CONCEPT FOR DEVELOPMENT OF SUSTAINABLE DRINKING-WATER PRODUCTION IN THE FLEMISH COASTAL PLAIN BASED ON INTEGRATED WATER MANAGEMENT

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INTRODUCTION

More than 10 years of research, starting with geological and hydro geological survey (Zeuwts, 1991) over pumping tests (Lebbe et al., 1995 and 1996) and pilot tests for treatment of the extracted water (Van Houtte et al., 1998 and 2001), showed that sustainable drinking-water production in the Avekapelle creek ridge is feasible and could in the long-term be an alternative for the existing dune water extraction.

Under the sandy Avekapelle creek ridge, situated in the polder area south of the Flemish dunes, fresh water appears in the upper part of the unconfined aquifer and salt water in the bottom part. The Kromme Gracht and Oude A-vaart, situated respectively in the west and east of the creek ridge, drain huge amounts of fresh to brackish drainage water out of the polder area to the sea. This water could be reused: alongside an infiltration canal, that could run from west to east over the creek ridge, the drainage water could be recaptured after a soil passage. In dryer periods and summer, when drainage water is not available, wastewater effluent could refill this canal.

This paper summarises research and proposes a concept for a sustainable water production in this area based on integrated water management. The treatment of the extracted water would be based on membrane filtration techniques.

This concept of water reuse combined to aquifer recharge, could be used in many regions all over the world and could resolve problems of water scarcity and aquifer pollution.

PRELIMINARY HYDROGEOLOGIC SURVEY IN AND AROUND AVEKAPELLE CREEK RIDGE (1985- 1991)

In the western part of the Flemish coastal plain Quaternary sediments lay on top of 100 to 110 m thick Tertiary clay, called the Ypresian clay. During the 1970s and early 1980s many studies were performed in the dune part of this area where fresh water was present. However little was known about the hydrogeology of the areas south of these dunes. Zeuwts (1991) performed a hydrogeological survey of this so called ‘polder area’ where two geomorphologic units could be distinguished: the more elevated sandy creek ridges (+3,5 to +5) and the lower marsh basins (+2,5 to 4). This ‘polder area’ is drained by canals. Especially during winter periods large amounts of water are drained to the sea.

In the ‘polder area’ fresh water filled the upper and relict salt water the lower part of the unconfined aquifer. A small transition zone of brackish water lies in between. In comparison with the marsh basins the amounts of fresh water is higher under the creek ridges. This is in the first place due to the higher hydraulic conductivity of the Quaternary sediments on the creek ridges and in the second place due to the more intensive drainage in the marsh basins.

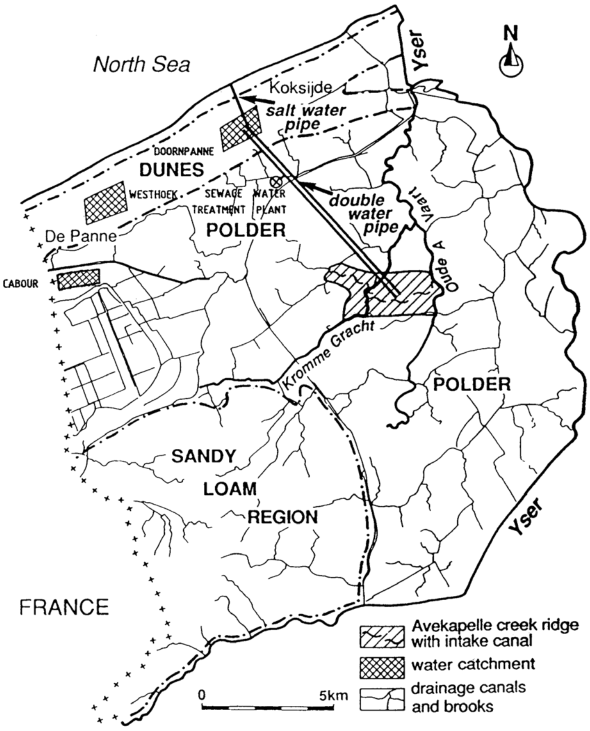

***Figure 1** Situation of the studied area*

Zeuwts (1991) studied the Avekapelle creek ridge (Figure 1), which is the largest creek ridge in the region with Quaternary sediments up to 25 m thick, most of it consisting out of sandy material. Using pumping tests Zeuwts (1991) showed that the horizontal conductivity varied from 4,7 m/d in the finer sandy sediments to 19,9 m/d in the more coarser sands. The vertical conductivity of the finer sands range between 0,25 and 0,3 m/d

The quality of the groundwater in the central part of the Avekapelle creek ridge varies from top to bottom. According to the classification of Stuyfzand (1986), Zeuwts (1991) observed a succession of the following types of water from top to bottom : (1) fresh water of the F-$CaHCO_3$, F-CaMix and F-$CaSO_4$-types; (2) fresh-brackish water of the F_b-$CaHCO_3$ and F_b-$NaHCO_3$-types; (3) brackish water of the B-$CaHCO_3$ and B-$NaHCO_3$-types; (4) brackish water of the B-NaCl-type; (5) brackish-salt water of the B_s-NaCl-type and (6) salt water of the S-NaCl-type. In the vicinity of the Kromme Gracht and the Oude A-vaart the fresh/salt water interface rises because of the drainage activity of those canals. The groundwater movement in the central part of the Avekapelle creek ridge was dominated by the drainage canals, which meant that there is a flow of groundwater under the creek ridge towards the Kromme Gracht and the Oude A-vaart.

Symbol or code	Description	Chloride content (mg/l)
F	Fresh	< 150
F_b	Fresh to brackish	150 – 300
B	Brackish	300 – 1.000
B_s	Brackish to salt	1.000 – 10.000
S	Salt	10.000 – 20.000
H	Supersalt	> 20.000

***Table 1** Description of first symbol according to Stuyfzand classification (1986).*

Using mathematical modelling Zeuwts (1991) showed that a fresh water catchment under the Avekapelle creek ridge could be feasible if first the salt water from the bottom part of the aquifer could be removed. A first long term pumping test was performed to show the possibility that this salt water could be removed at the same time that fresh water can be removed in the upper part of the aquifer. This pumping test was performed in the vicinity of the Kromme Gracht so that at the same time there was an induction of artificial recharge of canal water.

FIRST LONG-TERM DOUBLE PUMPING TEST IN THE AVEKAPELLE CREEK RIDGE

A double pumping test in the Avekapelle creek ridge (Lebbe et al., 1995) showed a low hydraulic resistance aquifer (in the order of 9 days) between the intake canal and the upper part of the. The salt water from the lower part of the aquifer (PP1) was discharged during 3 days at a rate of 144 m^3/day. After the first day of pumping, fresh water from the upper part of the aquifer (PP2) was extracted at a rate of 59 m^3/day. Despite the small hydraulic resistance between the upper and lower part of the aquifer (6 days), the water pumped from the upper well did not become brackish, because the hydraulic head in the lower part of the aquifer was lower than in the upper part. The sediments in the upper part of the aquifer have a horizontal hydraulic conductivity of 5,54 m/d; the sediments of the lower part 5,70 m/d.

This pumping test was renewed (1995-1996) but for a 4 month period (Lebbe et al., 1996). The quality of the water extracted from well PP2 changed significantly: the chloride content changed from 298 mg/l (F_b3-NaMix type) to 858 mg/l (B3-$NaCl^+$ type). The maximum salt level was reached after 19 days of pumping (B_s4-$NaCl^+$ type) with discharges of 2,64 m^3/h and 5,09 m^3/h respectively from the upper and lower part of the aquifer. Once the surface water had reached the pumping well, the extracted water freshened until equilibrium was established (chloride content of 900 to 1000 mg/l).

