ACTUAL AND FUTURE BRACKISH WATER INTRUSION IN THE WATERBOARD OF RIJNLAND, THE NETHERLANDS

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ABSTRACT

Located in the western part of The Netherlands, the Waterboard of Rijnland lies almost completely below sea level. Salt water intrusion occurs mainly through polders and shiplocks. The waterboard harbours several (world famous) agricultures, which depend on water with low levels of salt. To reduce chloride concentrations in the surface water, the water system is being flushed by fresh Rhine water in summer. It is expected that, due to autonomous salinization, climate change, sea level rise, and a different management of the Haringvliet sluices in the Rhine estuary, not only will salt water intrusion increase, but also will the only source of fresh water be no longer available. Together with Kiwa Water Research, the Waterboard of Rijnland started a research project to investigate present and future brackish water intrusion. This paper gives an overview of the analyses and results.

THE WATER SYSTEM OF RIJNLAND

The Waterboard of Rijnland is located in the western part of the Netherlands, along the North Sea coast between The Hague and Amsterdam. In an area of about 110.000 ha the water board is responsible for water quantity, water quality and the condition of the dikes. The area is generally situated below sea level and comprises a system of polders (areas surrounded by dikes) and a so called ´boezem´, which is the main system of canals and lakes on which the polders discharge their water surplus. Figure 1 shows a map of the water board, figure 2 schematically depicts the system of boezem and polders. The water of the boezem is strictly maintained at a level of -0,62 m below sea level in winter and –0,59 m below sea level in summer; lower but still strict water levels are maintained in the polders (varying from 1,00 m tot 6,00 m below sea level).

The surplus precipitation from Rijnland and from a part of an adjacent water board (Bodegraven) is pumped out at four locations: Katwijk, Spaarndam, Halfweg and Gouda (blue arrows in Figure 1, see also table 1), generally in winter, but excessive rain in summer is also pumped out. During summer, water is taken in at Gouda from the tidal river Hollandsche IJssel (a branch of the Rhine) and diverted through the boezem to the polders, to compensate for evaporation and to maintain low levels of chloride. In the past a fair amount of water was also taken in at Gouda and transited to the adjacent water board of Delfland, through a pumping station at Leidschendam, in order to bring fresh water in that region.

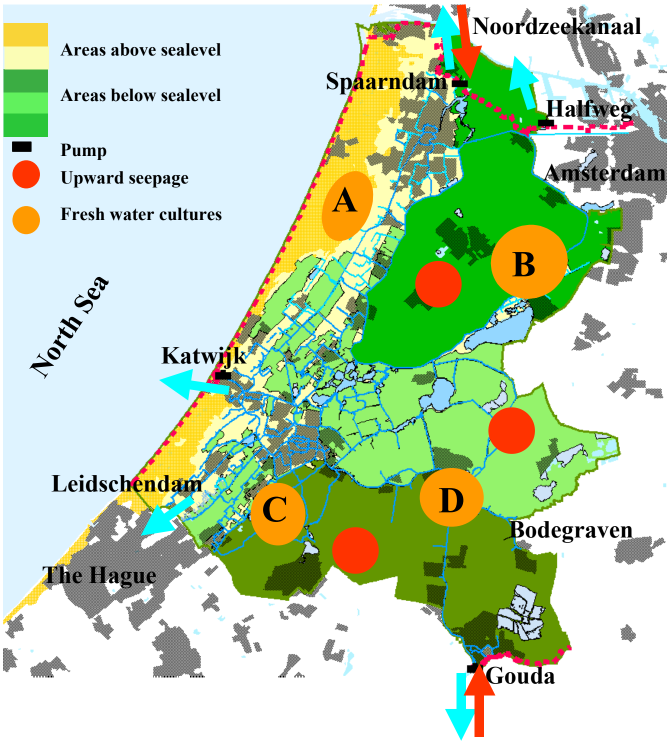


***Figure 1** Map of Rijnland*

Salt water intrusion occurs mainly through polders and shiplocks. Upward seepage of brackish groundwater is the main source of chloride (60%). The aquifers underneath the surface system contain brackish groundwater, due to former marine transgressions. A constant groundwater flow is induced between the North Sea (sea level) and the deeper polders caused by the lower water levels within the polders. The seepage process started in the middle ages, when people began to drain the land, and increased in the 19th century, by the reclamation of lakes (Figure 2). Especially the deeper polders attract brackish water.

