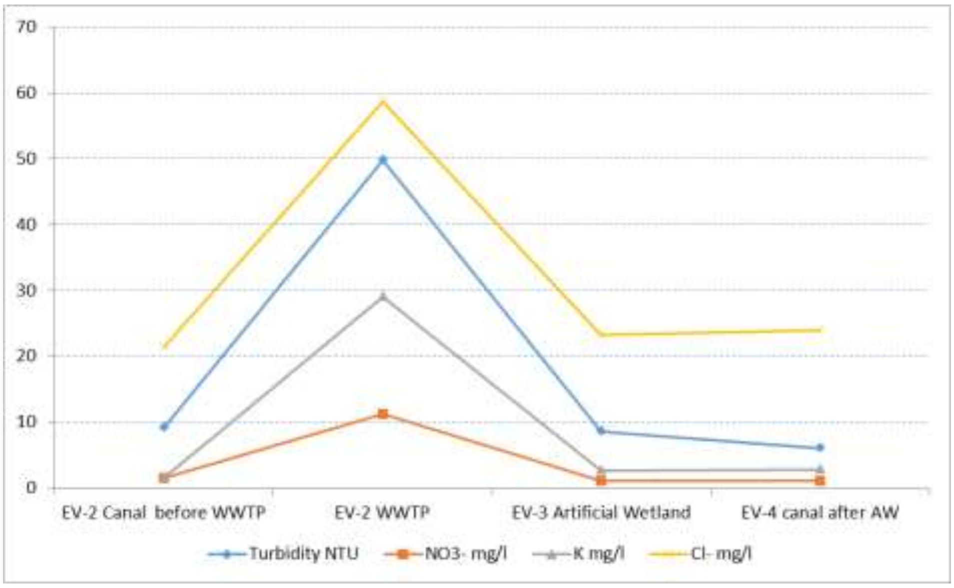
Cyclamate

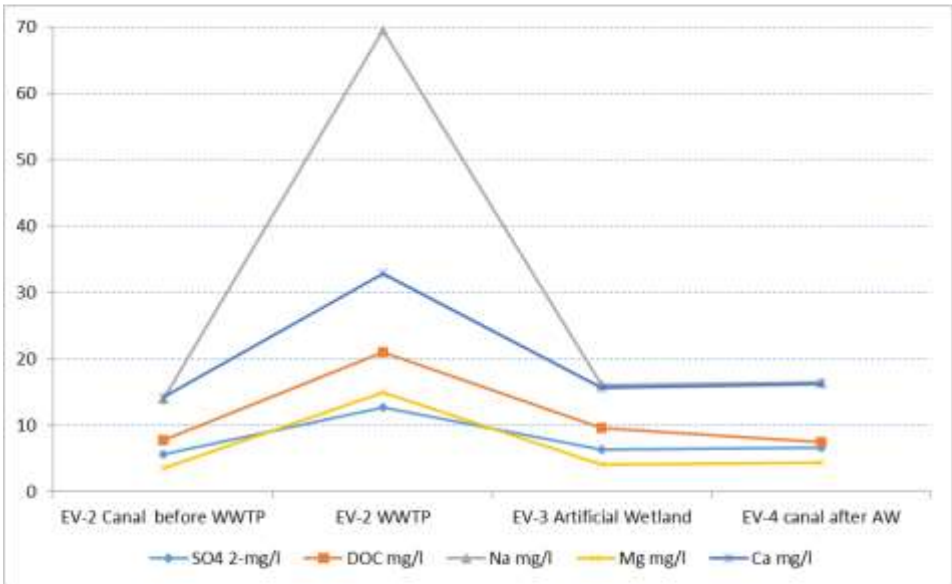
Saccharine

A1: Analysis results of 19 main biochemical parameters (change in % related to canal with fluvial recharge as a 100%):

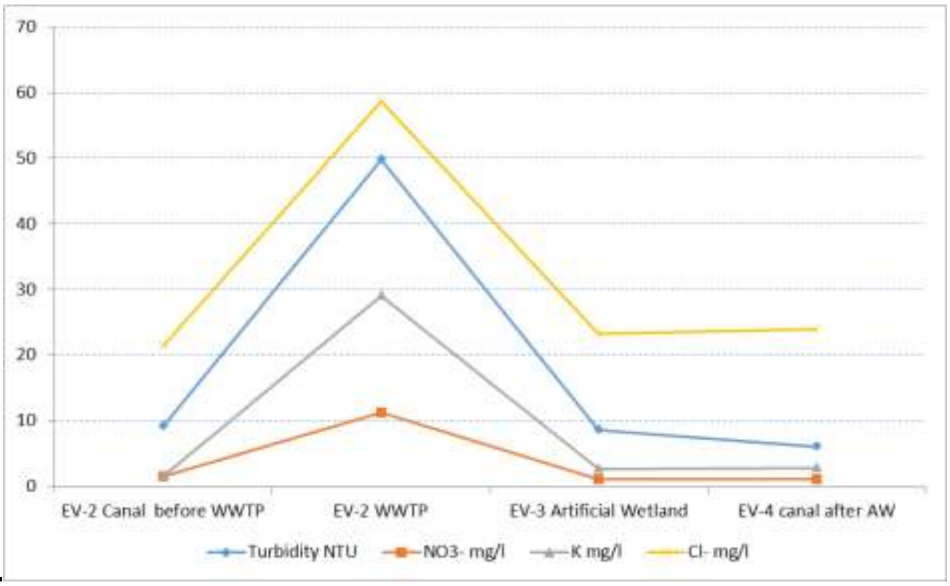
STATION	EV-2 Canal before WWTP	EV-2 WWTP	EV-3 Artificial Wetland	EV-4 canal after AW	EV4-EV3 difference
Fe	100%	63%	84%	32%	-53%
Cu	100%	74%	94%	66%	-28%
SO4 2-	100%	224%	125%	97%	-27%
Ca	100%	232%	167%	160%	-7%
DOC	100%	273%	74%	71%	-3%
Cl-	100%	273%	115%	118%	3%
Total alkalinity	100%	284%	114%	118%	3%
°dH	100%	284%	110%	114%	4%
As	100%	388%	108%	112%	4%
Conductivity	100%	408%	112%	116%	5%
Mg	100%	415%	111%	116%	5%
Na	100%	496%	111%	116%	5%
Turbidity	100%	546%	115%	121%	6%
NO3-	100%	706%	129%	135%	6%
K	100%	1824%	169%	176%	7%
P	100%	1902%	92%	104%	12%
PO4 3-	100%	1910%	130%	149%	19%
Caffeine	100%	5600%	130%	149%	20%
NH4+	100%	14211%	263%	289%	26%

A2: Selection for 19 biochemical parameters evolution graphs at Santiuste triplet before and after the WWTP inflow mixture:

