Summary of data concerning the quality of the reclaimed water produced at the Blanes Reclamation Plant (Costa Brava, Girona, Catalonia)

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Abstract. The municipality of Blanes is situated at the southern end of the Costa Brava and its economy is mainly based on industrial and tourist activities. It is located at the mouth of the Tordera River, the coastal aquifer of which was declared officially protected in 2003 due to both the drought of that time and to the heavy water extractions. Three main measures undertaken by the Catalan Water Agency were: i) the construction of a 10 hm^3/year desalination plant (2002), to reduce groundwater extraction; ii) the construction of a water reclamation facility (Title-22, 2003), to stop the discharge of effluent into the sea and to favour the aquifer recharge; and iii) the regulation of the aquifer extractions. Since then, an intense physicochemical and microbiological monitoring of the reclaimed water has been performed, including suspended solids, turbidity, transmittance at 254 nm, nutrients, cations and anions, heavy metals, trihalomethanes, pesticides and halogenated organic solvents, and the concentrations of *E. coli*, *Clostridium* spores, bacteriophages and three different serotypes of *Legionella*. These data have been instrumental in improving the performance of the reclamation plant and in providing confidence in the project itself and in the measures taken for public health protection.
Keywords: reclaimed water; microbiological quality; chemical quality

INTRODUCTION

The aquifer of the lower Tordera river, on the southern border between Girona and Barcelona provinces (NE Catalonia) has traditionally been a rich one and has provided drinking water to a growing population expanding on both sides of its delta and beyond (from Tossa de Mar to Arenys de Mar) and to the local agricultural and industrial sectors. This steady increase in water demand, together with a period of drought that lasted from 1998 to 2002, produced a decline in the water table and a loss of quality of the groundwater due to seawater intrusion and salinization. The Catalan Water Agency (ACA) undertook a set of measures in order to reverse the situation and restore the levels and the quality of the groundwater. The three main measures were: i) the construction of a 10 hm^3/year desalination plant, to reduce groundwater extraction for the supply of drinking water; ii) the construction of a water reclamation facility at the Blanes WWTP, in order to stop the discharge of secondary effluent into the sea through a submarine outfall and to provide treatment suitable for the recharge of the aquifer; and iii) the establishment of a plan for the regulation of the aquifer extractions (POE, Pla d'Ordenació d'Extraccions), which sets limits for the withdrawal and distribution of the local groundwater. Thus, fewer extractions and active recharging have been the two main actions that are improving the condition of the lower Tordera aquifer. Since summer 2006, a portion of the reclaimed water has also been supplied for agricultural irrigation in the area.

THE BLANES RECLAMATION FACILITY

Description

The municipality of Blanes (pop. 40,000) is located at the southern end of the Costa Brava and since 1998 has had an extended aeration plant that replaced the previous activated sludge plant in operation since 1972. In year 2002, a reclamation plant and a phosphorus removal treatment were added, and the biological reactor was upgraded in order to perform nitrification and denitrification of effluent. The reclamation plant consisted of coagulation, flocculation, lamella sedimentation, pulsed-bed sand filtration and disinfection. Until May 2006 the disinfection was only performed with sodium hypochlorite, when a UV system started operation and was added to the disinfection scheme. As proved by the results of the experiments performed in both the Castell-Platja d'Aro and Blanes reclamation plants, the combination of UV and chlorine has been shown to provide a higher level of removal of microorganisms, a wider range of disinfection and greater operational reliability and flexibility (Consorci de la Costa Brava, 2006a; Consorci de la Costa Brava, 2006b).

