Salinization of drinking water in the Netherlands: anamnesis, diagnosis and remediation

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ABSTRACT: Recent and ancient data on all 365 pumping stations which existed in the period 1853-1996 (most of them well fields), are combined in order to reconstruct historical trends in drinking water supply in the Netherlands. These trends include geographical, hydrological and hydrochemical information. The purpose is to: (a) get a better definition of the salinization problem (size, location, trends), (b) identify stations with salinization phenomena and classify their origin as either continental (related to agriculture, evaporation, bank infiltration, artificial recharge, local pollution or sea spray) or maritime (recent North Sea intrusion or upconing of ancient North Sea water), and (c) give a list of remedial or preventive measures for both types of salinization.
A rapid screening method is proposed and used (Table 3) to assign the salinization cause and scale to each pumping station. The following parameters are required for each pumping station: type of water resource and state (closed or active), Cl^- concentration at start of operation and in 1992 (or year of close down), and the most recent concentrations of NO_3^-, SO_4^{2-} and ^3H, and $\delta^{18}O$ only in dubious cases of Rhine bank infiltrate.
It is shown that 61 pumping stations (17%) of a total of 365 pumping stations are classified as salinized due to continental causes, and that 33 stations (9%) salinized for maritime reasons. From a total of 102 abandoned stations, 42 (41%) closed with salinization phenomena, of which 17 (5%) suffered from maritime salinization and were probably closed for that reason. Salinization is therefore a wide-spread problem in the Netherlands, which in about 50% of its cases is due to either continental or maritime reasons. The most susceptible areas are situated along the coast (intrusion and artificial recharge) and in the fluvial plain (bank infiltration and upconing).

Introduction

There is a definite increasing trend for the Na^+ and Cl^- concentrations of drinking water in the Netherlands (derived from data in Van Beek et al., 1990) and about 17 well fields are likely to salinize due to upconing of brackish groundwater (Peters & Meijer, 1993). This salinization is worrying for the following reasons: it may affect the potability of water (maximum permissible concentrations resp. 120 and 150 mg/l in the EU), it surely increases corrosion of pumping wells and the distribution network, reduces the effectiveness of detergents (and thereby raises their consumption) and lowers the diuretic activity on the consumer whose blood-pressure will rise too.
The centralized monitoring of raw and purified water for public drinking water supply is considered a task for both the government (mainly for national health protection) and the drinking water supply companies (mainly for safeguarding their water resources).
Data are therefore collected by both: the RIVM (the governmental institute for public health and environmental protection) and VEWIN (Netherlands' Waterworks Association). Both institutes suffer from the same problem: data prior to the mid 1980s are not readily available as digital data files, they scatter around in annual reports and 'fugitive sources', like unpublished project reports, governemental agency file documents, memoranda, old hand-written data files etc.
It was therefore a challenge to dive into this 'data-grave-yard', in order to (a) get a better anamnesis of the problem, (b) combine data for identification (the diagnosis) of the causes of salinization, using some of the tracers discussed during the previous SWIM (Stuyfzand & Stuurman, 1994), and (c) assign the right remediation (and prevention) for the different types of salinization. The various sources of data that were consulted, are listed in the references.

Anamnesis: historical developments in water supply and salinization

A centralized public drinking water supply started in the Netherlands in 1853 with the pumping of phreatic dune groundwater (Leeflang, 1974). The hygienic advantages (reduction of cholera epidemies) and better taste of groundwater gradually conduced to the national change over from surface to groundwater as the main source of drinking water. The increasing population and water consumption per capita raised the water demands from 70 Mm^3/y in 1900 to 335 Mm^3/y in 1950 to 1,250 Mm^3/y in 1992 (VEWIN, 1895-1996). This necessitated an expansion of water abstraction sites (pumping stations, in case of groundwater well fields).

The 1,250 Mm^3 of drinking water prepared in 1992, is composed of 7 types of water resources (Table 1), in decreasing order:

- 440 Mm^3 of (semi)confined groundwater from sandy aquifers (type B),
- 335 Mm^3 of phreatic groundwater from sandy aquifers (type A),
- 232 Mm^3 of directly purified surface water, mainly from the rivers Rhine and Meuse (type O),
- 161 Mm^3 of artificially recharged river Rhine and Meuse water (type I),
- 55 Mm^3 of Rhine bank infiltrate (type U), and
- 27 Mm^3 of groundwater from Cretaceous limestone (type K).

This water was abstracted in 1992 on 262 pumping stations (Fig.1). Further details on the characterics of the 7 types of pumping stations (water resources) are given in Tables 1 and 2.