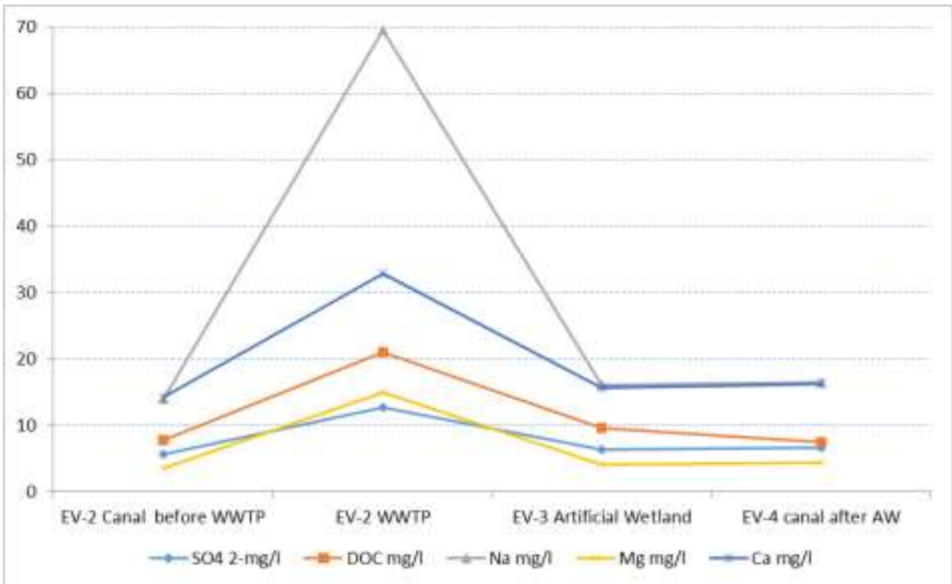


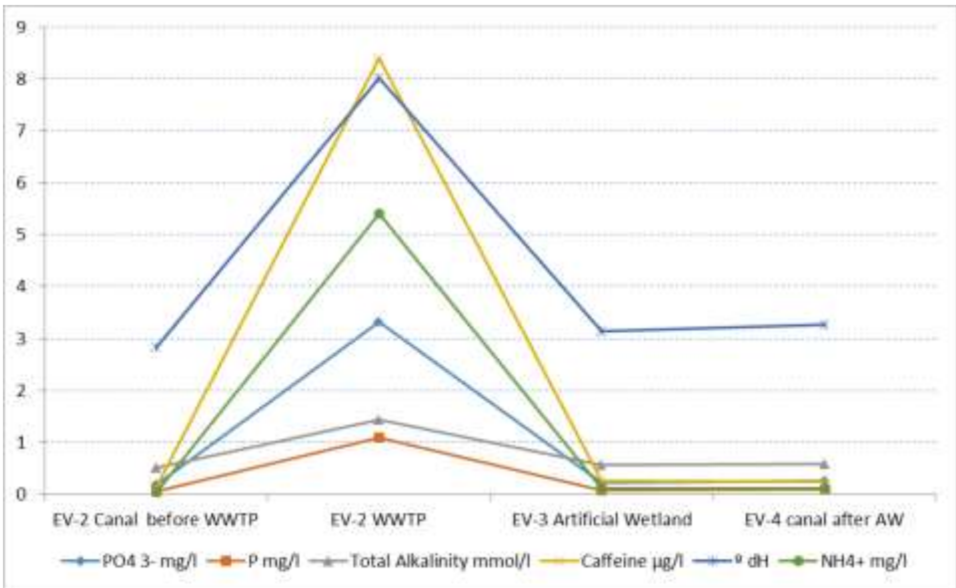


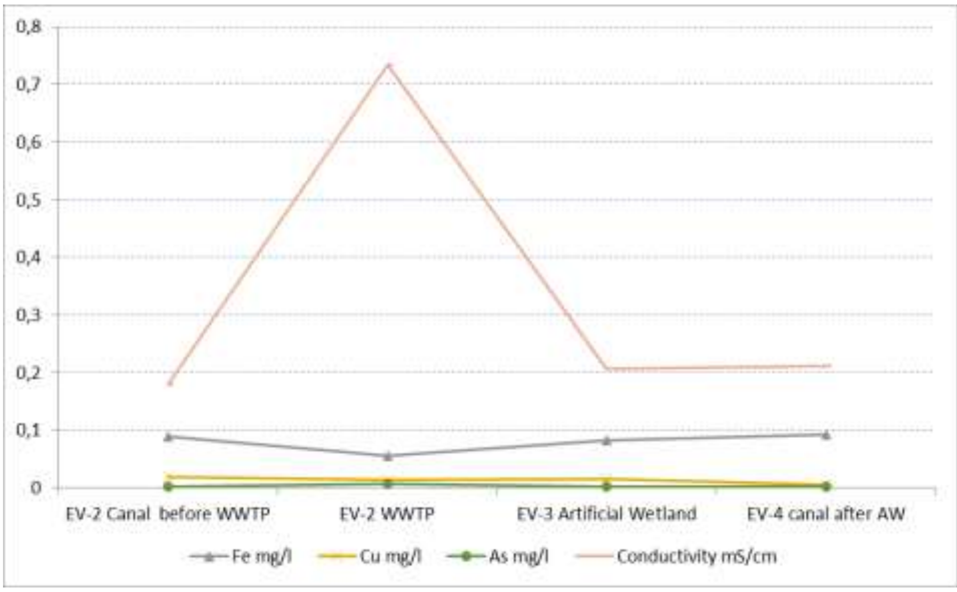
¡Error! No se encuentra el origen de la



referencia.






0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
EV-2 Canal before WWTP
EV-2 WWTP
EV-3 Artificial Wetland
EV-4 canal after AW
Fe mg/l
Cu mg/l
As mg/l
Conductivity mS/cm

6.5.3 Annex V-3: SAT-MAR study about the purification measures along the conductions

A1: Analysis results for the Alcazarén Plant between the WWTP and the MAR canals. Sampling collection points' determinations:

Sampling point	Parameter	Analysis	Date	Value	End date
WWTP Secondary treatment 1	TSS (mg/L)	2953202	26/01/2016	3640	02/02/2016
WWTP Secondary treatment 1	TSS (mg/L)	2953200	19/02/2016	3345	25/02/2016
WWTP Secondary treatment 1	TSS (mg/L)	2953203	16/03/2016	2150	23/03/2016
WWTP Secondary treatment 1	TSS (mg/L)	2953194	22/04/2016	2320	29/04/2016
WWTP Secondary treatment 1	TSS (mg/L)	2953195	26/05/2016	1660	02/06/2016
WWTP Secondary treatment 1	TSS (mg/L)	2953196	01/07/2016	2260	11/07/2016
WWTP Secondary treatment 1	TSS (mg/L)	2953198	15/07/2016	2013	22/07/2016
WWTP inletWWTP inlet	Ammonium (mg/L)	2953226	26/01/2016	16.6	04/02/2016
WWTP inlet	BOD (mg O_2/L)	2953226	26/01/2016	18	04/02/2016
WWTP inlet	COD (mg O_2/L)	2953226	26/01/2016	51	04/02/2016
WWTP inlet	TSS (mg/L)	2953226	26/01/2016	10	04/02/2016
WWTP inlet	pH (U. pH.)	2953226	26/01/2016	7.8	04/02/2016
WWTP inlet	Ammonium (mg/L)	2953224	19/02/2016	3.8	25/02/2016
WWTP inlet	BOD (mg O_2/L)	2953224	19/02/2016	11	25/02/2016
WWTP inlet	COD (mg O_2/L)	2953224	19/02/2016	42	25/02/2016
WWTP inlet	TSS (mg/L)	2953224	19/02/2016	22	25/02/2016
WWTP inlet	pH (U. pH.)	2953224	19/02/2016	7.5	25/02/2016
WWTP inlet	Ammonium (mg/L)	2953227	16/03/2016	3.1	30/03/2016
WWTP inlet	BOD (mg O_2/L)	2953227	16/03/2016	7	30/03/2016
WWTP inlet	COD (mg O_2/L)	2953227	16/03/2016	38	30/03/2016
WWTP inlet	TSS (mg/L)	2953227	16/03/2016	8	30/03/2016
WWTP inlet	pH (U. pH.)	2953227	16/03/2016	7.4	30/03/2016
WWTP inlet	Ammonium (mg/L)	2953218	22/04/2016	4.1	03/05/2016
WWTP inlet	BOD (mg O_2/L)	2953218	22/04/2016	5	03/05/2016
WWTP inlet	COD (mg O_2/L)	2953218	22/04/2016	33	03/05/2016
WWTP inlet	TSS (mg/L)	2953218	22/04/2016	9	03/05/2016
WWTP inlet	pH (U. pH.)	2953218	22/04/2016	7.4	03/05/2016
WWTP inlet	Ammonium (mg/L)	2953219	26/05/2016	14.8	02/06/2016
WWTP inlet	BOD (mg O_2/L)	2953219	26/05/2016	125	02/06/2016
WWTP inlet	COD (mg O_2/L)	2953219	26/05/2016	224	02/06/2016
WWTP inlet	TSS (mg/L)	2953219	26/05/2016	63	02/06/2016
WWTP inlet	pH (U. pH.)	2953219	26/05/2016	7.1	02/06/2016
WWTP inlet	Ammonium (mg/L)	2953220	01/07/2016	19.9	14/07/2016
WWTP inlet	COD (mg O_2/L)	2953220	01/07/2016	440	14/07/2016
WWTP inlet	BOD (mg O_2/L)	2953220	01/07/2016	210	14/07/2016
WWTP inlet	TSS (mg/L)	2953220	01/07/2016	234	14/07/2016
WWTP inlet	pH (U. pH.)	2953220	01/07/2016	7.0	14/07/2016
WWTP inlet	Ammonium (mg/L)	2953222	15/07/2016	18.5	26/07/2016
WWTP inlet	COD (mg O_2/L)	2953222	15/07/2016	55	26/07/2016
WWTP inlet	BOD (mg O_2/L)	2953222	15/07/2016	140	26/07/2016
WWTP inlet	TSS (mg/L)	2953222	15/07/2016	42	26/07/2016
WWTP inlet	pH (U. pH.)	2953222	15/07/2016	7.7	26/07/2016
WWTP outlet	Ammonium (mg/L)	2953238	26/01/2016	< 0.5	04/02/2016
WWTP outlet	BOD (mg O_2/L)	2953238	26/01/2016	7	04/02/2016
WWTP outlet	COD (mg O_2/L)	2953238	26/01/2016	25	04/02/2016
WWTP outlet	TSS (mg/L)	2953238	26/01/2016	4	04/02/2016

Sampling point	Parameter	Analysis	Date	Value	End date
WWTP outlet	pH (pH. U.)	2953238	26/01/2016	7.6	04/02/2016
WWTP outlet	Ammonium (mg/L)	2953236	19/02/2016	2.7	25/02/2016
WWTP outlet	BOD (mg O_2/L)	2953236	19/02/2016	6	25/02/2016
WWTP outlet	COD (mg O_2/L)	2953236	19/02/2016	19	25/02/2016
WWTP outlet	TSS (mg/L)	2953236	19/02/2016	12	25/02/2016
WWTP outlet	pH (pH. U.)	2953236	19/02/2016	7.4	25/02/2016
WWTP outlet	Ammonium (mg/L)	2953239	16/03/2016	0.5	30/03/2016
WWTP outlet	BOD (mg O_2/L)	2953239	16/03/2016	7	30/03/2016
WWTP outlet	COD (mg O_2/L)	2953239	16/03/2016	23	30/03/2016
WWTP outlet	TSS (mg/L)	2953239	16/03/2016	7	30/03/2016
WWTP outlet	pH (U. pH.)	2953239	16/03/2016	7.1	30/03/2016
WWTP outlet	Ammonium (mg/L)	2953230	22/04/2016	< 0.5	03/05/2016
WWTP outlet	BOD (mg O_2/L)	2953230	22/04/2016	6	03/05/2016
WWTP outlet	COD (mg O_2/L)	2953230	22/04/2016	25	03/05/2016
WWTP outlet	TSS (mg/L)	2953230	22/04/2016	6	03/05/2016
WWTP outlet	pH (pH. U.)	2953230	22/04/2016	7.2	03/05/2016
WWTP outlet	Ammonium (mg/L)	2953231	26/05/2016	< 0.5	06/06/2016
WWTP outlet	BOD (mg O_2/L)	2953231	26/05/2016	< 2	06/06/2016
WWTP outlet	COD (mg O_2/L)	2953231	26/05/2016	18	06/06/2016
WWTP outlet	TSS (mg/L)	2953231	26/05/2016	<4	06/06/2016
WWTP outlet	pH (U. pH.)	2953231	26/05/2016	7.4	06/06/2016
WWTP outlet	Ammonium (mg/L)	2953232	01/07/2016	19.3	11/07/2016
WWTP outlet	BOD (mg O_2/L)	2953232	01/07/2016	< 2	11/07/2016
WWTP outlet	COD (mg O_2/L)	2953232	01/07/2016	10	11/07/2016
WWTP outlet	TSS (mg/L)	2953232	01/07/2016	8	11/07/2016
WWTP outlet	pH (pH. U.)	2953232	01/07/2016	7.5	11/07/2016
WWTP outlet	Ammonium (mg/L)	2953234	15/07/2016	<0.5	26/07/2016
WWTP outlet	BOD (mg O_2/L)	2953234	15/07/2016	6	26/07/2016
WWTP outlet	COD (mg O_2/L)	2953234	15/07/2016	12	26/07/2016
WWTP outlet	TSS (mg/L)	2953234	15/07/2016	7	26/07/2016
WWTP outlet	pH (pH. U.)	2953234	15/07/2016	7.3	26/07/2016
WWTP dehydrated mud	Cd (mg/Kg d.w.)	2953266	22/04/2016	< 2.0	18/05/2016
WWTP dehydrated mud	Total Ca (mg CaO/Kg d.w.)	2953266	22/04/2016	20850	18/05/2016
WWTP dehydrated mud	Organic Carbon (%d.w.)	2953266	22/04/2016	41.4	18/05/2016
WWTP dehydrated mud	Cu (mg/Kg d.w.)	2953266	22/04/2016	175	18/05/2016
WWTP dehydrated mud	Cr (mg/Kg d.w.)	2953266	22/04/2016	21	18/05/2016
WWTP dehydrated mud	Escherichia coli (NMP/g)	2953266	22/04/2016	$5.9x10^4$	18/05/2016
WWTP dehydrated mud	Total P (mg P_2O_5/Kg d.w.)	2953266	22/04/2016	25071	18/05/2016
Fe	Fe (mg/Kg d.w.)	2953266	22/04/2016	671856	18/05/2016
WWTP dehydrated mud	Total Mg (mg MgO/Kg d.w.)	2953266	22/04/2016	10538	18/05/2016
WWTP dehydrated mud	Organic Matter (%d.w.)	2953266	22/04/2016	71.2	18/05/2016
WWTP dehydrated mud	Dry Matter (%)	2953266	22/04/2016	13.9	18/05/2016
WWTP dehydrated mud	Hg (mg/Kg d.w.)	2953266	22/04/2016	0.35	18/05/2016
WWTP dehydrated mud	Ni (mg/Kg d.w.)	2953266	22/04/2016	16	18/05/2016
WWTP dehydrated mud	Ammoniumcal N (% NH_4+ d.w.)	2953266	22/04/2016	0.25	18/05/2016
WWTP dehydrated mud	TKN (%N d.w.)	2953266	22/04/2016	5.9	18/05/2016
WWTP dehydrated mud	Total N (%N d.w.)	2953266	22/04/2016	5.9	18/05/2016
WWTP dehydrated mud	Pb (mg/Kg d.w.)	2953266	22/04/2016	52	18/05/2016
WWTP dehydrated mud	Total K (mg K_2O/Kg d.w.)	2953266	22/04/2016	5213	18/05/2016
WWTP dehydrated mud	C/N ratio (--)	2953266	22/04/2016	7.0	18/05/2016
WWTP dehydrated mud	Salmonella spp. (UNE-EN ISO 6579) (/25 g)	2953266	22/04/2016	Presencia	18/05/2016