In greater detail, the Blanes reclamation plant – with a treatment capacity of 700 m^3/h - consists of the following elements:

- *Header tank*. Before entering the treatment itself, the secondary effluent is stored in a header tank with a capacity of 1,500 m^3 in order to absorb flow variations and to allow the reclamation treatment to work under stable conditions. At design flow, the retention time in this tank is approximately 130 minutes.
- *Coagulation and flocculation*. These treatment units are designed to add a dose of up to 240 mg/L of coagulant and 230 mg/L of flocculant. However, due to the usual high quality of the secondary effluent, they are seldom used.
- *Lamella settlers*. There are two lamellar settlement tanks, with a total surface area of 110.2 m^2 (55.1 m^2/unit x 2 units). At design flow, the ascension velocity is 6.4 m/h.
- *Filtration*. It is performed on pulsed-bed sand filters (Hydroclear™). The filtering surface is 82.4 m^2 (20.6 m^2/cell x 4 cells), which gives, at design flow, a filtration velocity of 8.5 m/h. This step retains the smaller particles which lamellar settlement has not been able to remove.
- *UV disinfection*. It is performed by a maximum of 32 medium pressure lamps, distributed in 4 reactors of 8 lamps each. At design flow and with transmittance values of 70% at 254 nm, this facility can provide a maximum UV dose estimated at 189 mJ/cm^2. UV disinfection was set in operation in April 2006.
- *Chlorine disinfection and reclaimed water storage tank*. Right after UV disinfection, a final dose of sodium hypochlorite is added as the reclaimed water enters the storage tank. The size of this tank is 2,500 m^3 and thus it ensures a contact time of 210 minutes at peak flow. From January 2003 to March 2006, disinfection of the reclaimed water was performed only by the addition of sodium hypochlorite.

Quality criteria

The quality guidelines issued by the Catalan government for aquifer recharge with reclaimed water through percolation (ACA, 2007a) are compared with those proposed in the draft from the Spanish Environment Ministry (Iglesias, 2005.), and both can be found in Table 1. The quality requirements for agricultural irrigation are also met if the quality for recharge demanded by ACA is achieved. According to the report "Quality criteria of reclaimed water according to the different applications" issued by the ACA, these values, though absolute, shall be taken as guidelines, whereas the values given in the draft from the Spanish Ministry would be compulsory in the case of at least 90% of the annual sets of samples if the legislation were passed in its present form.

Reclaimed water production

The goal of the project at the Blanes reclamation plant is to produce the greatest daily volume of reclaimed water possible and to discharge it into the Tordera riverbed for groundwater recharge. As shown in Table 2, the average annual production of reclaimed water is 81%. Up to the present (June 2007), 88% of all the reclaimed water produced has been used for aquifer recharge, whereas 11% has been discharged into the sea, and 1% has been used for agricultural irrigation (corn and ornamental plants). Since the latter will come into full operation this summer, this percentage is expected to increase slightly in the near future.

Table 1. Summary of the quality guidelines for aquifer recharge with reclaimed water through percolation, according to the Catalan Water Agency (ACA, 2007a) and the draft of the Spanish Ministry (Iglesias, 2005).

Parameter	Guidance limit ACA	Guidance limit draft Spanish Environment Ministry
Suspended solids, mg/L	< 10	< 35
Turbidity, NTU	< 2	No limit
E. coli, cfu/100 mL	< 200	< 1,000
Parasitic helminth eggs	< 1 / 10 L	No limit
TOC, mg/L	< 16	No limit
Total nitrogen, mg N/L	< 10	< 35
Total phosphorus	< 2	No limit

Table 2. Summary of reclaimed water production and its ultimate uses from January 2003 to May 2007.

