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BEHAVIOUR OF CONTAMINANTS AFTER INJECTION OF TREATED URBAN WASTE WATER IN A WELL

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ABSTRACT

In a two months test, about 25 l/s of secondary treated urban sewage water were introduced into a well, in a coarse sand and gravel confined aquifer in the small Besós river delta (Barcelona, Spain). It contains 80 percent sea water, in a reducing environment. Four observation wells were drilled in order to monitor the breakthrough of the injected water. Natural flow velocity in the aquifer was about 3 m/day, disturbing the radial flow around the injection well. Thus the travel time and the breakthrough of the injected water depends on the orientation of the borehole. The fresh water was dragged along by the groundwater flow, and no stable fresh water was formed. There were some initial decrease in hardness and an increase in sodium. Ammonia is delayed but the retention capacity is soon saturated. Phosphorus is eliminated. Some iron can be dissolved. No destruction of organic matter was observed. The injected chlorine favored ground chromium dissolution. Bacteria traveled more than 12 metres, but probably not more than 30 metres.

INTRODUCTION

The area of Barcelona, on the Spanish NE Mediterranean coast, foresees future water supply problems. A detailed study to evaluate the sewage water potential for reuse was launched in 1975 by the Comisaría de Aguas del Pirineo Oriental (Eastern Pyrenees Water Agency) and the Municipality of Barcelona (ref. 3).

It included a pilot treatment plant for the sewage water of the Riera d'Horta-Besós (Prim) trunk and an experimental recharge test well, constructed and operated following the experience gained in some fresh water recharge wells in the area (ref. 2).

Although a much longer series of tests was foreseen, at the last moment some insoluble cash and labor problems appeared, and only a two month first phase of recharge could be completed.

The purpose of this paper is to present the relevant results concerning the injected water quality behaviour in the aquifer. Thus, other aspects such as the recharge hydraulics , well clogging rate, recharge water travel time, well operation procedure, etc., are not considered here. Only preliminary data are presented, since the final report is under way.

THE RECHARGE TEST

The recharge site and facilities

The recharge aquifer is the lower permeable unit of the Besós river delta, a 10 m thick layer of coarse fluviatile sand and gravel, including some cobbles and fine sand lenses, confined by clay and silt between 40 and 50 m. It is extensively exploited for industrial purposes. The sea water encroaches the aquifer and reaches some of the abstraction centers (ref. 1). Along the coast, a landward flow of salt water is clearly noticeable. It penetrates through the sea floor, where organic mud deposits probably explains the reducing groundwater environment.

Pumping, tracer and piezometric tests yield an aquifer transmissivity of 3600 m^2/day, with a storage coefficient of 2.10-4. The mean permeability is 300 m/day with a maximum value of 500 m/day. The tidal efficiency is 0.22. The overlying confining layer presents a vertical permeability of about 2.10^{-4} m/day (ref. 1).

Close to the shore, a 950 mm diameter recharge well was constructed and fitted with a 18 % open area slotted screen. Four observation wells were drilled at distances from the well of 4 m to the SE (P-1), 12 m to the NW (P-2), 30 m to the NE (P-3) and 140 m to the WNW (P-4). All of them fully penetrated the aquifer. The recharge well had permanently installed a 90 l/s pump and the four observation wells were fitted with small membrane pumps to allow for continuous water sampling.

At 480 m to the WNW, some industrial wells extracting about 150 l/s, created a pumping drawdown cone that dominated the local groundwater flow at the recharge site. Thus, the recharged water did not move radially out of the recharge well. Observation borehole P-1 was almost unaffected, but the injected water was dragged toward the P-2 and P-4 boreholes. The borehole P-3 was at right angles to the flow and only a fraction of the injected water could reach it.

Dilution radioactive tracer tests showed a groundwater flow velocity (darcy velocity) of 3 m/day. The induced fresh water body was unstable since it was displaced from the recharge well surroundings in a few days.

The recharge was performed by gravity injection of 25 l/s of water from the 16th October to the 17th December, 1977. The well was backpumped periodically to restore as much as possible the injection capacity. The chlorine added to the recharge water was a key factor in the retardation of irreversible clogging. A major interruption in the recharge occurred from 21 to 25 November in order to test the well and reduce the clogging by overchlorination.