Sampling point	Parameter	Analysis	Date	Value	End date
WWTP dehydrated mud	Zn (mg/Kg d.w.)	2953266	22/04/2016	953	18/05/2016
WWTP dehydrated mud	pH (pH. U.)	2953266	22/04/2016	6.1	18/05/2016
Sample point #2. WWTP outlet	DOC (mg/L)	3314492	16/03/2016	7.0	29/03/2016
Sample point #2. WWTP outlet	Conductivity at 20ºC (µS/cm)	3314492	16/03/2016	1208	29/03/2016
Sample point #2. WWTP outlet	Escherichia coli (c.f.u./100 mL)	3314492	16/03/2016	$38x10^2$	29/03/2016
Sample point #2. WWTP outlet	Nematodes (Eggs/10L)	3314492	16/03/2016	<1	29/03/2016
Sample point #2. WWTP outlet	NO3 (mg/L)	3314492	16/03/2016	44.0	29/03/2016
Sample point #2. WWTP outlet	NO2 (mg/L)	3314492	16/03/2016	0.16	29/03/2016
Sample point #2. WWTP outlet	TKN (mg/L)	3314492	16/03/2016	1.5	29/03/2016
Sample point #2. WWTP outlet	Total N (mg/L)	3314492	16/03/2016	14.2	29/03/2016
Sample point #2. WWTP outlet	TSS (mg/L)	3314492	16/03/2016	422	29/03/2016
Sample point #2. WWTP outlet	Turbidity (FNU)	3314492	16/03/2016	1.05	29/03/2016
Sample point #2. WWTP outlet	Dissolved Organic Carbon(mg/L)	3314338	22/04/2016	11.2	10/05/2016
Sample point #2. WWTP outlet	Conductivity at 20ºC (µS/cm)	3314338	22/04/2016	990	10/05/2016
Sample point #2. WWTP outlet	Escherichia coli (c.f.u./100 mL)	3314338	22/04/2016	260	10/05/2016
Sample point #2. WWTP outlet	Nematodes (Eggs/10L)	3314338	22/04/2016	<1	10/05/2016
Sample point #2. WWTP outlet	NO3 (mg/L)	3314338	22/04/2016	39.0	10/05/2016
Sample point #2. WWTP outlet	NO2 (mg/L)	3314338	22/04/2016	< 0.05	10/05/2016
Sample point #2. WWTP outlet	TKN (mg/L)	3314338	22/04/2016	< 1.0	10/05/2016
Sample point #2. WWTP outlet	Total N (mg/L)	3314338	22/04/2016	12.8	10/05/2016
Sample point #2. WWTP outlet	TSS (mg/L)	3314338	22/04/2016	773	10/05/2016
Sample point #2. WWTP outlet	Turbidity (FNU)	3314338	22/04/2016	0.64	10/05/2016
Sample point #2. WWTP outlet	Dissolved Organic Carbon (mg/L)	3314491	10/06/2016	37.3	01/07/2016
Sample point #2. WWTP outlet	Conductivity at 20ºC (µS/cm)	3314491	10/06/2016	968	01/07/2016
Sample point #2. WWTP outlet	Escherichia coli (c.f.u./100 mL)	3314491	10/06/2016	280	01/07/2016
Sample point #2. WWTP outlet	Nematodes (Eggs/10L)	3314491	10/06/2016	<1	01/07/2016
Sample point #2. WWTP outlet	NO3 (mg/L)	3314491	10/06/2016	11.9	01/07/2016
Sample point #2. WWTP outlet	NO2 (mg/L)	3314491	10/06/2016	< 0.05	01/07/2016
Sample point #2. WWTP outlet	TKN (mg/L)	3314491	10/06/2016	10.4	01/07/2016
Sample point #2. WWTP outlet	Total N (mg/L)	3314491	10/06/2016	16.4	01/07/2016
Sample point #2. WWTP outlet	TSS (mg/L)	3314491	10/06/2016	682	01/07/2016
Sample point #2. WWTP outlet	Turbidity (FNU)	3314491	10/06/2016	3.13	01/07/2016
Sample point #2. WWTP outlet	Organic Carbon disuelto (mg/L)	3314339	15/07/2016	5.7	05/08/2016
Sample point #2. WWTP outlet	Conductivity at 20ºC (µS/cm)	3314339	15/07/2016	694	05/08/2016
Sample point #2. WWTP outlet	Escherichia coli (c.f.u./100 mL)	3314339	15/07/2016	15	05/08/2016
Sample point #2. WWTP outlet	Nematodes (Eggs/10L)	3314339	15/07/2016	<1	05/08/2016
Sample point #2. WWTP outlet	NO3 (mg/L)	3314339	15/07/2016	19.0	05/08/2016
Sample point #2. WWTP outlet	NO2 (mg/L)	3314339	15/07/2016	<0.05	05/08/2016
Sample point #2. WWTP outlet	TKN (mg/L)	3314339	15/07/2016	2.7	05/08/2016
Sample point #2. WWTP outlet	Total N (mg/L)	3314339	15/07/2016	6.2	05/08/2016
Sample point #2. WWTP outlet	TSS (mg/L)	3314339	15/07/2016	524	05/08/2016
Sample point #2. WWTP outlet	Turbidity (FNU)	3314339	15/07/2016	0.44	05/08/2016
Sample point #4. WWTP spill. overflow channel	Ammonium (mg/L)	3314494	16/03/2016	< 0.5	30/03/2016
Sample point #4. WWTP spill. overflow channel	Organic Carbon disuelto (mg/L)	3314494	16/03/2016	6.8	30/03/2016
Sample point #4. WWTP spill. overflow channel	Fecal coliforms (c.f.u./100 mL)	3314494	16/03/2016	200	30/03/2016
Sample point #4. WWTP spill. overflow channel	Total coliforms (c.f.u./100 mL)	3314494	16/03/2016	$55x10^2$	30/03/2016
Sample point #4. WWTP spill. overflow channel	Conductivity at 20ºC (µS/cm)	3314494	16/03/2016	1174	30/03/2016
Sample point #4. WWTP spill. overflow channel	BOD (mg O_2/L)	3314494	16/03/2016	< 5	30/03/2016