Year	Production of secondary effluent (a) m^3	Production of reclaimed water m^3	Reclaimed water used for the recharge of the lower Tordera aquifer m^3	Reclaimed water discharged into the sea (b) m^3	Reclaimed water supplied for agricultural irrigation (c) m^3
2003	3,233,882	3,199,172	2,455,499	743,673	0
2004	4,228,059	3,298,460	2,984,787	313,673	0
2005	4,370,925	3,633,563	3,153,777	467,221	12,565
2006	4,321,968	3,154,593	3,018,385	91,503	44,705
2007 (Jan-May)	1,532,820	1,004,915	1,000,592	0	1,323
Total	17,687,654	14,290,703	12,613,040	1,616,070	58,593
Monthly Average	333,729	269,636	237,982	30,492	13,266
Annual Average	4,004,752	3,235,631	2,855,783	365,903	1,106
Percentages	-	81 (d)	88 (e)	11 (e)	1 (e)

(a) Secondary effluent not meeting the recharge criteria can be directly discharged into the sea. These volumes are the subtraction between the figures for the production of secondary effluent and the production of reclaimed water.
(b) Reclaimed water that did not meet any of the other recharge criteria, most likely related to nitrogen or phosphorus
(c) These figures are under-estimates, since the summer of 2007 will be the first with full irrigation.
(d) Reclaimed water production as a percentage of secondary effluent production
(e) Percentages of reclaimed water production

Monitoring

The Blanes reclamation plant was the first of its kind in Catalonia to produce reclaimed water for aquifer recharge. Therefore, the monitoring schemes were initially designed together with the

Health Department of the Catalan Government in order to cover all potential pollutants that it was suspected could be found in wastewater. The disinfection processes at the Blanes reclamation plant have also been the subject of applied research on the effect of the combination of disinfectant agents by a joint team of scientists from University of Barcelona and the Polytechnic University of Catalonia, and technicians from the operating company, Empresa Mixta d'Aigües de la Costa Brava SA, and the Consorci de la Costa Brava, under the supervision and approval of the Catalan Water Agency.

Routine monitoring. The performance of the Blanes reclamation plant is evaluated with the following frequencies and the following parameters to be analysed in the reclaimed water:

a. Daily: suspended solids (SS), turbidity, transmittance at 254nm, pH, electrical conductivity and total residual chlorine
b. Twice a week: *Escherichia coli*
c. Three times a week: NTK, ammonia, nitrite, nitrate and total phosphorus

Advanced monitoring. Beyond these routine parameters, the ACA arranged a second kind of monitoring on a monthly basis of several advanced chemical and microbiological parameters. Between January 2003 and February 2004, the chosen parameters were: colour, dissolved oxygen, cations and anions, heavy metals, organic pollutants, organochlorinated and organophosphate pesticides, polycyclic aromatic hydrocarbons (PAHs), faecal indicator microorganisms and parasitic helminth eggs.

A new advanced monitoring scheme was proposed to start on March 2004 and is still the one used as of today. In this new scheme, those parameters that can be affected by the reclamation process are analysed before (secondary effluent) and after (reclaimed water), whereas those that are not changed by the treatment and those that may be a result of the treatment are only analysed in the case of the reclaimed water. Parameters measured both in the secondary effluent and in the reclaimed water are: TOC, *E. coli*, spores of sulphite-reducing clostridia, somatic bacteriophages and *Legionella* (*Legionella* spp., *Legionella pneumophila* serotype 1 and *Legionella pneumophila* serotype 2-14), and those only measured in the reclaimed water are: main cations (calcium, magnesium, sodium, potassium) and anions (sulphate, chloride, bicarbonate), boron, iron, manganese, and trihalomethanes, including disinfection by-products.

RESULTS

The results of the routine monitoring are presented in Table 3 and they show a great overall stability in the quality of the reclaimed water throughout 53 consecutive months (from January 2003 to May 2007). Whereas the limit for suspended solids has been met at all times, turbidity and concentration of *E. coli* of the ACA guidelines are criteria that are harder to meet, especially at the higher end of the value distribution scale. Still, the maximum values for the concentration of *E. coli* compare favourably with those measured by the ACA in the Tordera river at Palafolls, near its mouth, which has a geometric mean of 8,200 cfu/100 mL from January 2003 to December 2006, according to the data available on ACA's website (ACA, 2007b). The nitrogen limit is always established on the percentile 90 criteria, whereas the phosphorus limit is established on the percentile 90 criteria over two full years (2004 and 2005) and on the first four months of 2007. Of all the results obtained during the advanced monitoring performed between January 2003 and February 2004, the most relevant ones were the following:

- Absence of colour in all the monthly samples but one (March 2003).
- Dissolved oxygen concentration has always been greater than 64% of saturation.

