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Drinking water supply by reverse osmosis plants: three years of experience at El Prat de Llobregat Municipality

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ABSTRACT

Deep coastal aquifer of Llobregat delta constitutes the main source of drinking water supply to El Prat de Llobregat municipality (64,000 inhabitants) near Barcelona (Spain). Since 70s this aquifer initiates a gradual salinization process by seawater intrusion, magnified by an exhaustive and not ordered water extraction. Also, aquifer pollution by volatile organic compounds (trichloroethylene and tetrachloroethylene) appeared in 90s. In order to remove groundwater pollution, three air stripping plants were built 15 years ago. When groundwater salinity achieved non-drinking water standards, two water treatment plants (Sagnier WTP and Mas Blau WTP) were built using reverse osmosis technology. Both WTPs by RO has a pre-treatment based in volatile organic compounds removal by air stripping, in-line coagulation (only for one WTP), multimedia filtration, cartridge filtration and scaling inhibitor dosage. Chlorination and dechlorination is available but it is not used. Each WTP has two RO lines with two stages and 75% recovery design. As energy recovery device, Turbo Charger is working as booster pump between first and second stage. Drinking water quality according to Spanish regulations is achieved using filtered water by-pass blend and postchlorination before distribution tank. Operation and maintenance aspects are monitored using supervisory control and data acquisition register and remote/local control by O&M team of Aigües del Prat (public company). Water quality (raw water, filtered water, RO feed, permeate, blend, distribution tank and point of use) is monitored daily by Aigües del Prat laboratory (accredited under ISO 17025) according to drinking water Spanish regulations and municipality health criteria. Since January 2009, Aigües del Prat produces without interruption the 90% of drinking water of El Prat municipality using RO plants. This paper presents the experience acquired on operation and maintenance, reliability, drinking water quality distributed control, groundwater quality evolution, network changes and public perception.

Keywords: Drinking water; Groundwater; Reverse osmosis; Seawater intrusion

1. Introduction

More than a century ago, deep groundwater aquifer of the Llobregat river delta was discovered, in the municipality of El Prat de Llobregat (Fig. 1). This deep aquifer is the basic resource for drinking water supply of the municipality, being the only municipality in the metropolitan area of Barcelona, with 64,000 inhabitants, which has a system of wells in the same municipality. Economic development of this municipality

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Fig. 1. El Prat de Llobregat.

from industrial, agricultural or social point of view has been always associated to the availability of deep aquifer resource.

Aquifer pollution by volatile organic compounds like trichloroethylene (TCE) and tetrachloroethylene (PCE) was the first water quality problem detected in the wells used to produce drinking water. Three air stripping plants were built during 1997 to remove these compounds. On the other hand, the construction of the new dock of Barcelona promoted a gradual process of aquifer salinization by seawater intrusion and it was increased by exhaustive and not ordered groundwater uses. Ten years after volatile organic compounds episode, seawater intrusion level obligated to build two drinking water treatment plants (WTPs) to produce drinking water according to Spanish regulations (Fig. 2). Reverse osmosis plants were built during 2008 by Aigües del Ter-Llobregat (ATLL). Since January 2009, Aigües del Prat, a public company, produces without interruption close to 90% of drinking water demanded by El Prat de Llobregat municipality.