SIMULATION OF EXTRACTION OF SALT AND FRESH WATER IN VICINITY OF A MAIN DRAINAGE CANAL

The evolution of the distribution of fresh, brackish and salt water was for the first time simulated in a cross-section perpendicular on the main drainage canal Kromme Gracht (Lebbe et al, 1996) using the MOC model of Konikow and Bredehoeft (1978) which was adapted so that density differences were taken into account (Lebbe, 1983). The schematization of the aquifer and some flow boundary condition are given in Figure 2. The applied hydraulic parameters were determined with the double pumping test. The ratio vertical versus horizontal conductivity is 0,4. The used values of the transport parameters are: 0,38 for the effective porosity, 60 mm for the longitudinal dispersivity and 15 mm for the transverse dispersivity. The buoyancy factor $(\Delta_s-\Delta_f)/\Delta_f$ is 0,020.

The finite-difference grid consists of 12 layers (each 1,6 m thick) and of 38 columns (each 2,5 m wide). The drainage canal is located in the upper left corner of the cross-section (Figure 2) and is considered as a constant fresh water head boundary (1,9 mTAW). The left vertical boundary is considered as a symmetric axis of the problem coinciding with the drainage canal axis. So, this boundary was considered as impervious. Also the lower boundary (Tertiary clay) and right vertical boundary (water divide) are impervious.

The initial fresh-salt water distribution corresponds with the dynamic equilibrium obtained after a constant recharge of fresh water at the upper boundary (280 mm/year, Figure 3). The evolution of the salt water percentage P_s was simulated during a period of four years in which the aquifer was pumped periodically and while the recharge rate fluctuates (see table 2). Salt water is pumped in the lower part of the aquifer (finite-difference cells indicated by numbers 4 in Figure 2) while fresh water just above it, in the upper part (numbers 3). During the seven months with the largest recharge rate water is pumped; there is no pumping during the five other months. During the first period of seven months fresh water is extracted with a rate of 0,8 m³/d per meter of drainage canal whereas the extraction rate of salt water is equal to 2,0 m³/d per meter. During the second period of seven months the discharge rate is 1,2 m³/d per meter of drainage canal on the upper part of the aquifer while the discharge rate on the lower part of the aquifer is 2,0 m³/d per meter on the lower part. During the third and fourth period of seven months the discharge rates are the same on the upper and lower part of the aquifer. During each month of pumping the total amount of natural recharge of fresh water is much smaller than the total pumped amount. In this period the largest part of the pumped water is provided by artificial recharge through the canal bottom.

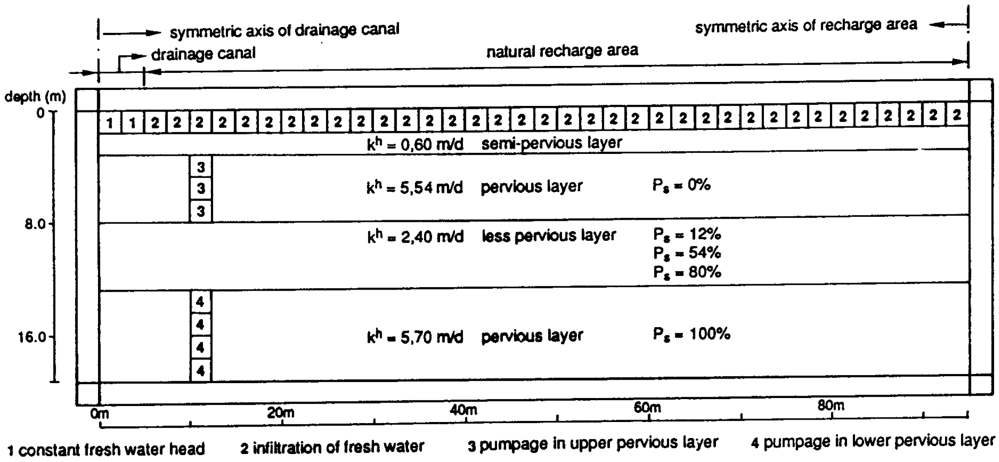

Figure 2 *Schematization of aquifer, some hydraulic parameter and some boundary conditions*

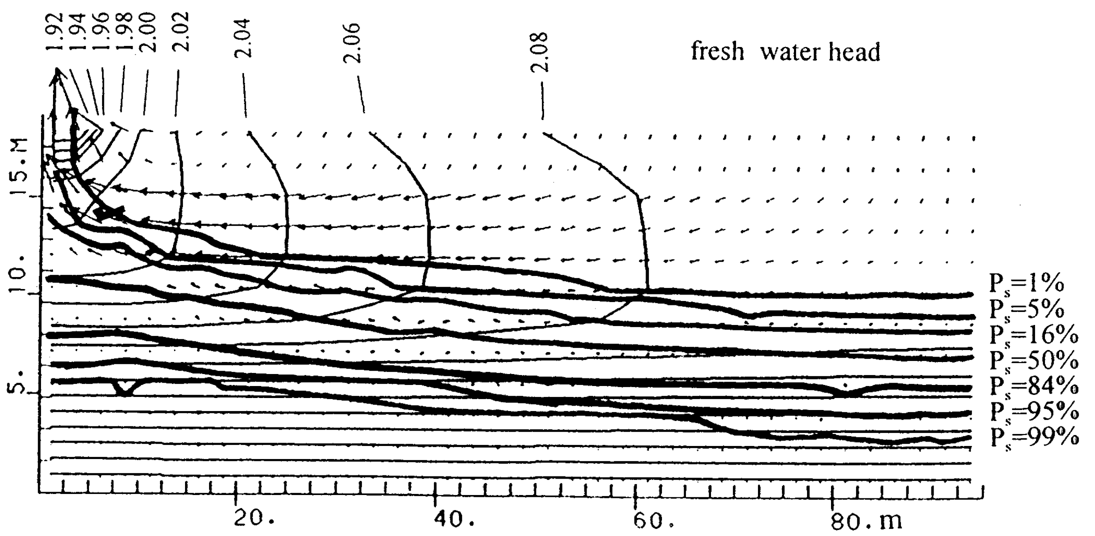

Figure 3 *Initial fresh-salt water distribution corresponds with dynamic equilibrium obtained after a constant recharge of fresh water (280 mm/year)*

April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
40.0	26.6	14.6	9.69	41.6	119.	362.	858.	685.	527.	488.	191.

Table 2 *Assumed recharge rate variation (mm/year) during each year of the simulated four-year period.*

The level of the drainage canal is constant. The salt water percentage of the drainage canal changes from 0% initially to 2% during the simulation. By this change it was possible to follow the effect of the water recharged from the canal. The simulated evolution of the salt water percentage in the different pumped cells is given in Figure 4. In the lower part of the aquifer the change in salt water percentage is strongly level dependent. Already after the first seven months the salt water percentage at the top of the lower part of the aquifer (cells 7,10 and 7,11) reaches the salt concentration of the drainage canal while the salt content at the base (cell 7,13) shows only a slight decrease. The salt content in the cell 7,12 decreases until 5% after the first seven months of pumping but increases again until ca. 10% after the following five months without pumping. This result is in agreement with the EM39 observation made at the end of the last long term pumping test (see next section) and seven months after its end

(Figure 10). The salt content in the upper part of the aquifer evolves during the first pumping period very quickly to the salt content of the canal (2%). After this period the salt content changes only slightly in the upper part of the aquifer. There is only a small difference between the pumping and the non-pumping periods.

Two pumping tests were performed using two pairs of wells. The first existing pair (PP1 and PP2), situated at about 10 m from the Kromme Gracht, was extended with a second pair (PP3 and PP4) at 25 m distance from the first pair and about 20 m away from the Kromme Gracht (Figure 5). For the second test PP4 was replaced by PP5.

Between the new pair of wells and the Kromme Gracht a 'multiple observation well' was installed (Figure 5), with screens at different depths. WP1.5, WP2.5, WP3.5 and WP4.5 were screened between 18 and 19, 13 and 14, 8 and 9, 4 and 5 m depth respectively. A similar 'multiple observation well' was installed on the same line but away from the surface water (WP1.6 to 4.6).