About 325 water samples were analysed, each including 20 to 30 determinations.

Characteristics of the native groundwater and the injection water

The local groundwater around the injection well is highly saline and represents a mixture of fresh water with 75-80% sea water. There is a slight dilution toward the pumping center, and this effect must be born in mind when computing the mixture with the injected water. The characteristics of the native groundwater around the injection well is shown in table 1. There is a reducing environment and a high iron and manganese content. The nitrogen compounds are almost absent.

TABLE 1

Characteristics of the native groundwater near the injection well and the recharge water during the injection test

Characteristic	Units	Native groundwater	Recharge water	
			Mean (1st month)	extremes
Temperature	^{o}C	17		
pH	units	6.7-7.0	7.9	7.8-8.2
Elec. cond. $25^{o}C$	mS/cm	38-44	2.1	1.2-2.6
Total hardness	g/l $CaCO_3$	6.7-6.9	0.49	0.3-0.6
HCO_3^-	mg/l	$\sim$260	390	250-460
SO_4^{-2}	mg/l	1850	190	140-210
Cl^-	g/l	16-17	0.46	0.16-0.65
Na^+	g/l	8.4-8.5	0.30	0.13-0.37
K^+	mg/l	95-125	26	20-30
Ca^{+2}	mg/l	760	140	80-160
Mg^{+2}	g/l	1.1-1.2	0.04	0.01-0.05
Ammonia	mg/l NH_4^+	$<$0.5	31	20-55
NO_3^-	mg/l	$<$0.1	$<$0.1	$<$0.1
NO_2^-	mg/l	$<$0.01	2.3	$<$0.1-2.5
Dissolved O_2	mg/l O_2	1.0-2.0	(6)	(5)-(7)
Phosphorus	mg/l PO_4^{-3}	$\sim$0.03	1.7	1.5-2.7
Total Fe	mg/l	8-20	0.1	0.06-0.2
Total Mn	mg/l	$\sim$0.2	$<$ 0.05	$<$0.05
ABS detergents	mg/l	$<$0.05	1.0	0.1-5
COD($KMnO_4$ value)	mg/l O_2	$<$ 1	19	16-23
Suspended matter	mg/l	0.0	10	4-20
Color	mg/l Pt	0.0	-	15-45
Total coliforms	in 100 ml	$<$ 30	-	$\leq$ 300-460000
Fecal streptococci	in 100 ml	$<$30	-	$\leq$ 30-23000
Fecal coliforms	in 100 ml	$<$30	-	$\leq$ 300-460000

Both in the native groundwater and in the recharge water, phenols, cadmium, zinc, copper, chromium and nickel were absent, and sulphides only appeared sometimes in very small quantities in the groundwater.

The raw recharge water is mainly domestic sewage, although some industrial sewage is incorporated and sometimes oils, toxics and saline water are poured into . The chemical characteristics are variable. This water was treated with lime, and then aerated to start and maintain a biological process with sludge recirculation. After clarification the water went to the recharge site, where it was pressure filtered and chrorinated just before the injection, in ammounts between 10 and 60 mg/l (the breakpoint was 150-200 mg/l Cl_2), although in a some periods the chlorine was not added. Table 1 shows the quality of the injected water. There were a trend to decrease the water salinity and to increase the ammonia content and pH. Although the $N\text{-}NO_2^-$ content was low, high values could be found sometimes.

RESULTS

Movement of the injected water

Since the chloride ion is not modified, the injected water movement can be shown by the chloride breakthrough curves in the observation boreholes (fig. 1). Since its content in the recharge water was variable, the final part of the curves are poorly defined. Some simplified results are:

Borehole	Distance m	Chloride arrival, days 50% mixture	Extremes	Observations
P-1	4 SE	0.018	0.016-1.5	No residual salinity
P-2	12 NW	1.0	0.3-14	Some small residual salinity
P-3	30 NE	-	4-20	Only a mixture is possible
P-4	140 WNW	52	25- ?	No full breakthrough

For a 25 l/s recharge flow, borehole P-3 reached a steady state when a 45% fresh water mixture was attained, due to its location at right angles to the groundwater flow. That figure is very sensible to changes in the hydraulic conditions.