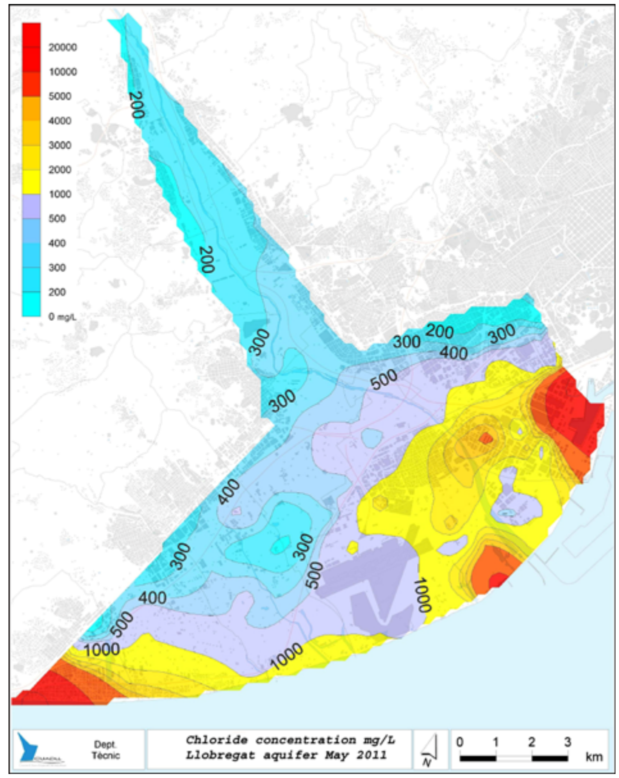

Fig. 2. Llobregat aquifer: seawater intrusion monitored by chloride concentration distribution (May 2011).

Fig. 3. RO skid at Sagnier WTP.

2. Water treatment plants

Two WTPs were built: Sagnier WTP and Mas Blau WTP. Both WTPs use reverse osmosis technology and each one is capable of producing up to 8,000 m^3/day. Each plant has two RO lines with identical configuration (Fig. 3). RO design was two stages configuration (18:9, 6 elements pressure vessels) with a recovery of 75%. RO membranes selected were DOW FilmTec LE-440i. Colloidal quality of groundwater (SDI lower than 3, 100% of samples) allowed RO pretreatment using only multimedia filtration step after air stripping. Sometimes well water presents some colloidal iron, but SDI was lower than three. In these cases, organic coagulant was dosed before filtration to remove colloidal iron. To prevent scaling, a phosphonate-based antiscalant is dosed. Permeate was blended with filtered water to obtain a drinking water quality according Spanish regulation. To achieve this quality, Sagnier WTP has a filtered water by-pass of 10–12%, and Mas Blau 24–26%. Air-stripping is used only at

Fig. 4. Turbo Charger between stages.

Mas Blau WTP, because TCE and PCE concentrations were higher than 10 μg/L.

In order to reduce energy consumption, each RO system included a Turbo Charger between stages working like a booster pump (Fig. 4). Turbo Charger increased second-stage feed pressure 4 bar.

2.1. *Raw water quality*

Raw water conductivity was monitored because seawater intrusion phenomena could change values used for RO design. Each WTP used three wells: two wells to feed RO systems and one in stand-by. Sagnier WTP used wells number 8, 12, and 17. Well 8 increased its conductivity above 10,000 μS/cm and were closed during the first year of plant operation. Wells 12 and 17 presented opposite conductivity trends. After plant commissioning, average raw water conductivity increased at Sagnier WTP (Fig. 5).

Mas Blau WTP used wells number 14, 15, and 16. Raw water conductivity was lower than Sagnier because seawater intrusion phenomena were less important, but volatile organic concentration was higher than Spanish regulation. After commissioning, raw water conductivity increased but quickly was stabilized. Because this plant works practically always (24 h/day), well's conductivity records presented variations between stand-by and production status (Fig. 6).

3. Reliability and performance

After commissioning, Aigües del Prat operated both facilities with wells and distribution system. Since January 2009 (Sagnier WTP) and February 2009