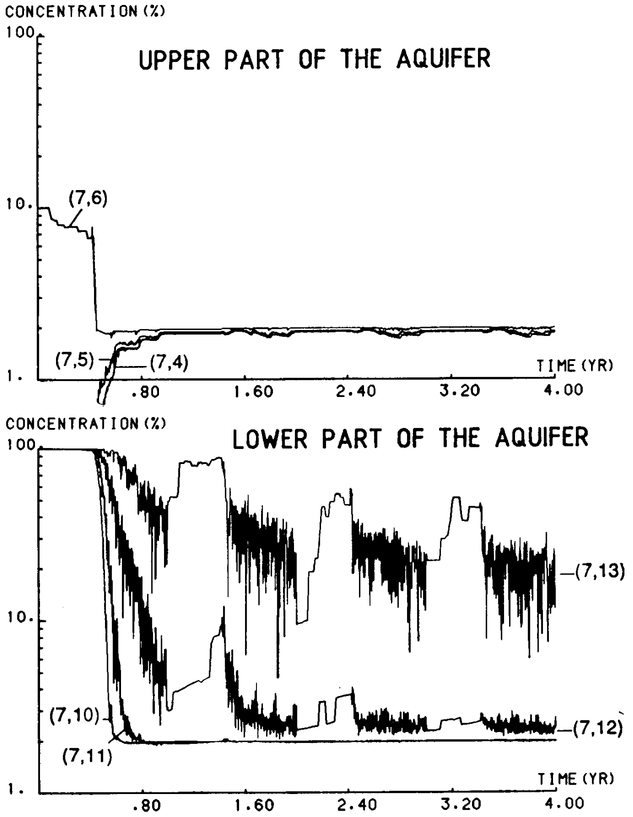

Figure 4 *Simulated evolution of salt water percentage for the pumped cells. Long term pumping tests combined with membrane filtration of soil filtered water*

The first pumping test lasted from 3 December 1997 until 4 May 1998; the second test was extended for a longer period: it started 19 November 1999 and lasted until 14 March 2001. The fluxes of the different pumping wells registered during the second test are shown in Figure 6[2].

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[2] During the pumping test the fluxes varied from time to time due to technical problems.

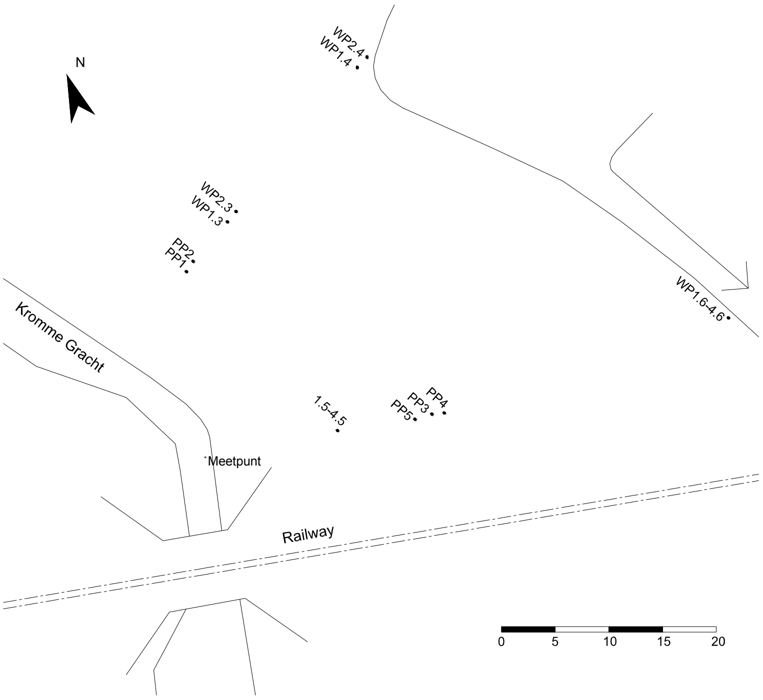

Figure 5 *Situation at the test site in Avekapelle*

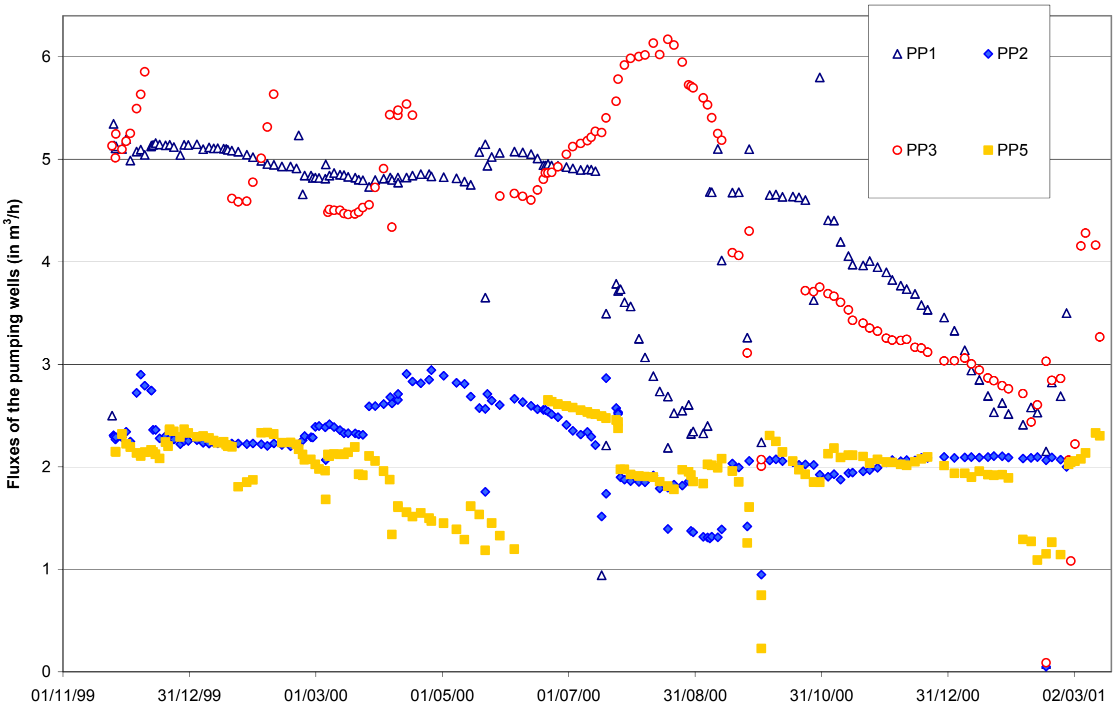

Figure 6 *Fluxes of different pumping wells during second extended pumping test.*

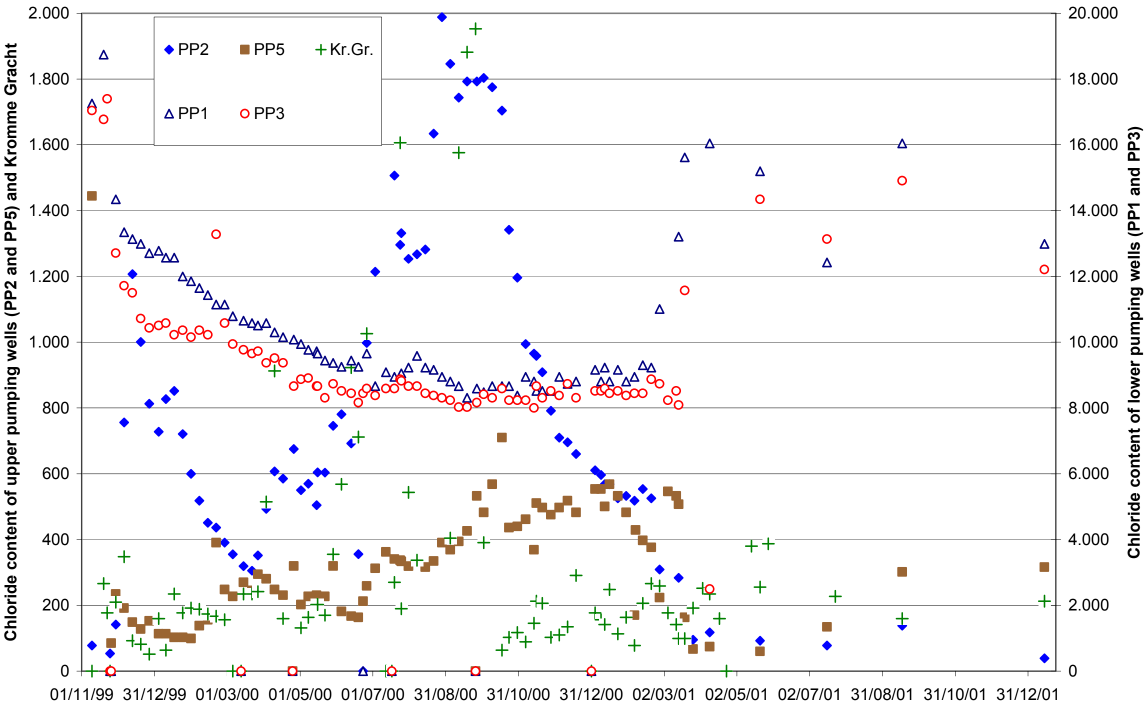

Figure 7 *Chloride content of groundwater from pumping wells during second extended pumping test.*