A very important facet is the record on the close-down of pumping stations, because it constitutes a sensor of environmental problems. The location, type and size of abandoned pumping stations are shown in Fig.1, their distribution over the various types in Table 1 and the development in the course of time in Fig.2. In 1992 a cumulative total of 102 abandoned pumping stations was reached, with the highest closure rate for pumping stations using (semi)confined groundwater, and the lowest for those using recharged surface water. The highest percentage of closed stations (the lowest persistence) is observed for stations that used Rhine bank infiltrate.

TABLE 1. General characteristics of the 7 types of water resources for public drinking water supply in the Netherlands, anno 1992.

Type:	A	B	I	K	O	U
Diagnostic features	phreatic ground-water	(semi) confined ground-water	artificial recharge and recovery	ground-water from limestone	surface water	Rhine bank infiltrate
First year of operation of first station‡	1853	1893	1940	1904	1881	1890
No. of active pumping stations	103	104	9	15	16	15
No. of closed pumping stations	31	34	1	8	13	15
Percentage of closed stations*	23	25	10	35	45	50
Mean closure rate** (N/y)	0.22	0.34	0.02	0.09	0.11	0.15
Mean raw water production (Mm^3/y)	3.3	4.2	17.9	1.8	38.8	3.6
Amount of drinking water produced (Mm^3/y)	335	440	161	27	232†	55
Percentage of total amount of drinking water	27	35	13	2	19†	4
Mean number of wells/collection points	13	16	94	6	1	14
Mean surface Level = SL (m+MSL@)	18.1	13.1	8.6	76.0	2.1	1.8
Mean abstraction level (m-SL)	32-65	63-125	8-30	23-74	0	28-69
Mean depth to brackish water## (m-SL)	166	194	62	170	-	128
Age spectrum (y)	2-200	20-25,000	0.1-0.3	2-200	0-1	1-50

* = 100*closed/(active + closed); ** = closed/(1993-first year); @ = Mean Sea Level; ## = 150 mg Cl^-/l interface;
† = excluding the amount of surface water which is (a) pretreated for artificial recharge and industrial water supply (246 Mm^3/y, 9 stations), and (b) posttreated elsewhere (148 Mm^3/y, 2 stations); ‡ = still active.

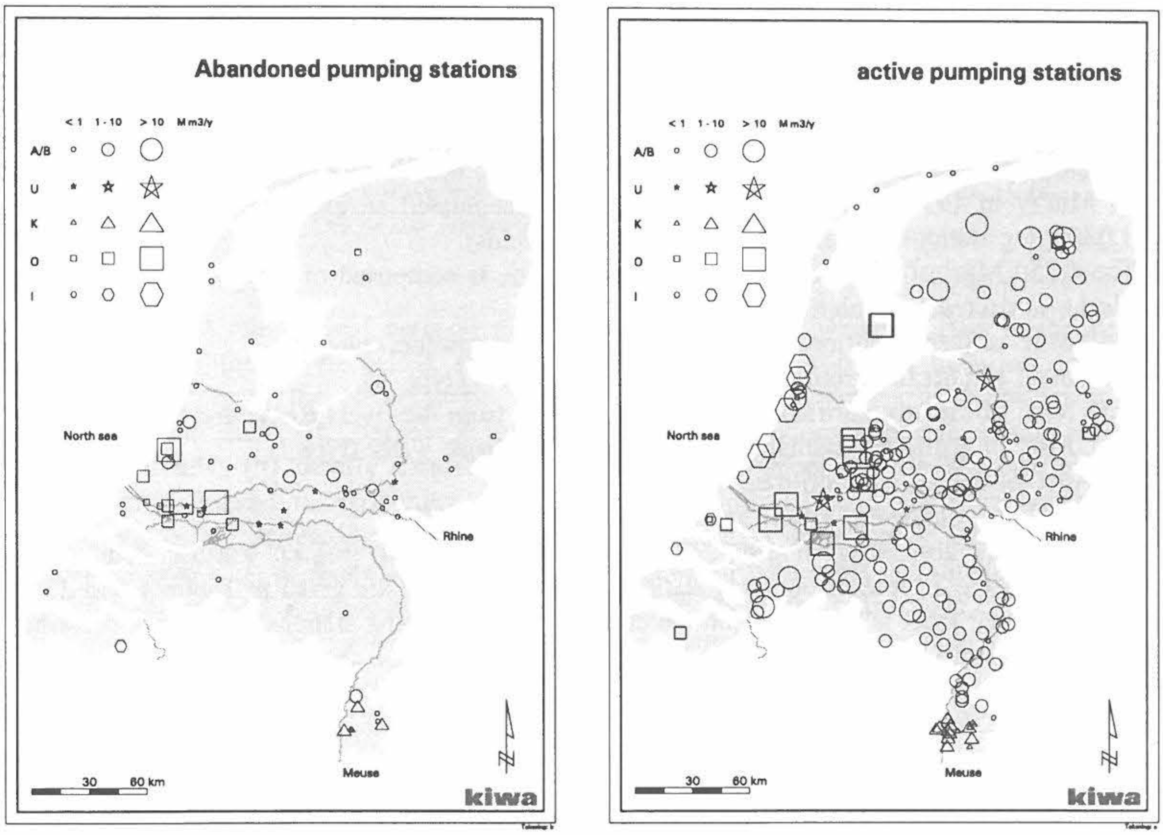

FIG. 1 The active and abandoned (closed) pumping stations for public drinking water supply in the Netherlands in 1992, with indication of type (A/B, I, K, O, U; see Table 1) and annual production.