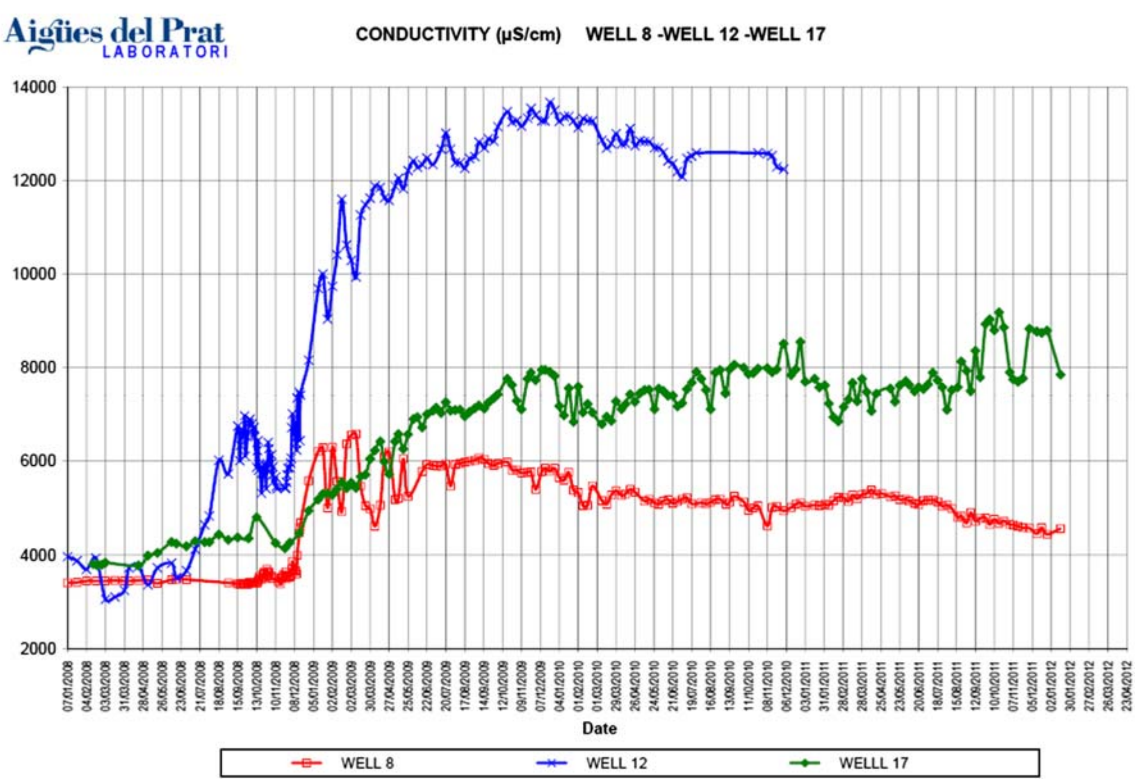

Fig. 5. Raw water conductivity evolution at Sagnier WTP.