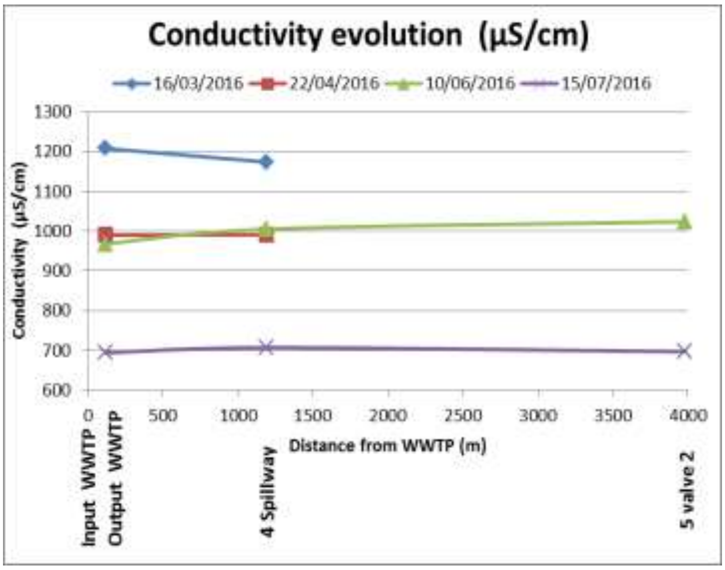
Sampling point	Parameter	Analysis	Date	Value	End date
Sample point #4. WWTP spill. overflow channel	COD (mg O_2/L)	3314494	16/03/2016	23	30/03/2016
Sample point #4. WWTP spill. overflow channel	Escherichia coli (c.f.u./100 mL)	3314494	16/03/2016	91	30/03/2016
Sample point #4. WWTP spill. overflow channel	Nematodes (Eggs/10L)	3314494	16/03/2016	<1	30/03/2016
Sample point #4. WWTP spill. overflow channel	NO3 (mg/L)	3314494	16/03/2016	45.0	30/03/2016
Sample point #4. WWTP spill. overflow channel	NO2 (mg/L)	3314494	16/03/2016	0.19	30/03/2016
Sample point #4. WWTP spill. overflow channel	TKN (mg/L)	3314494	16/03/2016	1.5	30/03/2016
Sample point #4. WWTP spill. overflow channel	Total N (mg/L)	3314494	16/03/2016	12.8	30/03/2016
Sample point #4. WWTP spill. overflow channel	DS (mg/L)	3314494	16/03/2016	714	30/03/2016
Sample point #4. WWTP spill. overflow channel	TSS (mg/L)	3314494	16/03/2016	5	30/03/2016
Sample point #4. WWTP spill. overflow channel	Turbidity (FNU)	3314494	16/03/2016	1.52	30/03/2016
Sample point #4. WWTP spill. overflow channel	pH (U. pH.)	3314494	16/03/2016	6.9	30/03/2016
Sample point #4. WWTP spill. overflow channel	Ammonium (mg/L)	3314341	22/04/2016	< 0.5	14/05/2016
Sample point #4. WWTP spill. overflow channel	Organic Carbon disuelto (mg/L)	3314341	22/04/2016	10.7	14/05/2016
Sample point #4. WWTP spill. overflow channel	Fecal coliforms (c.f.u./100 mL)	3314341	22/04/2016	23	14/05/2016
Sample point #4. WWTP spill. overflow channel	Total coliforms (c.f.u./100 mL)	3314341	22/04/2016	64	14/05/2016
Sample point #4. WWTP spill. overflow channel	Conductivity at 20ºC (µS/cm)	3314341	22/04/2016	991	14/05/2016
Sample point #4. WWTP spill. overflow channel	BOD (mg O_2/L)	3314341	22/04/2016	15	14/05/2016
Sample point #4. WWTP spill. overflow channel	COD (mg O_2/L)	3314341	22/04/2016	28	14/05/2016
Sample point #4. WWTP spill. overflow channel	Escherichia coli (c.f.u./100 mL)	3314341	22/04/2016	20	14/05/2016
Sample point #4. WWTP spill. overflow channel	Nematodes (Eggs/10L)	3314341	22/04/2016	<1	14/05/2016
Sample point #4. WWTP spill. overflow channel	NO3 (mg/L)	3314341	22/04/2016	40.8	14/05/2016
Sample point #4. WWTP spill. overflow channel	NO2 (mg/L)	3314341	22/04/2016	< 0.05	14/05/2016
Sample point #4. WWTP spill. overflow channel	TKN (mg/L)	3314341	22/04/2016	1.5	14/05/2016
Sample point #4. WWTP spill. overflow channel	Total N (mg/L)	3314341	22/04/2016	12.7	14/05/2016
Sample point #4. WWTP spill. overflow channel	DS (mg/L)	3314341	22/04/2016	762	14/05/2016
Sample point #4. WWTP spill. overflow channel	TSS (mg/L)	3314341	22/04/2016	11	14/05/2016
Sample point #4. WWTP spill. overflow channel	Turbidity (FNU)	3314341	22/04/2016	2.84	14/05/2016
Sample point #4. WWTP spill. overflow channel	pH (U. pH.)	3314341	22/04/2016	7.3	14/05/2016
Sample point #4. WWTP spill. overflow channel	Ammonium (mg/L)	3314493	10/06/2016	9.3	30/06/2016
Sample point #4. WWTP spill. overflow channel	Organic Carbon disuelto (mg/L)	3314493	10/06/2016	37.3	30/06/2016
Sample point #4. WWTP spill. overflow channel	Fecal coliforms (c.f.u./100 mL)	3314493	10/06/2016	560	30/06/2016
Sample point #4. WWTP spill. overflow channel	Total coliforms (c.f.u./100 mL)	3314493	10/06/2016	$40x10^2$	30/06/2016
Sample point #4. WWTP spill. overflow channel	Conductivity at 20ºC (µS/cm)	3314493	10/06/2016	1005	30/06/2016
Sample point #4. WWTP spill. overflow channel	BOD (mg O_2/L)	3314493	10/06/2016	7	30/06/2016
Sample point #4. WWTP spill. overflow channel	COD (mg O_2/L)	3314493	10/06/2016	19	30/06/2016
Sample point #4. WWTP spill. overflow channel	Escherichia coli (c.f.u./100 mL)	3314493	10/06/2016	500	30/06/2016