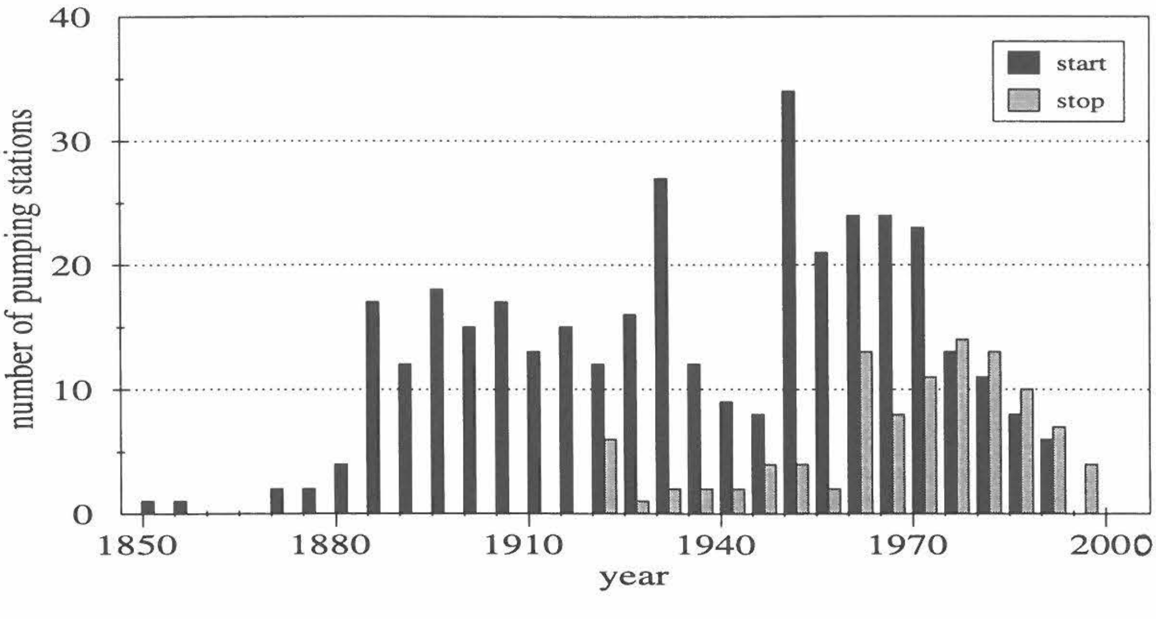

FIG. 2 Historical development of the total number of resp. new and closed pumping stations during 5-years periods from 1850 till 1995.

Reasons for close down were not always registered, but are clearly related to clogging, too serious environmental damage (like subsidence), salinization and other water quality problems, like 'anoxia' (too high methane, colour and ammonia), nitrate and micropollutants (mainly pesticides).

The size of the salinization problem is depicted in Figs.3-5, and quantified in Tables 2 and 4. It can be concluded from the chloride increase (ΔCl^-) and salinization rate (v_{Cl}) in Table 2 (regarding all active pumping stations), that on average:
(a) all types except for type O show some salinization, (b) type O (surface water) does not show any salinization (most of them started after 1955 when the salinization of surface water already had reached a high level), and (c) the types I and U exhibit most salinization of all (due to the change over from autochthonous groundwater to saltier surface water in case of I, and due to a strong salinization of river Rhine water in the period 1900-1975 in case of U).
The data in Table 4 show that 26% of a total of 365 pumping stations suffers or suffered from serious salinization (>20 mg Cl^-/l increase since the first production year), and that at least about 5% had to be closed due to salinization (salinization scale 5). The spatial distribution of the salinization process in Fig.5 shows that the most seriously affected areas are located along the North Sea coast (intrusion and artificial recharge) and along branches of the rivers Rhine and Meuse (bank infiltration and upconing). Typical salinization rates for pumping stations range in between 1 and 5 mg Cl^-/l/y, in only 2 out of 94 cases higher rates were observed (Fig.5). The salinization rates of 'bad' individual pumping wells normally is substantially higher (5-50 mg Cl^-/l/y), and in individual piezometers rates as high as 500 mg Cl^-/l/y are not rare in coastal aquifers.