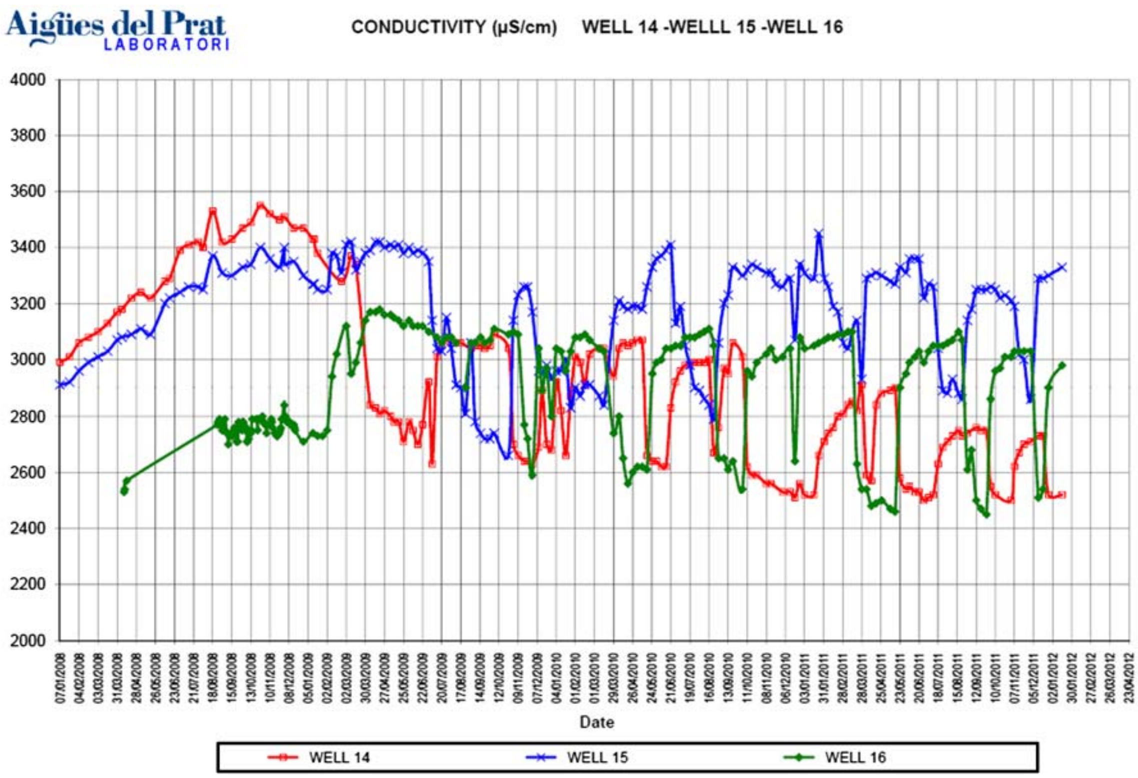

Fig. 6. Raw water conductivity evolution at Mas Blau WTP.

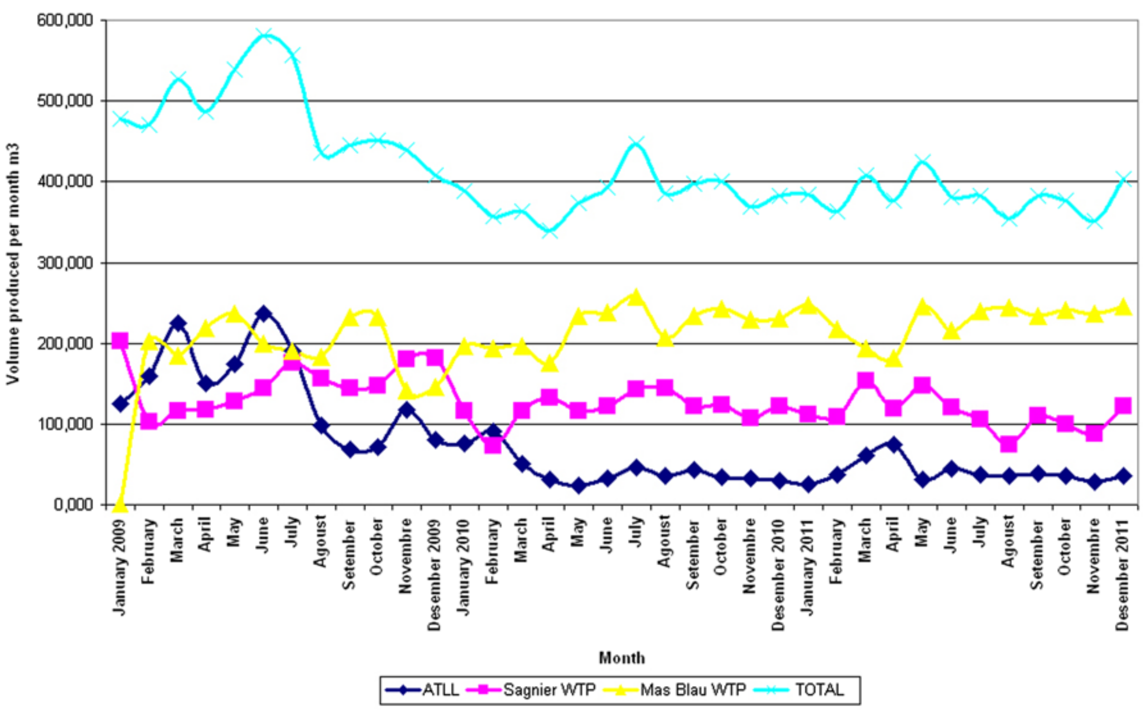

Fig. 7. Monthly water produced by Sagnier and Mas Blau WTP and external resource (ATLL).

(Mas Blau WTP) water consumption depends on reliability of desalination process. During 2009 there were some problems with distribution systems. Pipe lines failures obligated WTP to close during pipe replacement and buy more water to external resource (ATLL). A network improvement was done during this first year in order to achieve WTP maximum production capacity by Aigües del Prat. Year 2010 and 2011 presented a good stability of water produced. Fig. 7 shows evolution of water production and external resources (ATLL).