Both tests showed the same results (Figure 7):

- the salt content of the groundwater from the bottom part of the aquifer (PP1 and PP3) gradually decreased during pumping;
- when pumping was stopped the salinity in the lower part of the aquifer rapidly increased;
- the salt content of the groundwater from the upper part of the aquifer (PP2 and PP5) initially increased until it stabilized;
- when stabilized the salt content from the upper wells reflects the salinity in the surface water (with a certain delay); this effect is stronger for the well (PP2) closer to the surface water[3].

The increase of salinity in the upper wells depends on the proportion of extraction from the lower and upper part of the aquifer and on the distance between the canal and the wells. The lower the part of extraction from the upper wells, the lower the salt content of the water extracted from it (Figure 8 and 9). During the second test (1999-2000) the groundwater quality in the upper pumping well (PP5) moved from fresh (F3-$CaHCO_3$) over fresh-brackish (F_b3-$CaHCO_3$) to brackish (B3-NaMix), whereas in the first test (1997-1998), when the withdrawal in the upper pumping well (PP4) was lower, the groundwater quality remained fresh (F3-$CaHCO_3$).

The closer the wells are situated to the surface water, the larger the increase in the upper wells (Figure 8). This is due to the higher fresh/salt water interface nearby the Kromme Gracht. As the distance from the upper well to the canal increases, the quality of the extracted groundwater is fresher and more stable.

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[3] The water from the upper and lower wells was discharged 100 m downstream, but due to the low discharge in the summer of 2000 (dry period) it streamed temporarily back to the test site causing high salinity of the surface water (Kromme Gracht).

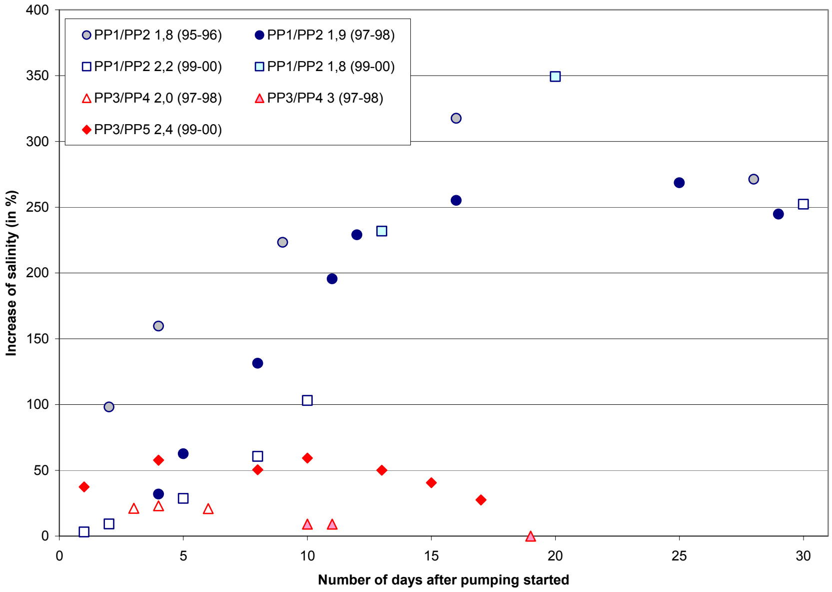

***Figure 8** Comparison of salinity increase during the different long-term pumping tests*

The quality of the groundwater in the lower part of the aquifer remains salt (S6-NaCl type), except in the pumping well itself where it moves to brackish-salt water (Bs6-NaCl). The salt content of the lower pumping wells decreased by about 50% at the end of the test.

The groundwater quality in the aquifer between the pumped levels gradually freshened during pumping (Figure 10). The groundwater quality in the most upper part of the aquifer also remained stable[4]. It reflects the quality of infiltrating rainwater and is not influenced by infiltrating surface water.

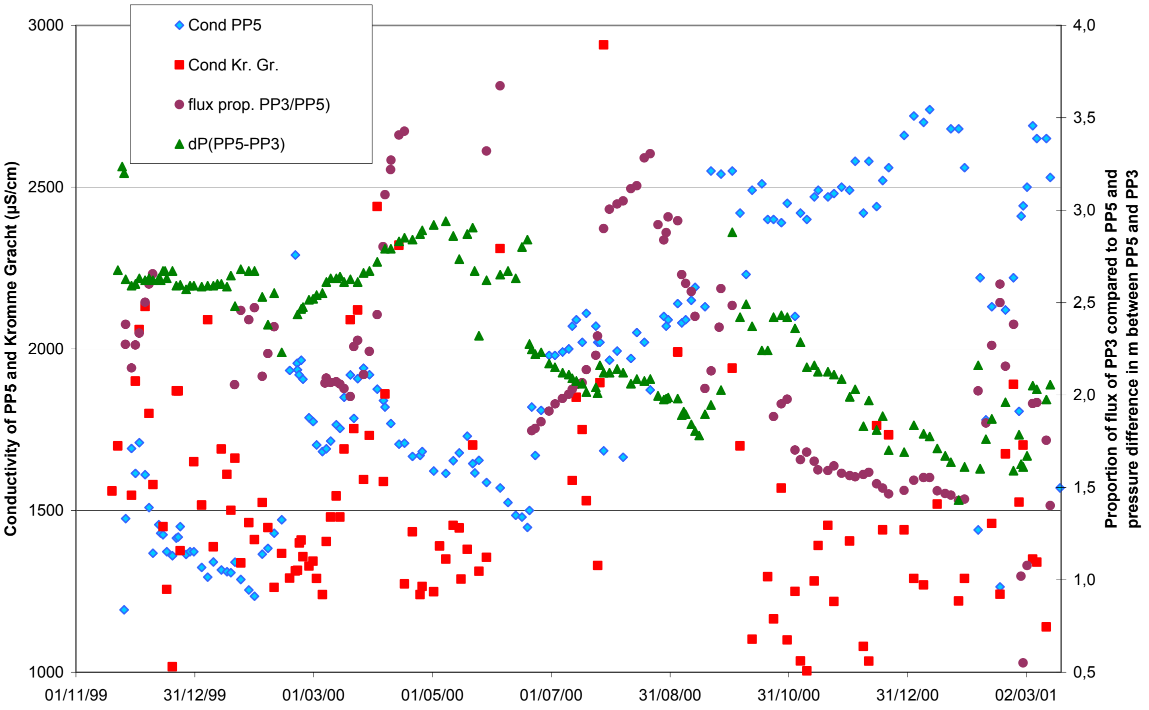

***Figure 9** Relation between salinity, pressure difference and proportion of extraction of a pair of wells*

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[4] The higher salinity in the second test was due to leakage of the discharge pipe for salt groundwater.