TABLE 2. Chemical characteristics of the 7 types of water resources for public drinking water supply in the Netherlands, anno 1992.

Type:	unit	A	B	I	K	O	U
Diagnostic features		phreatic groundwater	(semi) confined groundwater	artificial recharge and recovery	groundwater from limestone	surface water	Rhine bank infiltrate
No of active pumping stations		103	102	9	15	14	15
Cl^-	mg/l	33	29	114	31	98	116
SO_4^{2-}	mg/l	38	14	76	68	65	47
NO_3^-	mg N/l	1.72	0.11	1.32	2.89	3.00	0.26
HCO_3^-	mg/l	166	217	189	355	158	244
B *	μg/l	24	56	170	20	105	76
Ba	μg/l	34	31	26	73	56	95
EOCl	μg/l	0.13	0.14	0.25	0.11	0.25	0.37
F	μg/l	83	102	239	151	223	130
I #	μg/l	5	7	12	5	8	20
Li #	μg/l	6	5	11	-	-	7
^3H **	Bq/l	2.43	0.95	6.93	2.29	7.43	6.07
^{226}Rn **	mBq/l	1.8	1.8	1.3	9.0	0.6	1.8
Cl^-, start	mg/l	22	20	$41^§$	15	102	49
ΔCl^-	mg/l	11	9	73	14	-15	67
$v_{Cl} = \Delta Cl/\Delta t$	mg/l/y	0.21	0.18	0.88	0.48	-0.81	0.87

$\Delta Cl^- = Cl^-_{1992} - Cl^-_{start}$; v_{Cl} = salinization rate = $\Delta Cl^-/(1993$ - start year).
** = total iodine in drinking water in 1978 (based on data in Reijnders et al., 1980); * = in drinking water in 1984 (unpubl. results from RIVM, obtained from A.J. van den Eshof); ** = in drinking water in period 1981-1984 (based on data in Glastra et al., 1989); § = at the start, prior to the introduction of artificial recharge.

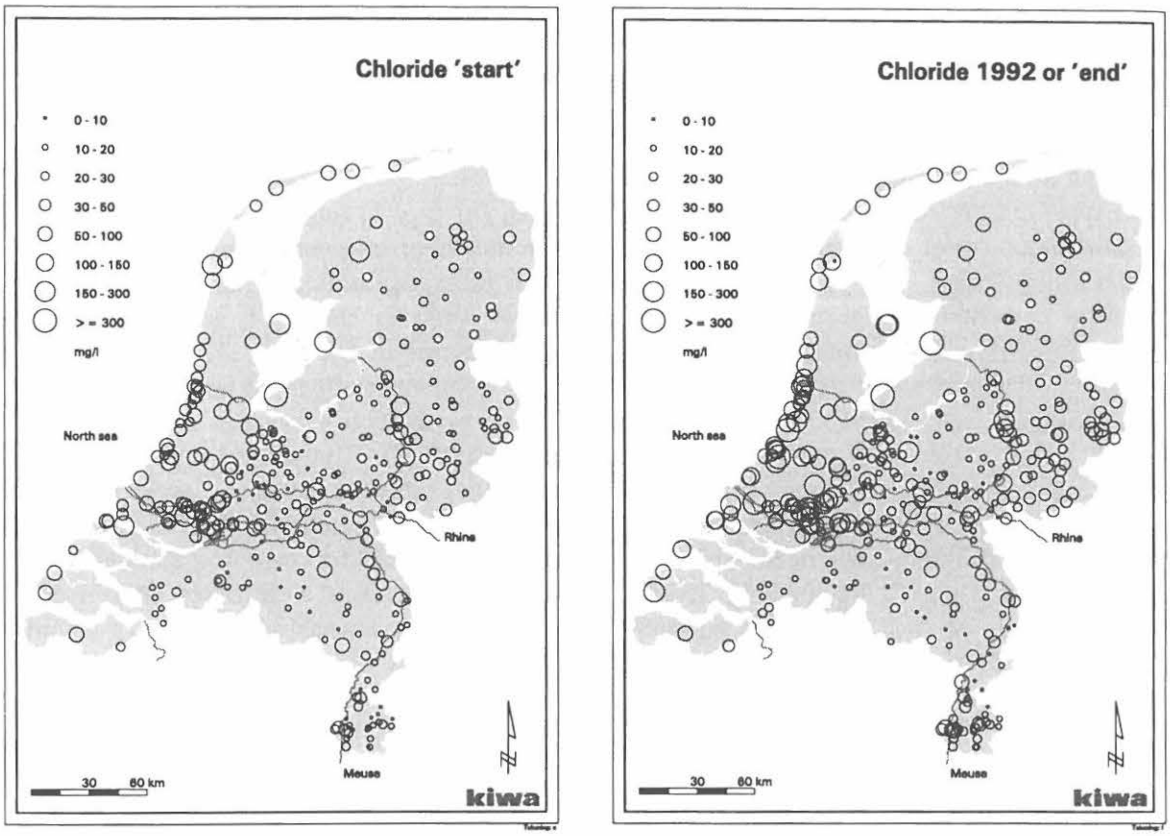

FIG. 3. Areal distribution of the chloride concentration of raw water from pumping stations in the Netherlands, at their start (first year of operation) and in 1992 (or for the closed stations, in the year of closure).