Also, water leakage in the pipe line caused the first year an overproduction. First year annual average production was around 26% higher than second and third year (Table 1). After 2009, water from desalination facilities was around 90% of total water demanded. Economical and technical reasons (fixed cost ATLL contract; different pressure pipe lines) obligated to maintain external resource (ATLL) close to 5% minimum. In these conditions, practically all supplied water of municipality was from desalination plants.

About RO maintenance, after commissioning only one preventive cleaning per year has been done. During commissioning there was a failure of scale inhibitor dosage at Sagnier WTP. Calcium sulfate scaling was observed in the second stage of both RO lines. According DOW instructions, specific cleaning (EDTA,

Table 1
Source distribution of drinking water supply. Period 2009–2011

Source	2009	2010	2011
ATLL (%)	29.2	11.4	10.6
Sagnier WTP (%)	30.9	31.3	29.7
Mas Blau WTP (%)	37.3	57.3	59.7
Sagnier & Mas Blau (%)	68.2	88.6	89.4
Wells (%) only first year	2.7	0	0
Annual average (m^3/day)	15,937	12,595	12,572

Table 2
Operation and maintenance costs during 2010

	Sagnier WTP	Mas Blau WTP	Both WTP
Concept during 2010	Cost, €/m^3	Cost, €/m^3	Cost, €/m^3
Energy	0.172	0.121	0.139
Reagents and replacement	0.055	0.041	0.046
Labor	0.052	0.028	0.037
Quality control	0.065	0.065	0.065
Depreciation	0.139	0.076	0.098
Others	0.011	0.011	0.011
Total cost	0.494	0.342	0.396

Table 3
Operation and maintenance costs during 2011

	Sagnier WTP	Mas Blau WTP	Both WTP
Concept during 2011	Cost, €/m^3	Cost, €/m^3	Cost, €/m^3
Energy	0.154	0.118	0.130
Reagents and replacement	0.081	0.050	0.060
Labor	0.055	0.027	0.037
Quality control	0.065	0.065	0.065
Depreciation	0.147	0.073	0.097
Others	0.011	0.011	0.011
Total cost	0.513	0.345	0.401

Table 4
Specific energy consumption during the period 2009–2011

Year	Sagnier WTP. Energy (kWh/m^3)	Mas Blau WTP. Energy (kWh/m^3)
2009	1.25	0.86
2010	1.19	0.92
2011	1.22	0.92

Table 5
Water quality indicators after Sagnier WTP (network samples)

Sagnier WTP	Conductivity (µS/cm)	THMs (µg/L)	TCE + PCE (µg/L)	TOC (µg/L)
Number of analysis	20	36	61	58
Minimum	1,041	1.3	0.4	0.2
Maximum	1,203	19	2.3	0.6
50th Percentile	1,079	4.1	1.2	0.2
95th Percentile	1,155	19	2.0	0.34

Table 6
Water quality indicators after Mas Blau WTP (network samples)

Mas Blau WTP	Conductivity (µS/cm)	THMs (µg/L)	TCE + PCE (µg/L)	TOC (µg/L)
Number of analysis	20	35	52	57
Minimum	1,025	1.3	1.5	0.2
Maximum	1,204	19	8.5	1.0
50th Percentile	1,065	6.6	3.5	0.3
95th Percentile	1,181	19	6.8	0.54

sodium hydroxide, and sodium chloride, pH 12, 30˚C) was applied in order to disperse sulfate scaling and recover performance. Turbo Charger had no failures or special maintenance works.

Operation and maintenance team monitored performance using the RO data normalization. Normalization was done by means FTNORM software from DOW. After three years, normalized permeate flow, salt passage and differential pressure have been practically without variation. These results are consequence of good Llobregat groundwater quality.

4. Economical aspects

The water desalination project of El Prat de Llobregat required an investment of 6.3 million Euros. European Union contributed with 80% using Cohesion Funds, and the remaining 20% were provided by ATLL.

During the first year of operation (2009) water network was improved in order to decrease water losses changing older pipe lines and to reduce RO overproduction consequence of leakages. Water network efficiency increased from 67% in 2009 to 82% in 2010 and 79% in 2011. Because of that, the economical analysis was not representative for this first year of operation. After water network improvements, it was possible to calculate correctly the operation and maintenance costs during the years 2010 and 2011. Total operation and maintenance cost (including wells pumps, RO plant, and network pump station) during the years 2010 and 2011, respectively, is shown in Tables 2 and 3. Both years show similar total cost around 0.40 €/m^3.