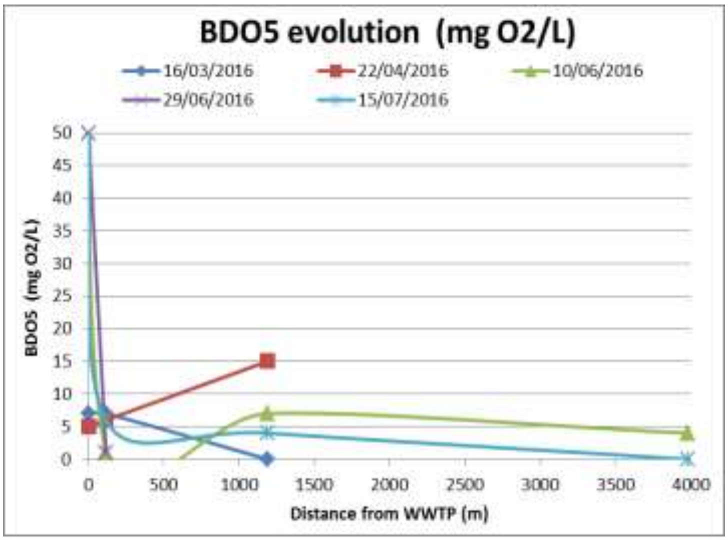
Sampling point	Parameter	Analysis	Date	Value	End date
Sample point #4. WWTP spill. overflow channel	Nematodes (Eggs/10L)	3314493	10/06/2016	<1	30/06/2016
Sample point #4. WWTP spill. overflow channel	NO3 (mg/L)	3314493	10/06/2016	2.5	30/06/2016
Sample point #4. WWTP spill. overflow channel	NO2 (mg/L)	3314493	10/06/2016	< 0.05	30/06/2016
Sample point #4. WWTP spill. overflow channel	TKN (mg/L)	3314493	10/06/2016	7.6	30/06/2016
Sample point #4. WWTP spill. overflow channel	Total N (mg/L)	3314493	10/06/2016	14.9	30/06/2016
Sample point #4. WWTP spill. overflow channel	DS (mg/L)	3314493	10/06/2016	761	30/06/2016
Sample point #4. WWTP spill. overflow channel	TSS (mg/L)	3314493	10/06/2016	7	30/06/2016
Sample point #4. WWTP spill. overflow channel	Turbidity (FNU)	3314493	10/06/2016	2.49	30/06/2016
Sample point #4. WWTP spill. overflow channel	pH (U. pH.)	3314493	10/06/2016	7.5	30/06/2016
Sample point #4. WWTP spill. overflow channel	Ammonium (mg/L)	3314342	15/07/2016	1.1	05/08/2016
Sample point #4. WWTP spill. overflow channel	Organic Carbon disuelto (mg/L)	3314342	15/07/2016	6.2	05/08/2016
Sample point #4. WWTP spill. overflow channel	Fecal coliforms (c.f.u./100 mL)	3314342	15/07/2016	89x10²	05/08/2016
Sample point #4. WWTP spill. overflow channel	Total coliforms (c.f.u./100 mL)	3314342	15/07/2016	99x10²	05/08/2016
Sample point #4. WWTP spill. overflow channel	Conductivity at 20ºC (µS/cm)	3314342	15/07/2016	707	05/08/2016
Sample point #4. WWTP spill. overflow channel	BOD (mg O_2/L)	3314342	15/07/2016	<5	05/08/2016
Sample point #4. WWTP spill. overflow channel	COD(mg O_2/L)	3314342	15/07/2016	14	05/08/2016
Sample point #4. WWTP spill. overflow channel	Escherichia coli (c.f.u./100 mL)	3314342	15/07/2016	70x10²	05/08/2016
Sample point #4. WWTP spill. overflow channel	Nematodes (Eggs/10L)	3314342	15/07/2016	<1	05/08/2016
Sample point #4. WWTP spill. overflow channel	NO3 (mg/L)	3314342	15/07/2016	12.1	05/08/2016
Sample point #4. WWTP spill. overflow channel	NO2 (mg/L)	3314342	15/07/2016	<0..05	05/08/2016
Sample point #4. WWTP spill. overflow channel	TKN (mg/L)	3314342	15/07/2016	2.7	05/08/2016
Sample point #4. WWTP spill. overflow channel	Total N (mg/L)	3314342	15/07/2016	6.1	05/08/2016
Sample point #4. WWTP spill. overflow channel	DS (mg/L)	3314342	15/07/2016	568	05/08/2016
Sample point #4. WWTP spill. overflow channel	TSS (mg/L)	3314342	15/07/2016	2	05/08/2016
Sample point #4. WWTP spill. overflow channel	Turbidity (FNU)	3314342	15/07/2016	0.91	05/08/2016
Sample point #4. WWTP spill. overflow channel	pH (pH. U.)	3314342	15/07/2016		05/08/2016
Sample point #5. WWTP spill	Ammonium (mg/L)	3314495	10/06/2016	10.5	28/06/2016
Sample point #5. WWTP spill	Dissolved Organic Carbon (mg/L)	3314495	10/06/2016	34.6	28/06/2016
Sample point #5. WWTP spill	Fecal coliforms (c.f.u./100 mL)	3314495	10/06/2016	820	28/06/2016
Sample point #5. WWTP spill	Total coliforms (c.f.u./100 mL)	3314495	10/06/2016	98x10²	28/06/2016
Sample point #5. WWTP spill	Conductivity at 20ºC (µS/cm)	3314495	10/06/2016	1024	28/06/2016
Sample point #5. WWTP spill	BOD (mg O_2/L)	3314495	10/06/2016	< 5	28/06/2016
Sample point #5. WWTP spill	COD(mg O_2/L)	3314495	10/06/2016	< 10	28/06/2016
Sample point #5. WWTP spill	Escherichia coli (c.f.u./100 mL)	3314495	10/06/2016	600	28/06/2016
Sample point #5. WWTP spill	Nematodes (Eggs/10L)	3314495	10/06/2016	<1	28/06/2016
Sample point #5. WWTP spill	NO3 (mg/L)	3314495	10/06/2016	2.1	28/06/2016
Sample point #5. WWTP spill	NO2 (mg/L)	3314495	10/06/2016	< 0.05	28/06/2016
Sample point #5. WWTP spill	TKN (mg/L)	3314495	10/06/2016	10.8	28/06/2016
Sample point #5. WWTP spill	Total N (mg/L)	3314495	10/06/2016	15.8	28/06/2016
Sample point #5. WWTP spill	DS (mg/L)	3314495	10/06/2016	731	28/06/2016