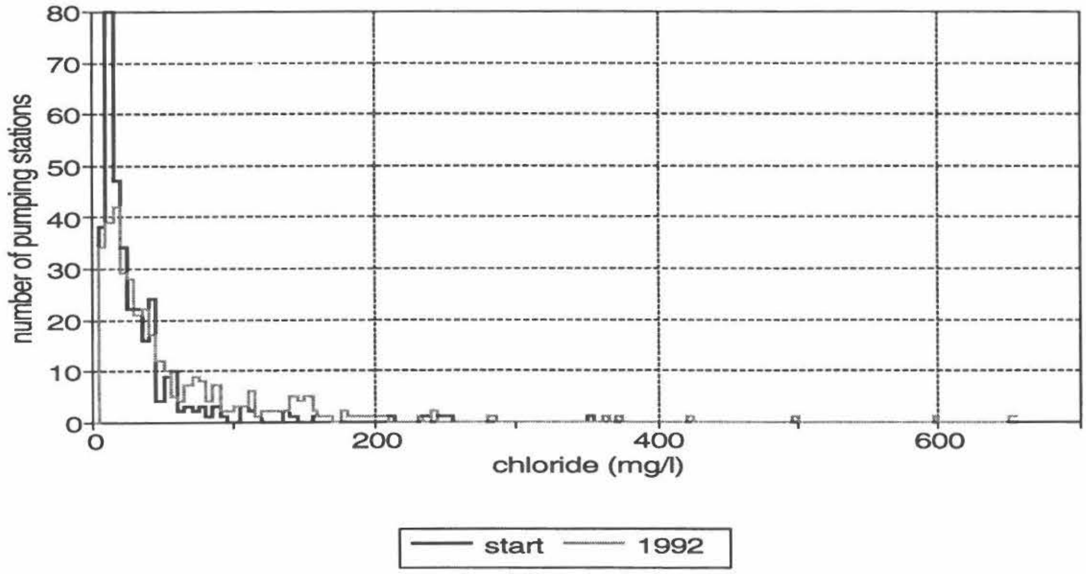

FIG. 4. Histogram showing the frequency distribution of the chloride concentration of raw water from all pumping stations, at their start (first year of operation) and in 1992 (or for the closed stations, in the year of closure).

Diagnosis: looking for the causes

METHODS: In this survey of the raw water produced by 365 pumping stations in the period 1853-1992, salinization is defined as a net rise in chlorinity superior to 20 mg Cl^{-}/l in 1992 (or in the year of close-down) since the pumping station became active. Stuyfzand & Stuurman (1994) recognized 11 sources of salinization of groundwater in the Netherlands, and recommended several tracers for identifying them. In the case of water abstracted for drinking water preparation, 2 main groups of salinization are discerned for simplicity:

- the continental salinization type, which is related to either agriculture, evaporation, bank infiltration, artificial recharge, local pollution sources and sea spray; and
- the maritime salinization type, which is related to direct North Sea intrusion, and ancient North Sea water (which transgreded during the Holocene or was trapped during sedimentation of marine, fine-grained deposits during the Holocene and Lower Pleistocene and Upper Tertiary).

The criteria for both types of salinization are given in Table 3: the continental type was assigned in any case to surface water (O), artificially recharged surface water (I) and Rhine bank infiltrate (U). Pumping stations were a priori classified as such on the basis of their water resource and previous research, including ^{18}O isotopic data for difficult cases of Rhine bank infiltrate (Stuyfzand, 1989; Stuyfzand, 1993). The continental type was also assigned in case of the other types of pumping stations (the true groundwater stations: A, B or K), on the condition that in 1992 either nitrate was $\geq$5 mg N/l, or the SO_4^{2-}/Cl^- ratio was $\geq$0.5 (on mg/l-basis), or tritium was $\geq$4 Bq/l (= $\geq$34 TU). In all other cases the maritime salinization type was assigned.

FIG. 5. Salinization rate and scale for pumping stations of raw water for drinking water supply in the Netherlands. The salinization rate (v_{Cl}) is defined as $\Delta Cl^-/\Delta t$ (see foot notes in Table 3), the salinization scale is fully explained in Table 3 (scales - and -1 combined into '+ sign').