Specific energy consumption was recorded since 2009. These values included wells, RO plant and distribution system pump station (Table 4). Difference between Sagnier and Mas Blau WTPs was consequence of different well water salinity.

5. Drinking water quality at network

In the practice, water quality goal was to maintain conductivity at point of use close to 1,100 µS/cm

Fig. 8. Public information program: Water Weekend, "Aigua del Prat" commemorative bottle and flyers.

blending RO permeate and filtered water by PID control loop. Three parameters were selected as water chemical quality indicators: trihalomethanes (THMs), volatile organic compound (TCE + PCE), and total organic carbon (TOC). Tables 5 and 6 show monthly results of analysis for these parameters. THMs value was very low as a consequence of low TOC achieved in RO permeate water and bromide removal.

Water quality control by Aigües del Prat laboratory included all parameters according Spanish regulation (RD 140/2003), with weekly and monthly frequency. Wells, RO systems, blend and points of use were monitored.

6. Public perception

Aesthetic water quality concerning chloride and hardness had deteriorated before the production of drinking water from desalination plants. The Municipal Council and Aigües del Prat prepared a very strong public information program (see Fig. 8) in order to explain to citizens the water quality improvement using the slogan "2009 is the year of the change of water". Text prepared in a letter distributed to all citizens was:

> As you know, Aigües del Prat has worked in recent years to improve the quality of the water in the municipality. These improvements have been achieved thanks to two new treatment plants using reverse osmosis have allowed to reduce salinity and hardness characteristics of drinking water. To celebrate the arrival of the new water to the city, we invite you to the "water weekend where you will find all the information about the new water and the benefits will be for citizenship. In addition, if you bring the coupon of change that I attached, you will get the bottle of the new water "Aigua del Prat"! I if you can not come to the "water weekend", you can collect your bottle from March 10th to April 10th in the other distribution points that we indicated you! I hope the 7 and 8 March at the water weekend!.

Also, this program included radio interviews, flyers, video available on the Internet, and articles in local press (magazines and newspapers). After commissioning of facilities, reclaims from citizen about aesthetic characteristics of drinking water, or household goods problems disappeared.

7. Conclusions

Aigües del Prat produces drinking water from Llobregat aquifer using two reverse osmosis facilities since 2009. After three years of operation and maintenance Aigües del Prat presents in this paper the experience on operation and maintenance, performance and reliability, drinking water quality obtained and public perception.

After three years of operation the two facilities supply close to 90% of drinking water of municipality without shut-off. RO systems only need one preventive cleaning per year according membrane manufacturer recommendations. Turbo Charger had no failures or special maintenance works.

Total operation and maintenance cost is in average 0.40 €/m^3. Sagnier WTP cost, with more raw water conductivity than Mas Blau WTP, is 0.34 €/m^3 and Mas Blau WTP cost is 0.49–0.51 €/m^3. Sagnier and Mas Blau specific energy consumption is 1.22 and

0.92 kWh/m^3, respectively. Total cost and specific energy consumption includes all equipments from aquifer to drinking water distribution system.

Desalination process achieves drinking water quality according Spanish regulations. Three chemicals parameters were monitored as indicators: THMs, volatile organic compounds (TCE + PCE), and TOC. After blending RO permeate and filtered water to obtain drinking water, THMs percentile 95th were 19 μg/L (both facilities); TCE + PCE percentile 95th were 2.0 μg/L (Sagnier WTP) and 6.8 μg/L (Mas Blau WTP); and TOC percentile 95th were 0.34 μg/L (Sagnier WTP) and 0.54 μg/L (Mas Blau WTP).

Municipal Council and public company Aigües del Prat designed a public information program promoting the public knowledge and perception of the change of water. They explain to citizens the water improvement sending letters by postal mail, radio interviews, local press and creating the "Water Weekend" and offering a commemorative bottle "Aigua del Prat" with drinking water from RO facilities.

During the three years of drinking water production, reclaims from citizen about aesthetic characteristics of drinking water, or household goods problems disappeared.