Major ions

The HCO_3 and SO_4 ions behave almost identically as the Cl ion. The pH changes in the recharge water were transmited through the aquifer to the P-1 and P-2 boreholes. The other major ions parallel the chloride behaviour in borehole P-1, but show small differences in the P-2 and P-4 (fig. 2). No definite conclusions can be drawn from P-3. The interpretation of figure 2 must consider that, but for the NH_4^+ , all the shown ions are more abundant in the native groundwater. They are delayed when in greater relative concentration than Cl^- through ion exchange, as can be easily shown by means of ionic balances. NH_4^+ was strongly adsorbed; in figure 2 its concentration is reduced since it is more abundant in the recharge water. For more than 20% mixtures, hardness was decreassed, the effect beeing more accentuated for Ca^{+2}, and Na^+ was conversely increased in the same equivalent quantity. K^+ was almost unchanged. These major ion changes are of little importance and in P-2 a a tendency to saturation was apparent after 20 days.

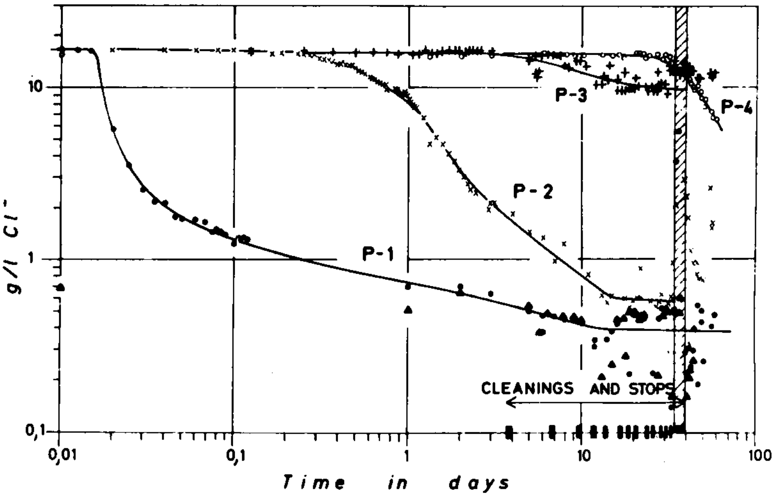

Fig. 1. Breakthrough curves for the chloride ion. Rechage interruptions for well back pumping or for major tests are shown. P-1 is at 4m upflow, P-2 and P-4 at 12m and 140m downflow, and P-3 at 30m at right angles to the groundwater flow.