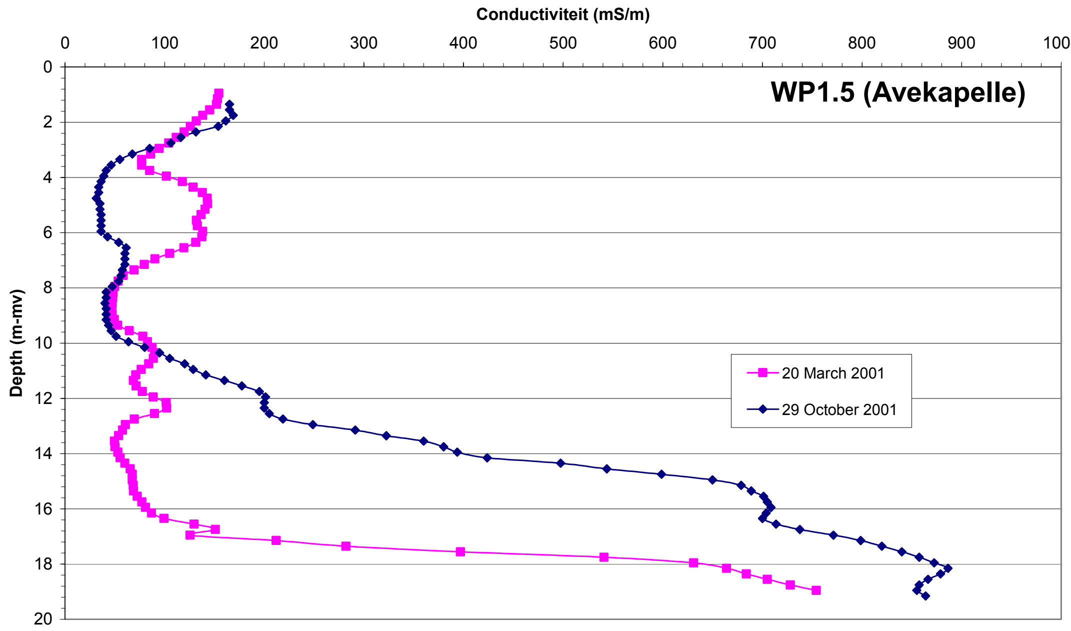

***Figure 10** EM39 measurement of WP5shortly after the pumping test (20 March 2001) compared to a normal situation on (20 October 2001)*

During the pumping test and even some time after this, the level of the water table around the test site was measured (Figure 11). Before pumping started the Kromme Gracht had a draining effect; once pumping started the Kromme Gracht infiltrated towards the pumping wells.

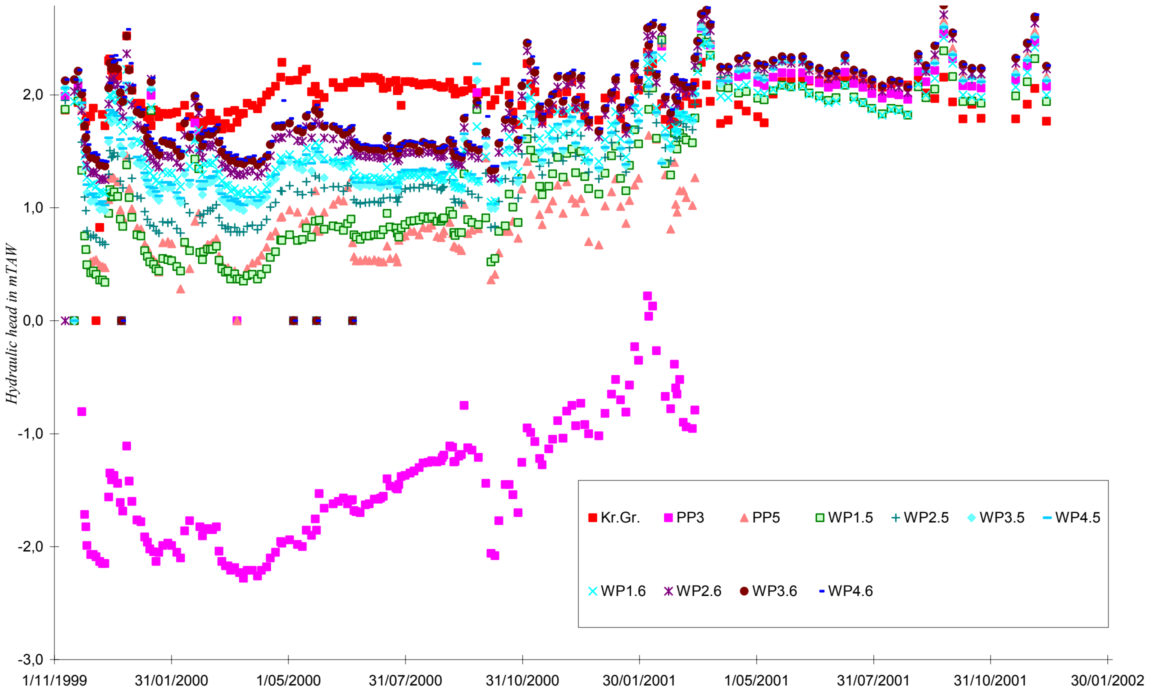

***Figure 11** Level of surface water (in mTAW) and of wells (pumping and observation) of line near the railway*

The groundwater levels stabilised very quickly and there was a good relation between the level of the groundwater and that of the surface water (Figure 11). Generally there was a pressure difference between the lower and upper part of the aquifer, indicating that the groundwater was moving upwards (Figure 12).

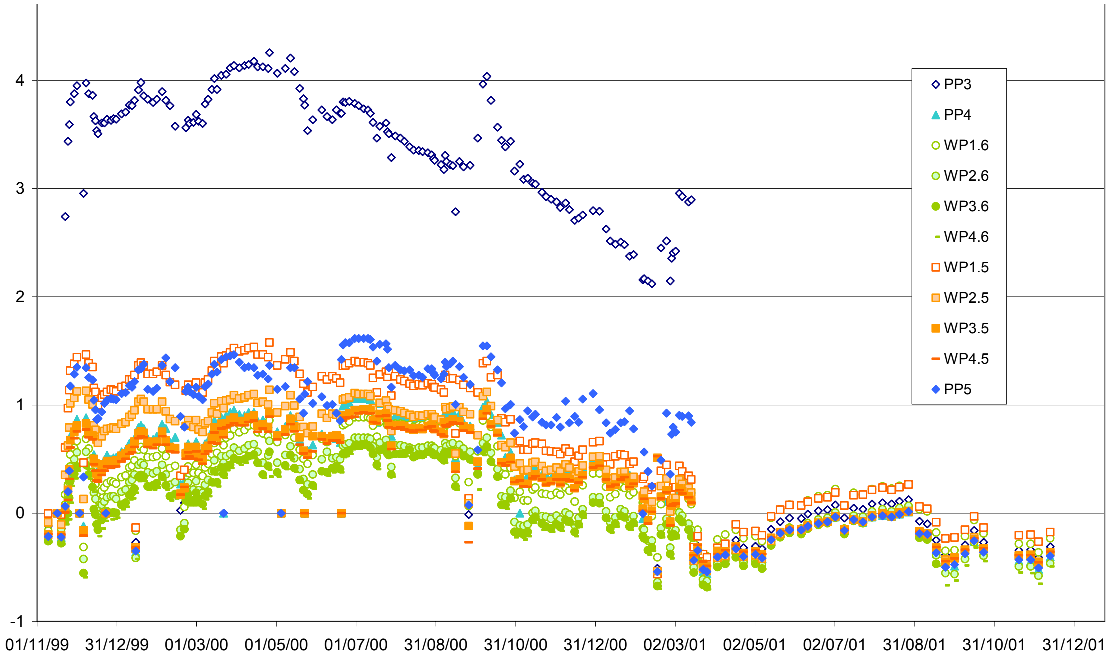

***Figure 12** Level difference (in m) between surface water and wells (pumping and observation) of line near the railway*

The water table restored very quickly when pumping was stopped.

The maximum difference between the surface water and the water table 25 m outside the pumping area (WP4.6 and WP2.4) is only 75 cm (Figure 12). This would mean that if the level of the canal could be increased, the water table could be kept on the same level despite pumping alongside the canal. As the level in the Kromme Gracht varied around +2 (Figure 11), it should be possible to increase the level in a future intake canal by 1 to 1,5 m (the surface level being +4 to +4,5).