- Heavy metals, cyanides, phenols, hydrocarbons, organochlorinated and organophosphate pesticides, polycyclic aromatic hydrocarbons (PAHs) and parasitic helminth eggs were always below the detection level for the method used.
- The only detectable measure in the concentration of hydrocarbons gave a value of 118 mg/l corresponding to the sample of July 2003. It was considered to be non-representative, since the rest of the samples were below the detection level and no incidences were recorded on the WWTP when the sample was taken.
- Chloroform-extractable products were always below the detection level, except in the samples of January and February 2004, with values of 0.8 and 0.7 mg/L, respectively.
- Anionic detergents were always below the detection level, except in the sample of March 2003 (0.16 mg/L).
- A single positive sample was also found for mercury (0.002 mg/L, detection level) in March 2003, copper (0.06 mg/L), zinc (0.05 mg/L), faecal streptococci (3 cfu/100 mL) and *Salmonella* (presence), all of them corresponding to the sample of May 2003. Total and faecal coliforms could only be counted (up to 8 cfu/100 mL) in May and June 2003.

Table 3. Summary of the quality of the water produced at the Blanes reclamation plant between January 2003 and May 2007 according to the routine monitoring.

Parameter	Evolution of the quality of the water produced at the Blanes reclamation plant (a)				
	2003	2004	2005	2006	2007 (Jan-May)
Suspended solids, mg/l					
Average	2.0	1.5	1.7	1.8	1.9
Percentile 90	2.6	2.0	2.0	2.4	2.6
Range	0.2 - 5.6	0.3 – 3.8	0.4 – 3.0	0.2 – 4.8	0.6 – 4.4
Turbidity, NTU					
Average	1.7	1.5	1.7	1.8	1.7
Percentile 90	2.4	2.2	2.0	2.5	2.2
Range	0.3 - 4.9	0.5 – 3.8	0.7 – 3.7	0.8 – 5.7	0.8 – 3.5
Transmittance at 254 nm, %					
Average	71	74	75	72	71
Percentile 90	79	79	80	77	78
Range	55 - 93	58 - 84	63 – 87	58 - 83	58 - 83
pH					
Average	7.5	7.6	7.8	7.7	7.7
Percentile 90	7.7	7.7	8.0	7.9	7.9
Range	6.9 – 8.0	7.2 – 7.9	7.4 – 8.3	7.2 – 8.2	7.4 – 8.3
Electrical conductivity, dS/m					
Average	1.5	1.2	1.4	1.4	1.3
Percentile 90	1.8	1.6	1.6	1.5	1.4
Range	0.7 – 2.5	0.5 – 2.9	0.8 – 4.3	0.8 – 2.9	0.9– 1.7
Total nitrogen, mg N/L					
Average	8.7	8.5	8.2	7.1	7.9
Percentile 90	13.7	9.8	9.7	9.8	9.2
Range	2.7 – 19.3	4.9 – 11.0	4.0 – 10.5	1.6 – 15.0	4.9 – 12.0
Total phosphorus, mg P/L					
Average	1.4	1.4	1.4	1.6	1.2
Percentile 90	2.4	2.0	2.0	2.4	1.8
Range	0.3 – 5.3	0.2 – 2.0	0.4 – 2.0	0.4 – 2.8	0.4 – 4.0
Escherichia coli, cfu/100 mL					
Average	< 1	< 1	<1	< 2	< 2
Percentile 90	6	< 2	<1	< 4	< 2
Range	<1 - 124	< 1 -20	< 1 - 10	<1 - 98	<1 - 10

(a) Statistical data only of the water used for the recharge except for 2003, in which statistical data have been calculated with the whole annual set of data.