The shiplock at Spaarndam is presently the second source of salt water intrusion (20%). This shiplock connects the boezem of Rijnland to the Noordzee Kanaal. This canal is brackish and has a higher water level than Rijnland's boezem. The shiplock is used especially in summer for recreational purposes.

To maintain low chloride levels, the water system is being flushed in summer. Fresh water is taken in at Gouda from the Hollandsche IJssel, and water is simultaneously pumped out at Katwijk, or at Spaarndam and Halfweg. At present, the water of the Hollandsche IJssel has generally low chloride levels, but during dry spells chloride levels may become too high, due to a wedge of seawater travelling up the Rhine, past the branching point of the Hollandsche IJssel.

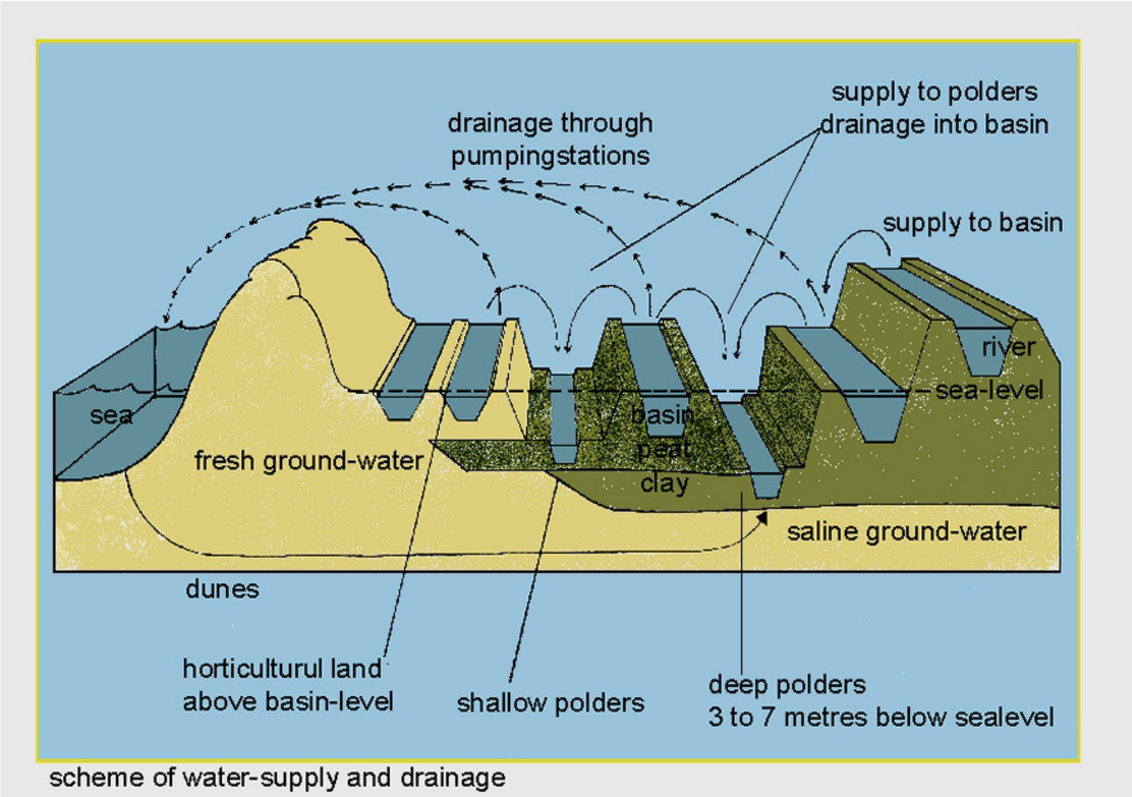
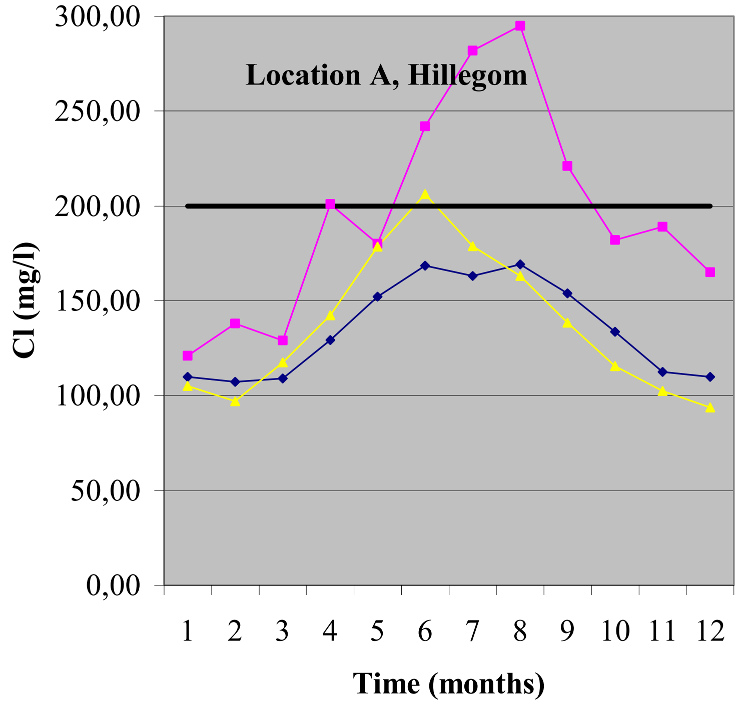
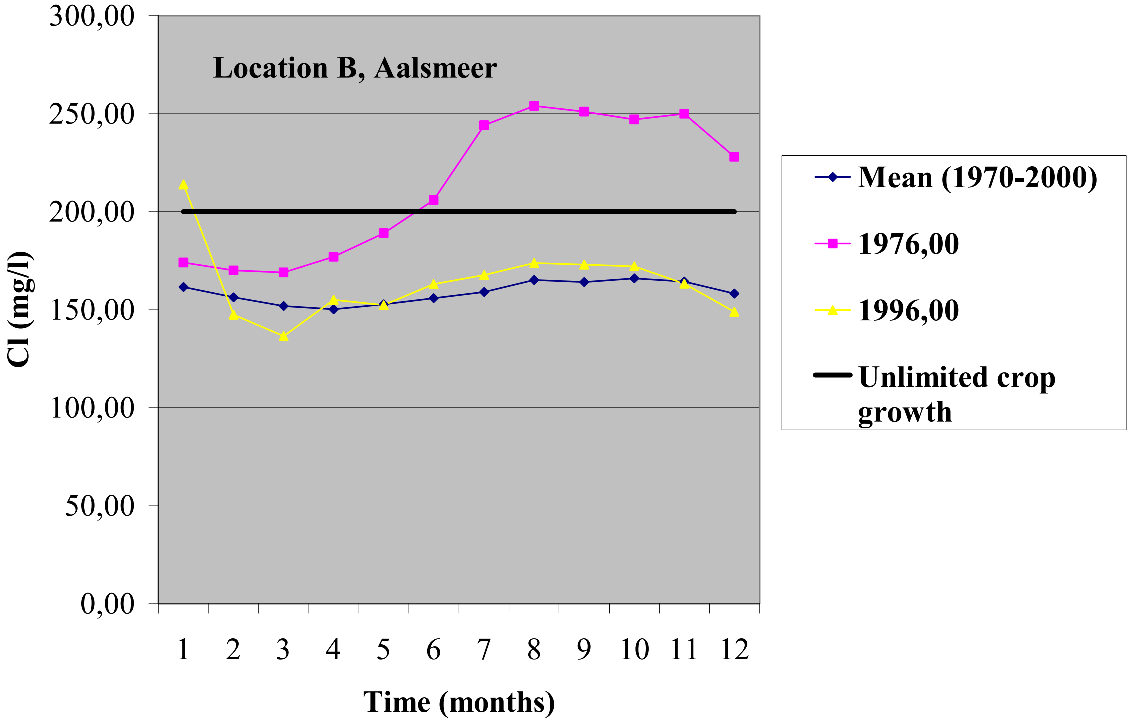