TABLE 3. The salinization scale for drinking water, with its criteria.

	description of scale No	state of pumping station (PS)	ΔCl^- § mg/l	vCl ## mg Cl/l/y	ΔH ** m	Continental or Maritime: types of PS	NO_3 mg N/l	SO_4/Cl mg/l	^3H Bq/l
-	undefined	act./closed	{? or	? or	? or	? or	? or	? or	?}
-1	no salinization	closed	<20	-	-	all	-	-	-
0	no salinization, no risk	active	<20	<1	-	all	-	-	-
1	no saliniz., risk present	active	<20	{>1 or	<20}	all	-	-	-
2	continental salinization	active	≥20	-	-	{I,O,U or	{≥5 or	≥0.5 or	≥4}}
3	maritime salinization	active	≥20	-	-	{A,B,K and	{<5 and	<0.5 and	<4}}
4	cont. saliniz., PS closed	closed	≥20	-	-	{I,O,U or	{≥5 or	≥0.5 or	≥4}}
5	marit. saliniz., PS closed	closed	≥20	-	-	{A,B,K and	{<5 and	<0.5 and	<4}}

§ = if active: $Cl^-_{1992} - Cl^-_{start}$, if closed: $Cl^-_{closure\ year} - Cl^-_{start}$; ## = if active: ΔCl^-/(1992 - start year), if closed: ΔCl^-/(1992 - closure year); ** = vertical distance between lower side of well screen and the brackish water interface (150 mg Cl^-/l).

TABLE 4. Survey of the salinization scale of raw water for public drinking water supply in the Netherlands, with the mean characteristics of each group.

Salinization scale:		-	-1	0	1	2	3	4	5
Diagnostic features		unknown by lack of data	no salin, PS closed	no salini-zation	no salin, risk present	contin. salini-zation	marit. salini-zation	contin. salin. (PS closed)	marit. salin. (PS closed)
No. of pumping stations		30	56	184	1	36	16	25	17
Percentage of all 365 stations		8	15	50	0.3	10	4	7	5
No of type A stations		7	**22**	**82**	0	8	6	4	5
No of type B stations		**9**	**21**	**79**	0	6	**10**	1	**12**
No of type I stations		0	1	1	0	8	0	0	0
No of type K stations		3	8	10	0	2	0	0	0
No of type O stations		**9**	3	8	**1**	2	0	7	0
No of type U stations		2	1	4	0	**10**	0	**13**	0
Mean first year of operation		1964	1925	1946	-	1921	1929	1914	1910
Mean raw water production	(Mm^3/y)	10.9	0.7	5.1	-	7.4	5.1	6.5	0.43
Mean surface Level = SL	(m+MSL@)	18	25	19	-	11	5.4	4.0	2.1
Mean abstraction level	(m-SL)	66-123	35-56	45-94	-	22-54	53-100	21-40	26-40
Mean depth to brackish water##	(m-SL)	206	170	187	-	97	140	88	52
Mean dist. screen to brack. water† (m)		118	123	92	-	45	41	29	17
Mean salin. rate (v_{Cl})	(mg Cl/l/y)	-	-0.03	-0.01	-	1.03	1.07	1.52	3.59
Mean Cl^- 1992/year of closure	(mg/l)	50	36	28	-	98	84	132	217
Mean Cl^- in first year	(mg/l)	-	38	26	-	35	24	49	73
Mean HCO_3^- 1992	(mg/l)	221	224	192	-	232	229	302	320
Mean SO_4^{2-} 1992	(mg/l)	49	28	30	-	33	8	52	30
Mean NO_3^- 1992	(mg/l)	2.0	1.7	1.2	-	0.8	0.1	1.1	0.2
Mean B 1984	(μg/l)	79	19	36	-	76	110	191	-
Mean Ba 1992	(μg/l)	59	29	34	-	59	36	57	34
Mean F^- 1992	(μg/l)	160	122	104	-	137	114	224	250
Mean I 1978	(μg/l)	9	9	5	-	13	25	18	18
Mean Li^+ 1978	(μg/l)	-	7	5	-	8	11	11	7
Mean ^{226}Rn 1981-84	(mBq/l)	4.4	2.5	1.9	-	3.0	1.8	2.3	0.6
Mean ^3H 1981-84	(Bq/l)	1.4	3.2	1.9	-	5.8	0.5	2.4	0.7

* = 100*closed/(active + closed); ** = closed/(1993-first year); @ = Mean Sea Level; ## = 150 mg Cl^-/l interface;
† = from lower side of well screen to the fresh-brackish water interface (150 mg Cl^-/l).