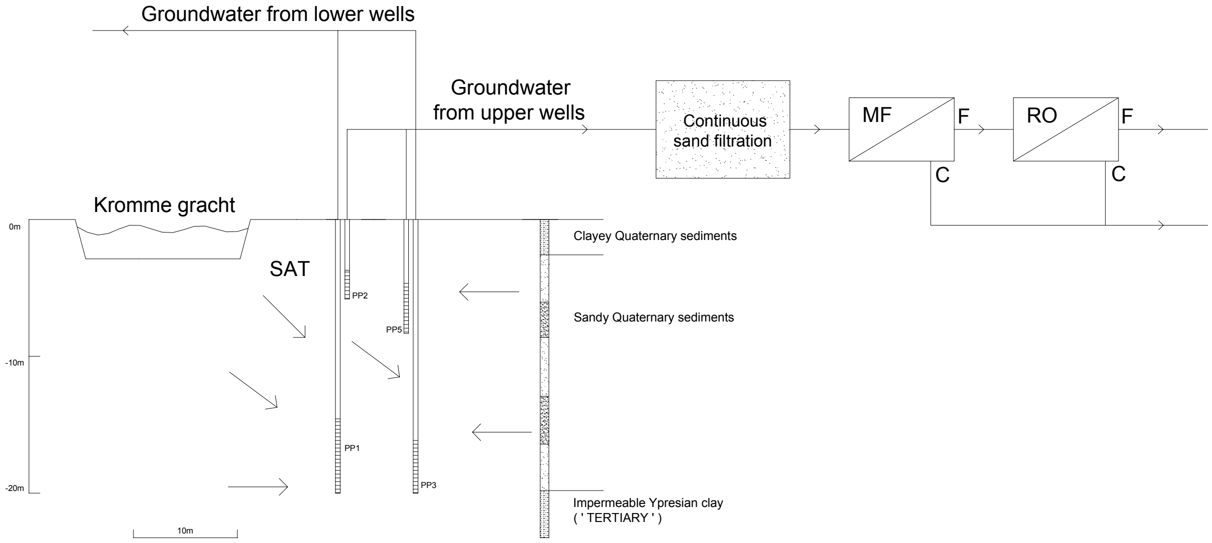

***Figure 13** Process scheme of the trials in Avekapelle*

During both pumping tests the 'bank filtered water' from the upper wells (PP2 and PP5) was treated using membrane filtration techniques[5] (Figure 13). The results showed the advantages of the soil passage in front of the MF/RO process, compared with direct treatment of surface water or wastewater effluent (Van Houtte et al., 2001).

First of all the bank-filtered water had a relative constant quality and, if the residence time was long enough, was free of coliforms. The heterotrophic plate counts (HPC) was much lower compared to surface water and wastewater effluent (table 3). Secondly the nutrient content of the water was reduced by the soil passage (Figure 14, 15 and 16) and the organic load was lower. Both effects, together with a constant moderate temperature, resulted in the biofouling potential, the biggest problem when using reverse osmosis, to be reduced.

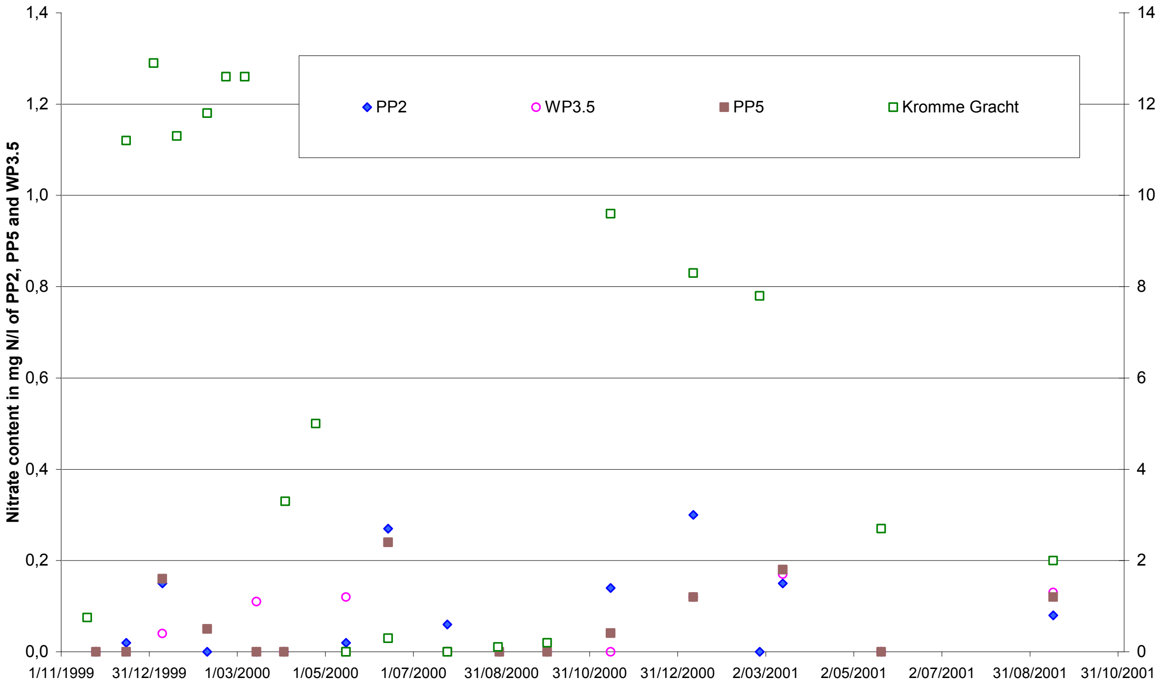

Figure 14 *Nitrate content (in mg N/l) of groundwater and surface water during second long term pumping test*

The 'normal' seasonal variation of nitrogen is reflected into the quality of the Kromme Gracht and even the fresh groundwater: more nitrate is present during the winter (Figure 14) and ammonia is more abundant during the summer (Figure 15).

On the other hand the iron content of the water increased due to the soil passage (1 – 1,5 mgFe/l), and the iron oxidised the MF membranes. An '*acid wash*' was introduced (Van Houtte et al., 1998). This short circulation (3 to 5 minutes) over the membranes using acidified feed water was typically performed when the pressure raised 10 to 20 kPa. It resulted in a pressure drop of 5 to 10 kPa.

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[5] Membrane filtration is a pressure driven process that separates colloidal and suspended solids from the water. **Microfiltration (MF)** is a form of membrane filtration with larger pores and it removes suspended solids and pathogens, including parasites such as Giardia and Cryptosporidium, but does not remove salts. It is a good pre-filtration for reverse osmosis. **Reverse osmosis** has much smaller pores and therefore removes micro organisms (also viruses), organic chemicals (e.g. pesticides) and inorganic chemicals (ions), producing very pure water.

Because MF does not remove salts, the concentrate has a similar salt content as the feed water. The RO concentrate is much saltier than its feed water as the salts are removed from it.