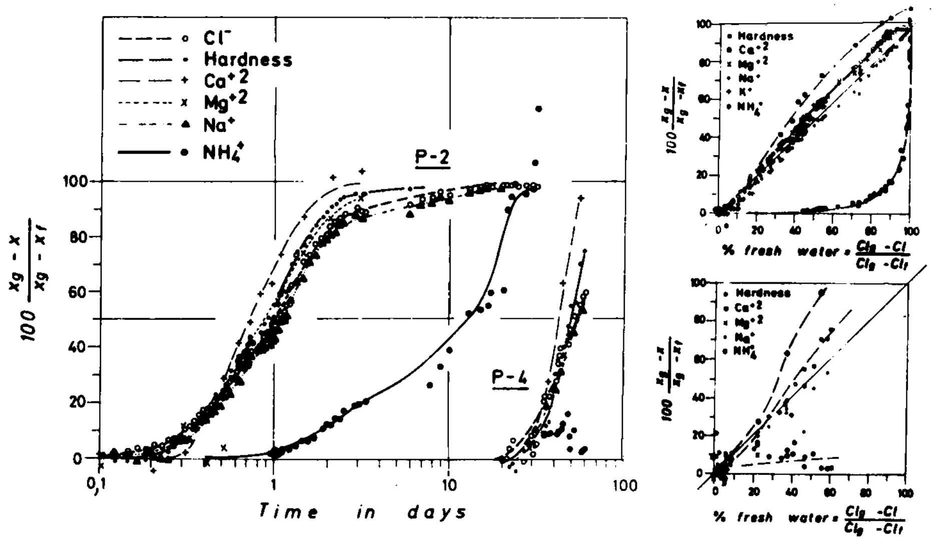

Fig. 2. The value $100(x_g-x)/(x_g-x_f)$ represents the percentage of the shown ions in the mixture (x), relative to the recharge water (x_f), beein the other extreme the native groundwater (x_g). In the left side relative breakthrough curves for P-2 and P-4 boreholes are plotted against the time and in the right side the same values are plotted against the porcentage of recharge water as deduced from the chloride (Cl) content for P-2 (upper) and P-4 (down) boreholes.

Nitrogen and phosphorus components

Almost all the available nitrogen was in ammonia from, the nitrate being always absent. Until borehole P-1, the NH_4^+ behaved as the Cl^- did, but when the travel distance increased it was greatly delayed (fig. 2), although finally it reached its full value (P-2). This occurs probably when the available ion exchange capacity of the aquifer was saturated. Travel time to P-2 borehole was 13 hours (13 times), and the maximum NH_4^+ deficit was produced at 3 hours (3 times). Preliminary calculations give a retention of 23 g NH_4/m^3 of aquifer volume, or 230 g NH_4/m^2 of aquifer surface.

The introduced N-NO_2^- reached unchanged the P-1 borehole. About a 4 times decrease was found at P-2, but after an interruption in Cl_2 addition (10th November), it desappeared, possibly due to the definitive reestablishment of the reducing environment. No NO_2^- could be found at P-3 and P-4 boreholes. When NO_2^- concentration increased there was a decrease in Fe.

Phosphates reached unchanged borehole P-1, but beyond that point no phosphorus compounds could be found.

Other characteristics and contaminants

Some of the dissolved oxygen in the recharge water reached P-1 but it did not penetrate further. Some residual chlorine reached borehole P-1 and P-2, in small concentrations, but it did not penetrate further.

In borehole P-1 the injected water did not incorporate iron, but after some weeks, in P-2 the iron concentration was greater than that corresponding to a simple mixture, especially when chlorine addition to the recharge water failed. Since no significant changes were observed in P-3 and P-4, it implied iron solution. Manganese seems to behave similarly.

The high variability in detergent concentrations in recharge water introduce some uncertainties in the results, but it seems that it was conserved through the aquifer.

No sulphides, phenols and heavy metals appeared, except for the chromium in borehole P-2, since during the first recharge day some samples reached 1 mg/l, mainly in hexavalent form. The origen is not clear since it was detected neither in the natural aquifer water nor in the recharge water. Since some chromium oxides could be deposited in the ground after an old chromium contamination of the aquifer, that still persists in other areas, it may dissolve as a result of the residual chlorine action.

The difficulties in measuring the chemical oxygen demand (COD) in saline water and the impossibility of processing a high number of samples for biological oxygen demand, precluded the control of these two values. No organic matter oxidation was appreciated, since the HCO_3^- content did not increase. The way the organic matter may be transformed is not known.

A pale yellow-green color was observed in the water from borehole P-1, but it was diluted in P-2 and imperceptible in the P-3 and P-4.

Bacterial counts

No increase in background bacterial counts could be found in borehole P-3 and P-4, but P-1 and P-2 showed very high figures. The scarce available data does not allow accurate conclusions, but it seems that until P-2 the fecal streptococci, total coliforms and fecal coliforms were conserved without modification when non chlorinated water was introduced, but they only appear in high counts in P-2 when sterilised chlorinated water was injected.

CONCLUSIONS

Fresh water storage into a saltwater aquifer is highly affected by the groundwater flow.

In a sand and gravel aquifer with a reducing environment some changes in the water chemistry occur when treated waste water is injected, with no significant destruction of organic matter, though the ammonia is absorbed until the terrain capacity is saturated, and the phosphorus compounds are eliminated. Introduced bacteria can travel 12 m but probably cannot reach a 30 m distance. Chlorine can oxidize some heavy metals trapped in the terrain.

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