The philosophy behind the fences posed by nitrate, sulphate/chloride-ratio and tritium is, that actual and ancient North Sea groundwaters normally do not contain nitrate and tritium, and normally have a SO_4^{2-}/Cl^-ratio ≤0.14 on mg/l-basis (Stuyfzand, 1993; Stuyfzand & Stuurman, 1994). And in addition, low levels of these quality parameters for groundwater generally point at a negligible contribution of shallow fresh groundwater to the mixture pumped.
Obviously, the criteria used for classifying a pumping station as salinized and the further ranking of it according to Table 3 may seem rather subjective. However, the results were verified for many cases where detailed field investigations had been carried out in the past, and the rapid screening method (the salinization scale) proved to work very well. Certainly there are some cases with both a continental and a maritime salinization process, like in case of several stations pumping both Rhine bank infiltrate and very deep autochthonous groundwater. In those cases the salinization type is to be considered as the dominant one.

RESULTS: The results of classifying all pumping stations according to their salinization scale (incl. their salinization type) are depicted in Fig.5. Additional mean characteristics for each salinization scale, viz. number and type of pumping stations, hydrological and hydrochemical data, are presented in Table 4.
The data in Table 4 show that 61 pumping stations (17%) of a total of 365 pumping stations are classified as salinized due to continental causes, and that 33 stations (9%) salinized for maritime reasons. From a total of 102 abandoned stations, 42 (41%) closed with salinization phenomena, of which 17 (5%) suffered from maritime salinization and were probably closed for that reason. Salinization is therefore a wide-spread problem in the Netherlands, which in about 50% of its cases is due to either continental or maritime reasons. Station type B (pumping (semi)confined groundwater) is most susceptible to maritime salinization (67% of all cases with scale 3 and 5) and close down (71%), probably for that reason. Station type U (Rhine bank infiltrate) is most susceptible to continental salinization (38% of all cases with scale 2 and 4) and close down (52%), probably for other quality reasons than salinization ('anoxia' and micropollutants).
Water with continental salinization shows, as compared to water without salinization, on average higher concentration levels of HCO_3^-, B, Ba, EOCl, F, and especially I and Li, but lower levels of NO_3^-. This is explained by a very high contribution of station types I and U (see Table 2 for their mean chemical composition).
The spatial distribution of the salinization process in Fig.5 and hydrological data in Table 4 reveal that the most susceptible stations are located in the lowest parts of the Netherlands (mean surface level ≤11 m+MSL) with the shallowest position of the fresh-brackish water interface below the lower side of the pumping screen: along the North Sea coast (intrusion and artificial recharge) and along branches of the rivers Rhine and Meuse (bank infiltration and upconing).

Remediation: how to lower salinization

The pumping of large amounts of water showing continental salinization (the mild variety), in general means for drinking water supply that the pumping station (or well field) does not need to be abandoned or pinched, but that additional purification of the raw water is or soon will be required. Further treatment is necessary to remove organic micropollutants and to reduce the nitrate and calcium (or aluminium) concentrations, as the salinization is associated in most cases with environmental pollution or the change-over from autochthonous to allochthonous groundwater (like in case of artificial recharge and bank infiltration).
Preventive measures are composed of sanitation of land-use and point sources of pollution within the contributing area of the well field or fluvial basin.
The pumping of small amounts of water showing maritime salinization (the more severe variety), normally implies that the well field has to be closed or rigorously pinched, unless desalinization techniques become economically feasible. Preventive measures consist of extensifying the well field (increasing the distance between wells), horizontal in stead of vertical wells, translocation of

hazardous wells to less susceptible areas within the concession (outside the upconing area or one aquifer higher), and artificial recharge (for instance just below the pumping well, one aquifer deeper).
In looking for new well fields, a low chance on salinization seems to be associated with the following hydrological conditions: (1) a high initial distance in between the fresh-salt water interface and the lower side of the pumping screen; (2) the presence of an aquitard in between the well screen and the initial fresh-salt water interface; (3) the absence of an aquitard with high vertical flow resistance and a large areal extent in between the well screen and groundwater table; (4) no restrictions in lateral flow due to other well fields upgradient or the presence of vertical semi-pervious boundaries (like glacial basins filled with varve clays, and faults); (5) position in the infiltrating parts of the groundwater flow domain; (6) no other human interferences (afforestation, urbanisation, intensive drainage, land reclamation); and (7) no other natural interferences (coastal erosion).
The mixing of fresh and salt groundwater should be prevented as much as possible, as this means a serious loss of potable water. This can be achieved to some degree, by pumping as continuously as possible. Strong fluctuations in the pumping rate may create the alternation of upconing and gravitational subsidence of the brackish upconing. In a frequently changing flow domain this contributes to the mixing of fresh and brackish water.