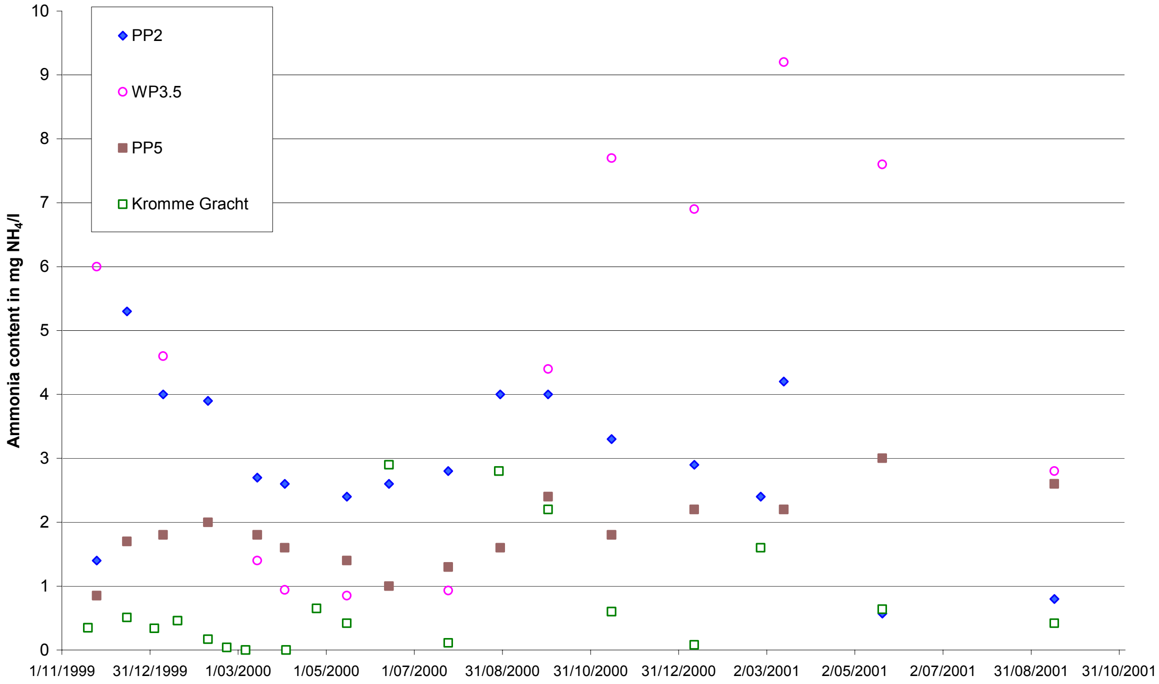

Figure 15 *Ammonia content (in mg* NH_4*/l) of groundwater and surface water during second long term pumping test*

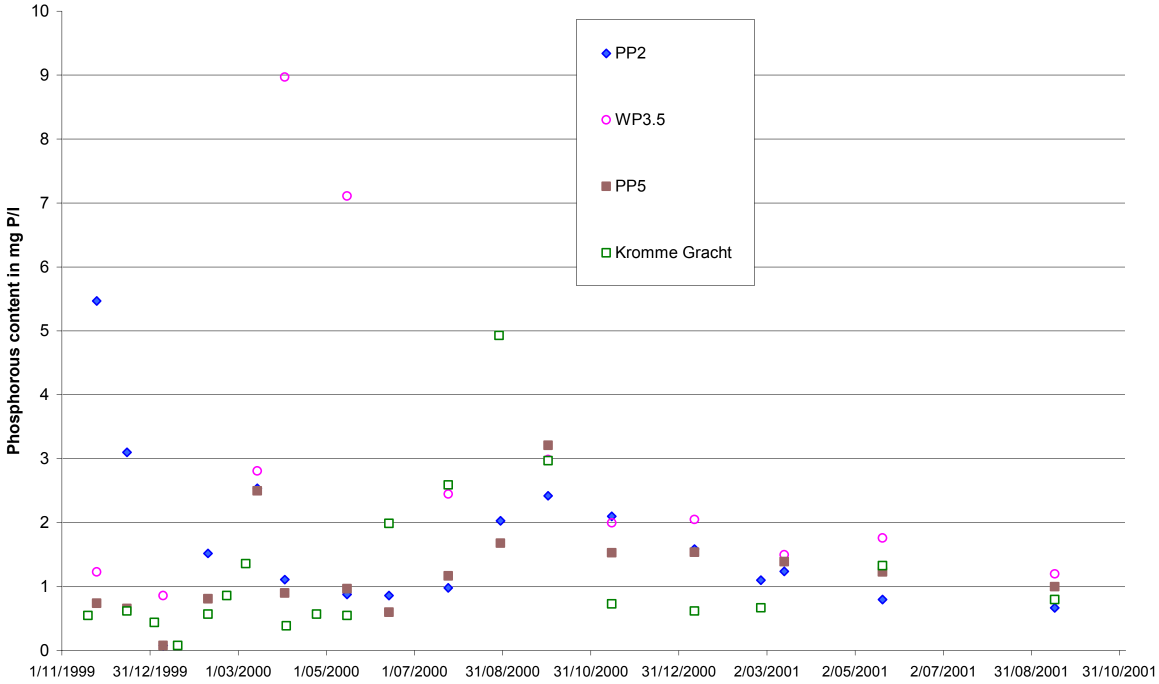

Figure 16 *Phosphorous content (in mg* P_4*/l) of groundwater and surface water during second long term pumping test*

During the second test continuous sand filtration was part of the treatment process to remove the iron from the groundwater in front of the MF process. It was still combined with an acid wash on the MF. This sand filtration would also remove the higher ammonia content that is caused by the reduction of nitrate. Table 4 shows that this combination improved the performance of the MF system even further: higher fluxes, less chemical cleanings (CIP’s) and consequently recoveries[6] of 98% and more.

Parameter		Kromme Gracht	Sand filtered groundwater	MF filtrate	RO filtrate	RO concentrate
Conductivity	µS/cm	1.252	2.100[7]	2.100	38	7.190
BOD	mg O_2/l	3	7	2,3	<2	4
COD	mg O_2/l	30	15,6	17,6	<5	84
Sodium	mg Na/l	113	255		10	974
Chloride	mg Cl/l	171	413		8	1.670
Sulphate	mg SO_4/l	54	73		<10	331
Phosphorous	mg P/l	0.60	1,12	1,08	0,3	3,01
Nitrate	mg NO_3/l	40	1,1	0,4	<0,1	10
TOC	mg C/l	20	14,5	12,6	<5	40
UV 254 absorption	cm^{-1}	0,39	0,26	0,24	0	1
Suspended solids	mg/l	25	11	<1	<0,1	<10
HPC 22°C	cfu/ml	31.111	677	123		133.200
HPC 37°C	cfu/ml	1.833	122	47		3.700

Table 3 *Mean quality of surface water, groundwater, MF and RO filtrate, RO concentrate during the second test (1999-2000) using soil aquifer treatment (5 samples) (Van Houtte et al., 2001)*

During both tests chloramination[8], which was used continuously when treating wastewater effluent, could be reduced to shock dosing, benefiting the environment and saving production costs. Another positive effect of the SAT would be a better quality of the concentrate (table 3), and this makes discharge of concentrate less problematic, especially according to the nutrient and organic load of it.

However the main advantage of SAT would be that in combination with sand filtration, it could prove to be a good pre-treatment for RO. MF would no longer be needed and this is a substantial saving of costs, both in investment, maintenance and production, even if the RO would have to be cleaned maybe more often.

Period	Temperature (°C)	Flux ($l/h.m^2$)	Conductivity (µS/cm)	Recovery (%)	Water volume treated between CIP’ s
First test: 27/3/1998 – 4/5/1998 Acid wash	11,0	68	1.463	82,5	337 m^3
Second test: 22/2/2000 – 13/5/2000 Acid wash and sand filtration	11,7	92	1.694	>98	633 m^3

Table 4 *Comparison of the hydraulic performance (average) of MF treating bank filtered water after optimising of the process*

The whole concept of using SAT before a membrane filtration process would not only mean that SAT improves the whole process, but in this way artificial recharge would no longer be necessary after the process. The soil passage is the first step and in this way in the near future drinking-water production could be moved to environmental less valuable areas.

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[6] Recovery is defined as the percentage of filtrate that is produced out of the feed water. For MF the loss of water is due to backwashes and chemical cleanings.

[7] The increase of salinity in the bank-filtered water is caused by the presence of salt water in the lower part of the aquifer and the rise of fresh/salt water interface nearby the Kromme Gracht (due to the drainage effect.

[8] Chloramination means that free chlorine and ammonia are dosed simultaneously to combine to chloramines (NH_2Cl). Contrary to free chlorine, chloramines do not damage the RO membranes. It is done to prevent biofouling.

CONCEPT FOR FUTURE DRINKING-WATER PRODUCTION IN THE AVEKAPELLE CREEK RIDGE

The research that was performed during many years finally showed that the production of drinking-water, using a combination of Soil Aquifer Treatment (SAT) and membrane filtration techniques, is feasible in the Avekapelle creek ridge. It could result in a direct production of drinking-water.