The monitoring scheme that started in March 2004 has given information not only on the general quality of the reclaimed water but also on how the reclamation treatment has changed its microbiological and chemical quality. In terms of TOC, virtually no changes are reported in the reclaimed water when compared to the secondary effluent due to the already high degree of oxidation achieved. *E.coli* inactivation has been stable around 4 log units and most of the samples in the reclaimed water have rendered undetectable colonies in 100 mL samples. For the two more resistant indicator microorganisms, *Clostridium* spores and somatic bacteriophages, inactivation rates have increased after the UV disinfection was set on operation. Average inactivation values have increased from 1.4 to 2.2 log units for the *Clostridium* spores and from 1.9 to 2.4 for somatic bacteriophages. *Legionella* analyses have shown the absence (<50 cfu/L) in 37 consecutive monthly samples of secondary effluent (from March 2004 to April 2007) for each of the tests performed (*Legionella* spp., *Legionella pneumophila* serotype 1 and *Legionella pneumophila* serotype 2-14), except for one sample, taken on Feb 26th, 2007, in which *Legionella* spp. analysis gave a count of 1,050 cfu/L. In reclaimed water all analyses (38 samples) showed the absence (<50 cfu/L) of all the forms of *Legionella* tested.

Trihalomethane (THM) monthly analysis has shown that attainable levels can consistently be lower than the requirements adopted by the Spanish drinking water regulations. Except for the peak measured in April 2004 due to the leakage of the chlorine storage tank into the reclaimed water tank and for two smaller peaks in September 2004 and February 2005, the rest of the values have been well below the limit of 100 µg/L of total THMs. The regular measure of this parameter has provided key information on how to achieve the desired disinfection levels without compromising public health due to the production of undesirable chemicals. Setting the UV disinfection on operation will also keep on preventing the formation of disinfection by-products in the future, thus ensuring an adequate quality in the reclaimed water either recharged or supplied for agricultural irrigation. Figure 1 shows the evolution of the concentration of total THMs from January 2004 to May 2007.

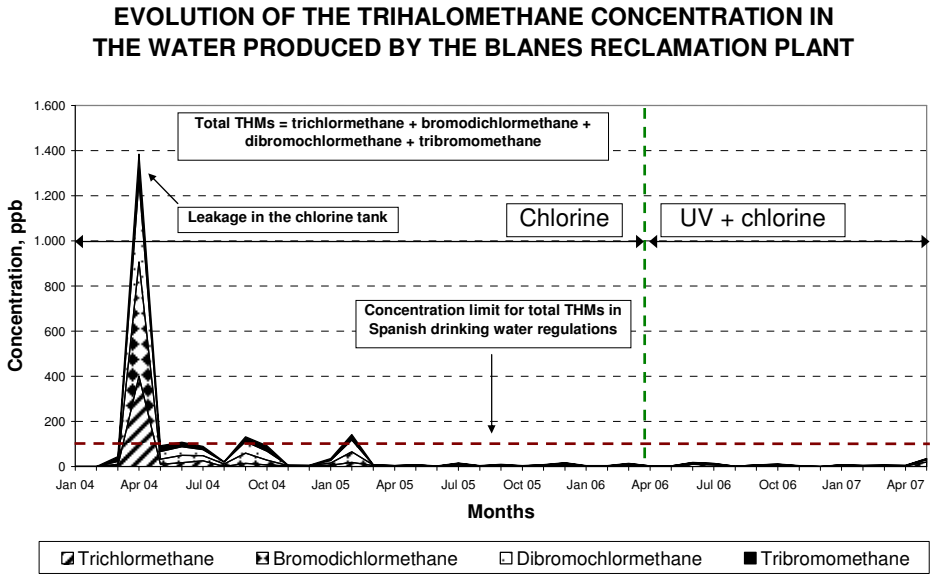

Figure 1 Evolution of the concentration of total THMs in the water produced by the Blanes reclamation plant from January 2004 to May 2007.