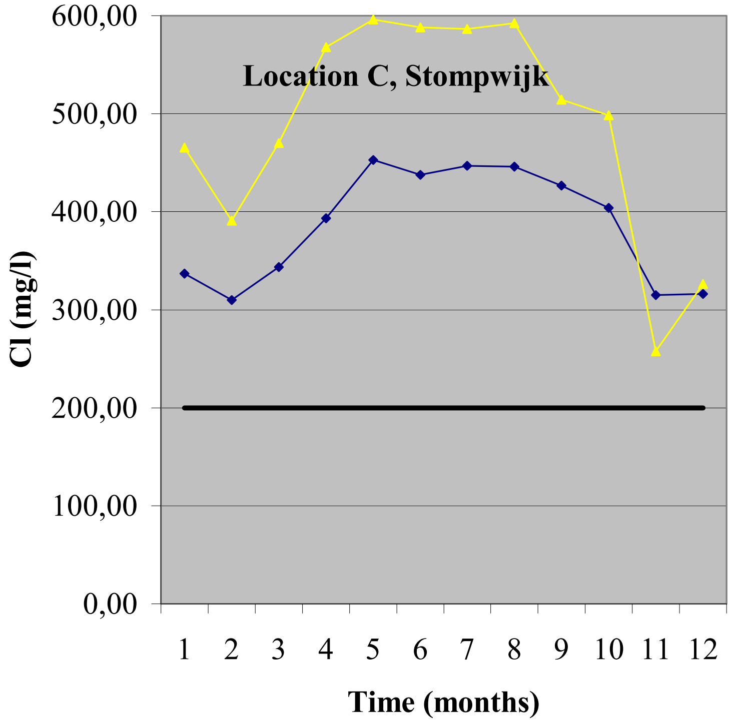
***Figure 2** Schema of polder-boezem system*

WHY IS BRACKISH WATER A PROBLEM IN RIJNLAND?

Most cultures have no problems with elevated chloride levels in the surface water. Some cultures, however, at various locations, suffer regular or incidental damage. They are capital intensive and world famous. Important examples are flower bulbs (tulips, etc), trees and flowers, and horticulture. They are located at sites, which are directly influenced by saltwater, either from upward seepage or shiplocks, or from the intake of water at Gouda. Figure 3a-d gives an overview of monthly averaged and past chloride concentrations at four typical locations (see Figure 1). The chloride level Rijnland tries to maintain (200 mg/l) is also given. Actual chloride concentrations in 1996 and 1976 illustrate the situation in a dry and an extremely dry year, according to Dutch standards. It is clear that locations A and B suffer from high chloride levels only in extremely dry years. The other two locations clearly show the influence of upward seepage (C and D) and of the intake of water from the Hollandsche IJssel (D).


Location A, Hillegom
300,00
250,00
200,00
150,00
100,00
50,00
0,00
Cl (mg/l)
1 2 3 4 5 6 7 8 9 10 11 12
Time (months)


Location B, Aalsmeer
300,00
250,00
200,00
150,00
100,00
50,00
0,00
Cl (mg/l)
1 2 3 4 5 6 7 8 9 10 11 12
Time (months)
Mean (1970-2000)
1976,00
1996,00
Unlimited crop growth