In 1998 the IWVA obtained two strokes of ground alongside a road in the central part of the sandy Avekapelle creek ridge. This stroke of ground lies close to the Kromme Gracht in the west and it goes to the east where it ends at the borders of the Oude A-vaart; the total length is nearly 2000 m. The stroke north of the road is 30 m wide, and in this part the intake canal could be excavated with a series of pumping wells north of it at approximately 10 to 15 m distance. A second series of wells could be installed in the stroke south of the road. In this way the distance to the intake canal would be between 19 and 25 m enabling a difference in residence time of the infiltrating water compared to the northern series of wells (Figure 17).

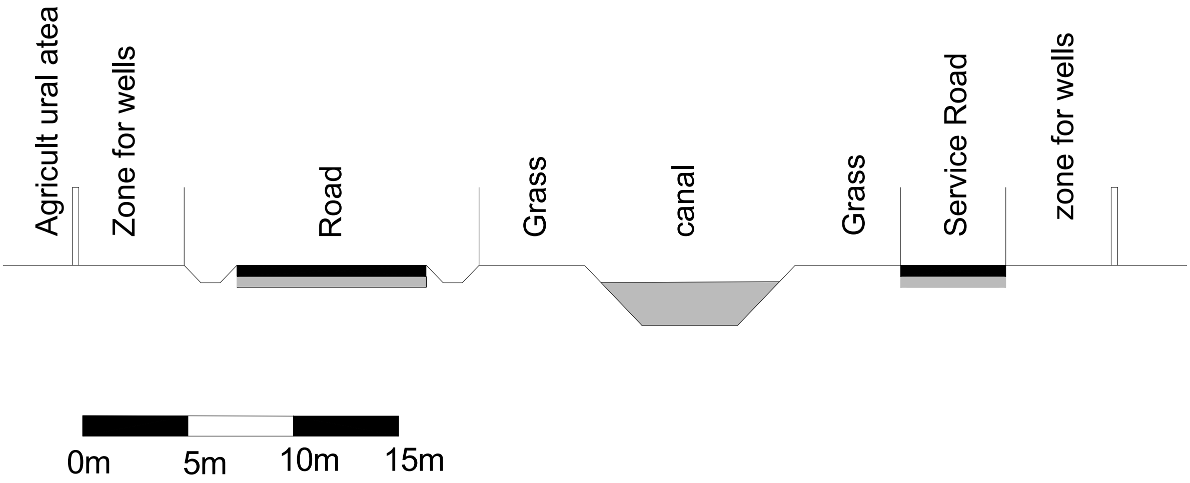

Figure 17 *Cross-section of stroke of ground available for the realization of a water catchment in Avekapelle*

The intake canal should cut the upper clayey sediments and could be fed by drainage water from the Kromme Gracht or Oude A-vaart. According to De Smet (1997) a depth of 3 m would match as the thickness of the clayey sediments varies around 2,6 in the west, 2 m in the centre and 2,75 in the eastern part of the stroke of ground. Alternatively wastewater effluent could be used or a combination of them. Using effluent would benefit the long term process as it contained less nutrients than drainage water (table 5) and also farmers should not fear restrictions on their agricultural activities (e.g. use of fertilisers and pesticides) as the drainage water (Kromme Gracht and Oude A-vaart) would not be used for drinking-water production.

When a higher level would be maintained in the intake canal, as explained previously, the impact of this project on the water table would be limited to a small zone near the wells. In this way the impact on the agricultural activity would be negligible. A higher level in the canal would also reduce the amount of salt water captured in the upper wells. This would benefit to the reverse osmosis.

On both sides of the canal a minimum of 40 pair of wells could be installed; the space between each pair would be 40 to 50 m. The extraction of fresh water could gradually be increased while the production of salt water could be diminished. A possible scenario is shown in table 6. As the modelling predicted (Lebbe et al. 1996) more fresh water will be produced over time while less water should be drained. The salt water from the lower part of the aquifer is relict, and therefore matches the quality of seawater. It should be no problem to drain this water to the sea, especially as it would only be a temporal situation because with time (between 5 and 10 years) all the extracted water could be treated to produce drinking-water. Van Meir et al. (1999) showed, using a regional modelling, that the freshening of the total aquifer specifically would happen in a small zone alongside the intake canal. This freshening of the aquifer would be the greatest in the central part of the creek ridge. This modelling also proved that more rainwater would infiltrate; with the current agricultural use most of this fresh rainwater is rapidly drained and is not able to replace the relict salt water.

Parameter	Wastewater effluent			Infiltration standard
	Mean	Min	Max	
pH	7,67	7,28	7,26	7,78
Temperature (°C)	15 ?	9,7	26,5	
Conductivity (µS/cm)	1.645	524	2,670	1.646
Suspended Solids (mg/l)	5,9	0	19	14,7
Turbidity (NTU)	2	0	11	9,5
Calcium (mg Ca/l)	131	56	184	154
Potassium (mg K/l)	34	2	100	17,5
Magnesium (mg Mg/l)	18	3	30	32
Sodium (mg Na/l)	210	60	379	162
Total phosphorous (mg P/l)	1,54[9]	0,29	3,45	1,2
Nitrate (mg NO_3/l)	23	4	45	38
Ammonia (mg NH_4/l)	1.8	0	25	1,2
Bicarbonate (mg HCO_3/l)	367	110	543	421
Sulphate (mg SO_4/l)	145	11	281	148
Chloride (mg Cl/l)	320	90	776	290
UV 254 absorption (cm$^{-1)}$	0,28	0,09	0,37	0,39
Total Organic Carbon (mg C/l)	18	5	43	17,5
Biological Oxygen Demand (mg O_2/l)	7	2	20	8
Chemical Oxygen Demand (mg O_2/l)	50	10	144	48
Total coliforms (cfu/100 ml)	10^5			10^4-10^5

Table 5 *Quality of the wastewater effluent (WWTP Wulpen) between September 1996 and February 1999 compared to surface water quality (Kromme Gracht) between September 1996 and September 1998*

	UPPER WELLS	Fresh water	LOWER WELLS	Salt water	Production of fresh water	Production of salt water
	Number	Production pro well	Number	Production pro well	Total	Total
Year 1 - 2	2 x 40	2 m^3/h	2 x 40	5 m^3/h	3.840 m^3/d	9.600 m^3/d
Year 3 - 4	2 x 40	2,5 m^3/h	2 x 40	4 m^3/h	3.840 m^3/d	7.680 m^3/d
Year 5 - 6	2 x 40	2,5 m^3/h	2 x 40	2,5 m^3/h	4.800 m^3/d	4.800 m^3/d
Year 7 - 10	2 x 40	2,5 m^3/h	2 x 40	2,5 m^3/h	9.600 m^3/d	0 m^3/d

Table 6 *Production capacity of the Avekapelle water catchment*

In May 2002 the plant that will produce infiltration water out of wastewater effluent from the WWTP Wulpen, will be operational. It is situated on the grounds of the wastewater treatment plant (WWTP) and will be able to treat the 'soil filtered water' from Avekapelle. Off course only if both sites, Wulpen and Avekapelle, are connected with pipelines.

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[9] Since September 1999 ferric chloride is dosed and the phosphorous content is permanently below 1 mg/l.

CONCLUSION

More than 10 years of research in the Avekapelle creek ridge showed that direct drinking-water production is feasible in this polder area. A double pair of pumping wells alongside both sides of an intake canal could produce fresh infiltrating groundwater from the upper part and salt water from the lower part of the aquifer.

The fresh groundwater could be treated to drinking-water quality using reverse osmosis in combination with a pre-treatment of MF or continuous sand filtration.

The water extracted from the lower part of the aquifer would gradually freshen, as was predicted by mathematical modelling and proven by long term pumping tests, and would after some years become fresh enough to be treated in the same plant.

The intake canal could either be fed by surface water or by wastewater effluent. Maintaining a higher level in this canal would minimise the effect on the water table and hence the impact for agricultural activities would be limited to a small zone nearby the wells.

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