A detailed description of the parameters tested and the results of both advanced monitoring schemes between January 2003 and April 2006 can be found at Consorci de la Costa Brava (2006c).

COSTS

Capital costs of the construction of the Blanes reclamation facility in 2002 were 2,825,000 €. This facility was integrated in the Blanes WWTP, which, at the same time, is integrated in the larger structure of the O&M area of southern Costa Brava, operated by the Costa Brava Water Agency. This has allowed for an important limitation of costs, since the O&M tasks related to the reclamation plant have been able to benefit from the already existing technical, maintenance and laboratory staff, and the real costs have mainly been associated with the direct operational costs of the new facility. Table 4 presents the breakdown of these operational costs of the Blanes water reclamation plant between 2003 and 2006 and shows that the relative cost is kept below 0.06 €/m^3, a very acceptable cost for the production of new water resources in the area.

Table 4. Summary of the volumes produced and the direct operational costs of the Blanes water reclamation plant between 2003 and 2006.

Year	Production reclaimed water, m^3	Total cost, €					Relative cost €/m^3
		Chemicals	Energy	Analysis	Lamp replacement	Total	
2003	3,199,172	108,343	37,213	12,405	0	157,961	0.049
2004	3,298,460	124,167	40,235	9,006	0	173,408	0.053
2005	3,633,563	132,897	41,793	9,388	0	184,077	0.051
2006	3,154,593	115,143	44,607	9,717	6,877	176,344	0.056

CONCLUSIONS

Between January 2003 and May 2007, the Blanes reclamation plant has produced 14.3 hm^3 of reclaimed water, of which almost 12.6 hm^3 have been used for the recharge of the lower Tordera aquifer (88%). The routine monitoring has shown that the quality of the reclaimed water has been consistent throughout the period and levels of the different parameters have been acceptable for the recharge during most of the time. When not, either secondary effluent or reclaimed water have been discharged into the sea through a submarine outfall.

The first advanced monitoring scheme was useful in proving that heavy metals, cyanides, phenols, hydrocarbons (with the exception of one possible false positive sample), organochlorinated and organophosphate pesticides, polycyclic aromatic hydrocarbons (PAHs) and parasitic helminth eggs were always below the detection level of the method used. Almost all samples also had undetectable levels of chloroform-extractable compounds except for two of them, and of anionic detergents, copper, zinc and mercury, except for one; these positive samples were always very near the detection level.

The second advanced monitoring scheme was instrumental in proving that there are virtually no changes in TOC concentration between secondary effluent and reclaimed water; that *E. coli* inactivation is complete and consistently reaches 4 log units; and that *Clostridium* spores and somatic bacteriophages are inactivated in an similar average proportion, 2.2 and 2.4 log units. All the Legionella tests performed (*Legionella* spp., *Legionella pneumophila* serotype 1 and *Legionella pneumophila* serotype 2-14) have shown the absence (< 50 cfu/L) in 38 consecutive monthly samples of reclaimed water and in 37 of secondary effluent. Trihalomethanes have also been measured and their formation has been minimized, being currently well below the limit imposed by Spanish drinking water regulations. All these studies have been carried out with the agreement of, and under the supervision of, the Health Department of the Catalan Government and the Catalan

Water Agency, and applied research on the combined use of disinfectant agents has been performed by a joint team bringing together the University of Barcelona, the Polytechnic University of Catalonia, the Empresa Mixta d'Aigües de la Costa Brava SA and the Consorci de la Costa Brava.

Capital costs of the construction of the Blanes reclamation facility accounted for € 2,825,000. It has been integrated into the O&M structure of the southern Costa Brava in order to keep the running costs low. Calculations of the direct operational costs of the Blanes reclamation plant give a relative cost below 0.06 €/m^3.

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