Concluding remarks

Pumping stations for drinking water supply constitute a powerful monitoring system for environmental pollution, including salinization. It requires, however, that ancient historical data be retrieved from dusty paper-archieves which were loaded in the pre-floppydisk-age. Data on the close-down, changes in water resources (from surface to groundwater, from autochthonous to allochthonous groundwater, etc.), changes in pumping depth, pumping rate and analytical methods need consideration as well for obtaining the right interpretations.
In this desk study attention focused mainly on chloride, but some other chemical parameters clearly show interesting distribution patterns: relatively high ^{226}Rn levels are mainly restricted to the limestone areas in the south (Table 2), and tritium activity was in the 1980s highest in surface water and groundwater derived from surface water (Table 2; contribution of nuclear power plants).

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References

GLASTRA, P., R. VAN ZANTEN, R.M.S. DROST & F.C.M. MATTERN 1989. Onderzoek naar de radioactiviteit van drinkwater over de periode 1981-1984. RIVM-rapport 248201001, Bilthoven, 30p.
FONDS, A.W. 1989. De som van adsorbeerbare organische halogeenverbindingen (AOX) in het Nederlandse drinkwater. RIVM-rapport 218108007, 17p.
LEEFLANG, K.W.H. 1974. Ons drinkwater in de stroom van de tijd. VEWIN, Rijswijk, 228p.
PETERS, J.H. & J.A. MEIJER 1993. Will upconing be a problem in the Netherlands? Water Supply 11, 157-163.
REIJNDERS, H.F.R., J. STOLTENKAMP & M.J. STOLTENKAMP-WOUTERSE 1980. Het totaal jodium, jodide en organisch-jodiumgehalte in drinkwater in Nederland in 1978. RIVM-rapport 87/80LMC, Bilthgoven, 12p.

REIJNDERS, H.F.R., J.J. VAN STADEN & N.W. NAGTEGAAL 1983. Voorkomen en trend van enige chemische bestanddelen in uitgaand water van drinkwaterpompstations in Nederland. RIVM-rapport 218108001, 71p.
STUYFZAND, P.J. 1989. Hydrology and water quality aspects of Rhine bank ground water in The Netherlands. J. Hydrol. 106, 341-363.
STUYFZAND, P.J. 1993. Hydrochemistry and hydrology of the coastal dune area of the Western Netherlands. KIWA Publication, also Ph.D Thesis Vrije Univ. Amsterdam, ISBN 90-74741-01-0, 366 p.
STUYFZAND, P.J. 1994. The impact of land reclamation on groundwater quality and future drinking water supply in The Netherlands. Water Sci & Technol. 31, 47-57.
STUYFZAND, P.J. & J.W. KOOIMAN 1996. Elimination of pollutants during artificial recharge and bank infiltration: a comparison. In 'Artificial recharge of groundwater' (A.L. Kivimäki & T. Suokko, eds), Proc. Int. Symp., Helsinki, June 3-5 1996, NHP-report 38, 223-231.
STUYFZAND, P.J. & R.J. STUURMAN 1994. Recognition and genesis of various brackish to hypersaline groundwaters in The Netherlands. Proc. 13th Salt Water Intrusion Meeting, June 1994 Cagliari, Italy, in press; also Kiwa-rapport SWI-95.133, 12p.
VAN BEEK, C.G.E.M., F.A.M. HETTINGA & P.K. BAGGELAAR 1990. Onderzoek naar trendmatige veranderingen in de kwaliteit van het grondwater onttrokken door de Nederlandse waterleidingbedrijven. Kiwa-rapport SWE 90.013, 48p.
VAN DUIJVENBOODEN, W. & G.T. BUSZ 1978. Overzicht van de grondwaterwinplaatsen voor de openbare drinkwatervoorziening op basis van een classificatie van de geëxploiteerde watervoerende pakketten. RID-rapport hy.h-78/01, 25p.
VEENENDAAL, G., C.G.E.M. VAN BEEK & L.M. PUIJKER 1986. Het voorkomen van organische stoffen in het grondwater onttrokken door de Nederlandse waterleidingbedrijven. KIWA-Meded. 97, 99p en KIWA-rapport SWO-86.267 (de analyseresultaten).
VERSTEEGH, J.F.M. & F.J. WETSTEYN 1994. De kwaliteit van het drinkwater in Nederland, in 1992. RIVM-rapport 731011002, VROM-rapport 1994/58, 60p.
VERWEIJ, W., T. VAN DER VELDE-KOERTS, J.L.M. DE BOER & W. MENNES 1994. Zeldzame aarden in drinkwater en drinkwaterbronnen. RIVM-rapport 734301003, 58p.
VEWIN, 1895-1996. Statistische overzichten van de waterleiding in Nederland, met uitkomsten van het fysisch en chemisch onderzoek. Jaarrapporten 1895-1939 (elk jaar), 1943, 1949, 1952, 1957, 1966, 1968, 1973, 1981, 1986, 1992.
VOGELAAR, A.J. 1993. Indeling van winplaatsen voor onderzoek naar sporenelementen. Kiwa-rapport SWI 92.162, 15p.