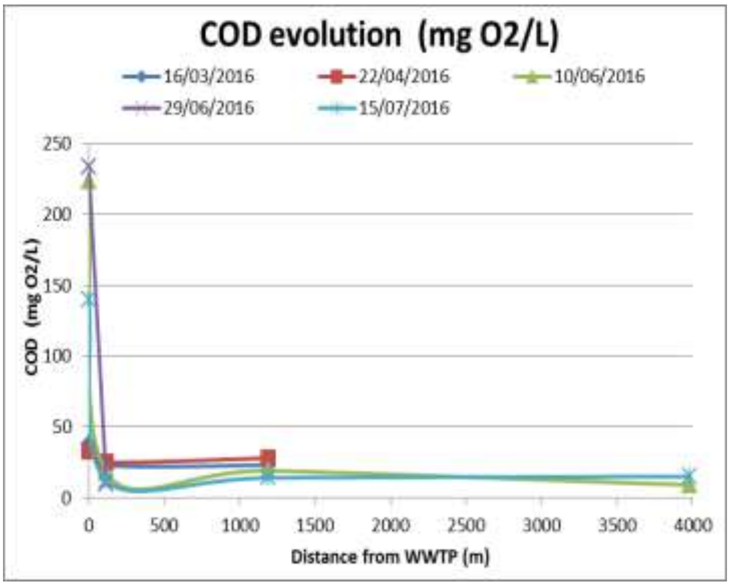
Sampling point	Parameter	Analysis	Date	Value	End date
Sample point #5. WWTP spill	TSS (mg/L)	3314495	10/06/2016	6	28/06/2016
Sample point #5. WWTP spill	Turbidity (FNU)	3314495	10/06/2016	1.99	28/06/2016
Sample point #5. WWTP spill	pH (U. pH.)	3314495	10/06/2016	7.5	28/06/2016
Sample point #5. WWTP spill	Ammonium (mg/L)	3314344	15/07/2016	<0.5	04/08/2016
Sample point #5. WWTP spill	Organic Carbon disuelto (mg/L)	3314344	15/07/2016	6.1	04/08/2016
Sample point #5. WWTP spill	Fecal coliforms (c.f.u./100 mL)	3314344	15/07/2016	$72x10^2$	04/08/2016
Sample point #5. WWTP spill	Total coliforms(c.f.u./100 mL)	3314344	15/07/2016	$97x10^2$	04/08/2016
Sample point #5. WWTP spill	Conductivity at 20ºC (µS/cm)	3314344	15/07/2016	697	04/08/2016
Sample point #5. WWTP spill	BOD (mg O_2/L)	3314344	15/07/2016	<5	04/08/2016
Sample point #5. WWTP spill	COD(mg O_2/L)	3314344	15/07/2016	15	04/08/2016
Sample point #5. WWTP spill	Escherichia coli (c.f.u./100 mL)	3314344	15/07/2016	$41x10^2$	04/08/2016
Sample point #5. WWTP spill	Nematodes (Eggs/10L)	3314344	15/07/2016	<1	04/08/2016
Sample point #5. WWTP spill	NO3 (mg/L)	3314344	15/07/2016	8..5	04/08/2016
Sample point #5. WWTP spill	NO2 (mg/L)	3314344	15/07/2016	0..44	04/08/2016
Sample point #5. WWTP spill	TKN (mg/L)	3314344	15/07/2016	3.0	04/08/2016
Sample point #5. WWTP spill	Total N (mg/L)	3314344	15/07/2016	6.2	04/08/2016
Sample point #5. WWTP spill	DS (mg/L)	3314344	15/07/2016	538	04/08/2016
Sample point #5. WWTP spill	TSS (mg/L)	3314344	15/07/2016	2	04/08/2016
Sample point #5. WWTP spill	Turbidity (FNU)	3314344	15/07/2016	1..27	04/08/2016
Sample point #5. WWTP spill	pH (pH. U.)	3314495	10/06/2016	7..4	28/06/2016

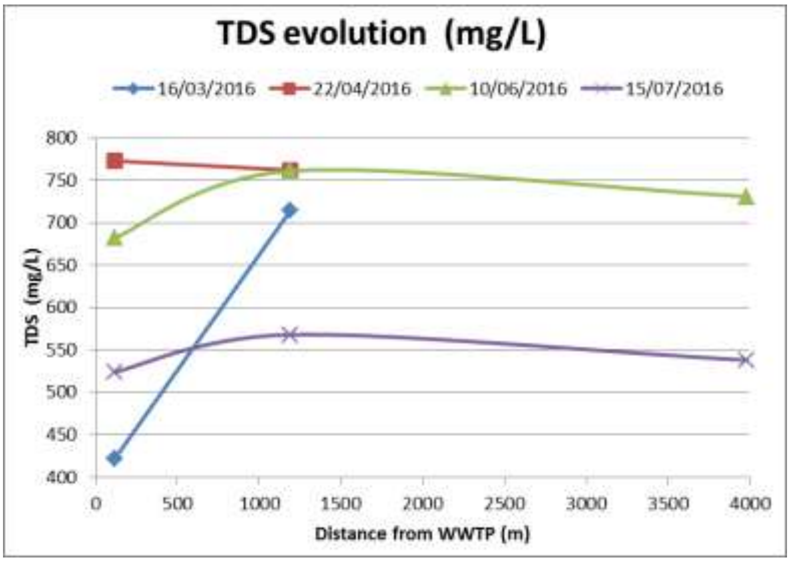
date	Nº campaign
16/03/2016	1
22/04/2016	2
10/06/2016	3
29/06/2016	4
15/07/2016	5

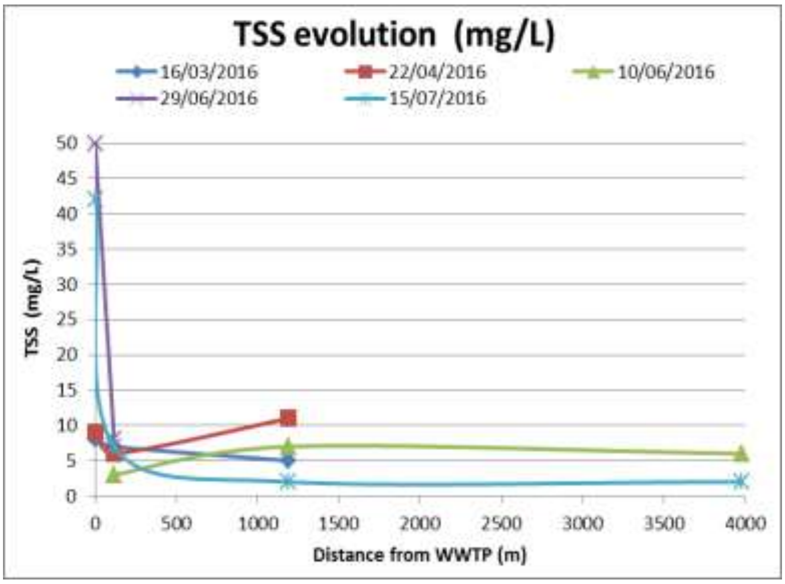
A2: Parameters evolution along the pipeline. Charts:

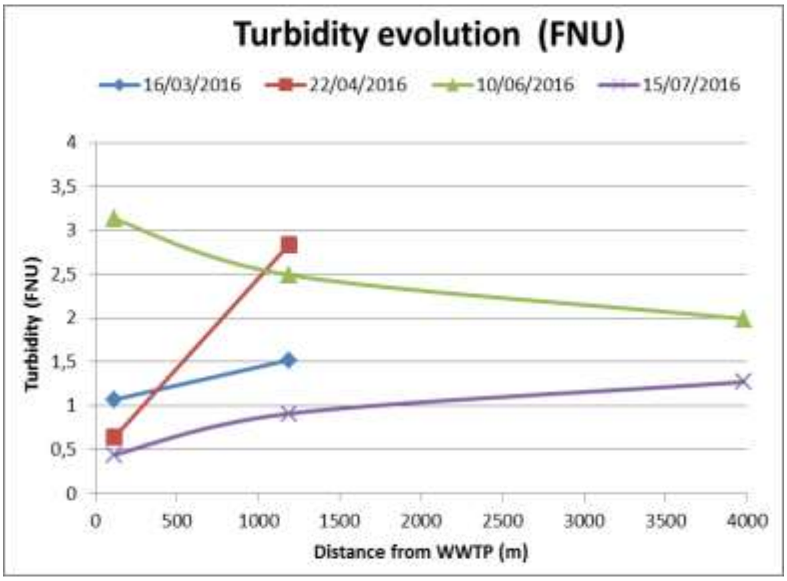


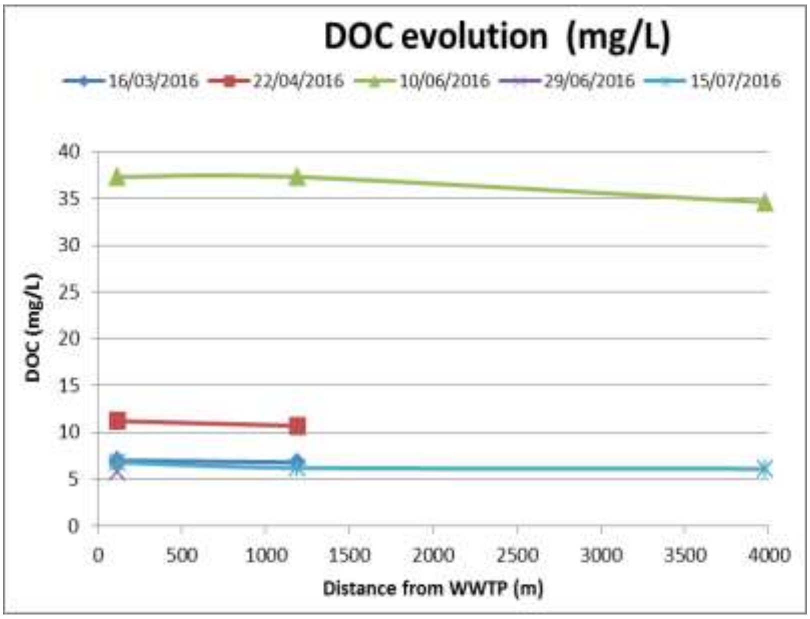


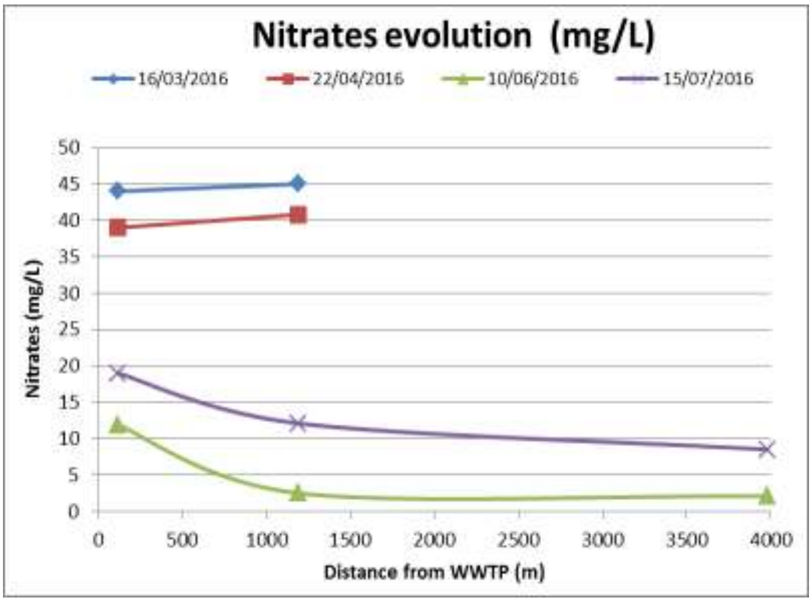


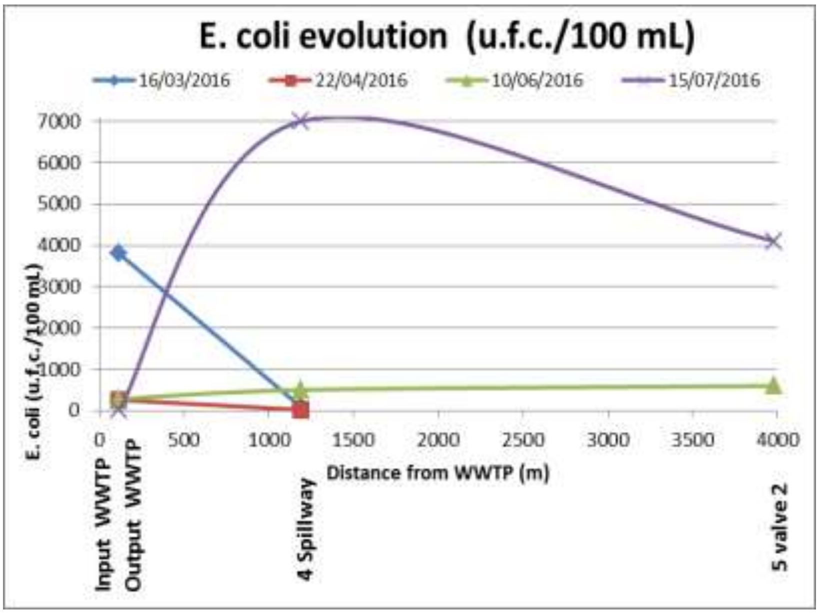

TDS evolution (mg/L)
16/03/2016
22/04/2016
10/06/2016
15/07/2016
TDS (mg/L)
800
750
700
650
600
550
500
450
400
0
500
1000
1500
2000
2500
3000
3500
4000
Distance from WWTP (m)


TSS evolution (mg/L)
16/03/2016
22/04/2016
10/06/2016
29/06/2016
15/07/2016
TSS (mg/L)
50
45
40
35
30
25
20
15
10
5
0
0
500
1000
1500
2000
2500
3000
3500
4000
Distance from WWTP (m)


Turbidity evolution (FNU)
16/03/2016
22/04/2016
10/06/2016
15/07/2016
Turbidity (FNU)
4
3,5
3
2,5
2
1,5
1
0,5
0
0
500
1000
1500
2000
2500
3000
3500
4000
Distance from WWTP (m)


DOC evolution (mg/L)
16/03/2016
22/04/2016
10/06/2016
29/06/2016
15/07/2016
DOC (mg/L)
0
5
10
15
20
25
30
35
40
0
500
1000
1500
2000
2500
3000
3500
4000
Distance from WWTP (m)


Nitrates evolution (mg/L)
16/03/2016
22/04/2016
10/06/2016
15/07/2016
Nitrates (mg/L)
0
5
10
15
20
25
30
35
40
45
50
0
500
1000
1500
2000
2500
3000
3500
4000
Distance from WWTP (m)


E. coli evolution (u.f.c./100 mL)
16/03/2016
22/04/2016
10/06/2016
15/07/2016
E. coli (u.f.c./100 mL)
0
1000
2000
3000
4000
5000
6000
7000
0
500
1000
1500
2000
2500
3000
3500
4000
Distance from WWTP (m)
Input WWTP
Output WWTP
4 Spillway
5 valve 2