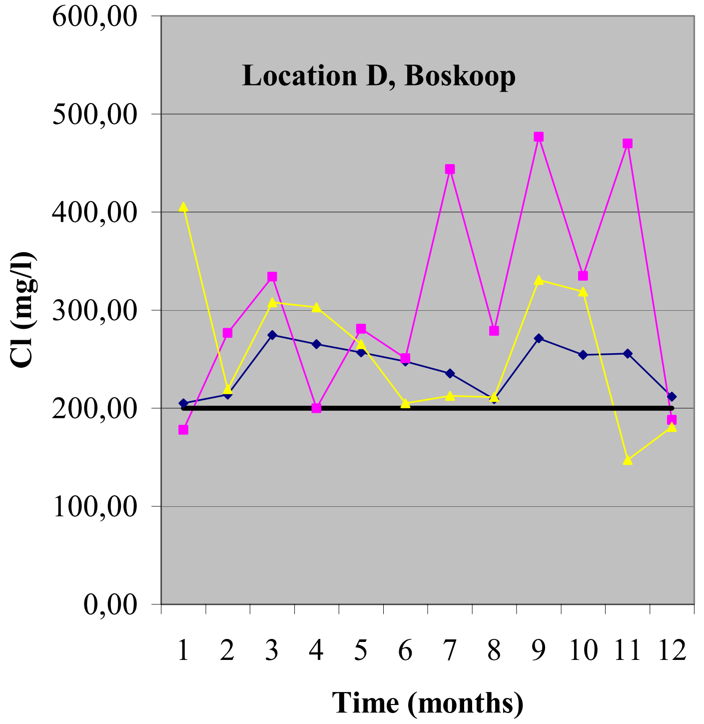


Figure 3a-d *Monthly chloride concentrations at different locations in Rijnland*

SOURCES OF SALT WATER

An analysis of the water- and chloride balance of the boezem over the last 30 years shows some distinct changes in its main items. Tables 1 and 2 show 10-year's average percentages of drainage to and from the boezem in terms of water and chloride. Some highlights from these tables are explained below.

In 30 years the water balance shows an increased input of direct precipitation, via polders and from wastewater plants, caused by an increased precipitation surplus, an ever-becoming stricter maintenance of polder water levels, and by increased population and related water use. Decreased input from Gouda and Bodegraven also took place, for a number of reasons, but mainly because of decreased transit of water to the water board Delfland via Leidschendam and increased water quality. As already stated, flushing is presently needed to reduce chloride levels. Formerly, fresh water was also used to flush wastewater.

The 10-year's average chloride balance shows that polders are responsible for about 60% of the chloride mass in the balance, shiplocks at present yield 20% of the mass. These percentages have increased during the last 30 years. In absolute terms, especially the shiplocks have become more important, mainly due to an increasing use of the shiplocks. A marked decrease of chloride intake from the Hollandsche IJssel at Gouda is also evident, mainly caused by decreased water intake, but also because of lower chloride levels of the River Rhine. Formerly, chloride levels of the Rhine were elevated due to the potassium mines in French Alsace.

In (Water) 10^6 m^3	**(1971 – 1980) 755**	**(1981 – 1990) 746**	**(1991 – 2000) 696**
Direct precipitation	4,4%	5,2%	5,7%
Wastewater plants	10,5%	12,1%	16,1%
Gouda intake	22,4%	12,1%	7,2%
Bodegraven	19,0%	16,7%	10,8%
Polders	39,5%	48,6%	50,1%
Rest (i.e. industry)	5,1%	5,5%	10%
Out			
Pump Spaarndam	17,8%	20,5%	18,3%
Pump Halfweg	17,4%	25,8%	25,5%
Pump Katwijk	29,6%	30,8%	31%
Pump Gouda	6,7%	9,8%	11,9%
Pump	12,0%	3,2%	0,5%
Evaporation	4,3%	3,9%	3,9%
Rest	4,9%	2,8%	4,4%
Polders	7,2%	3,1%	4,6%

Table 1 *10-year's average water balance of the boezem of Rijnland from 1971-2000*

In (Chloride) (10^6 kg)	**(1971 – 1980) 199**	**(1981 – 1990) 179**	**(1991 – 2000) 170**
Waste water plants	8,9%	10,6%	10,2%
Gouda intake	16,5%	8,2%	4,4%
Bodegraven	9,5%	6,6%	3,0%
Shiplocks	12,7%	16,3%	19,0%
Polders	42,1%	57,2%	58,5%
Rest (i.e. Industry)	0,2%	0,2%	4,6%
Out			
Pump Spaarndam	22,9%	22,1%	21,2%
Pump Halfweg	26,4%	34,5%	32,6%
Pump Katwijk	24,6%	23,4%	20,4%
Pump Gouda	4,3%	5,9%	7,3%
Pump Leidschendam	9,1%	2,3%	0,4%
Polders	8,6%	9,6%	15,2%
Rest	3,9%	2,1%	2,9%

Table 2 *10-year's average chloride balance of the boezem of Rijnland from 1971-2000*

SITUATION IN THE FUTURE (2050)

In the future the situation will change for a number of reasons. In the Netherlands, climate change and sea level rise are expected to result in changes as presented in table 3. In line with this table the following changes are expected:

- The autonomous salinization of the polders will continue, as brackish groundwater will get closer to the surface. Further, land subsidence and sea level rise will in the long run increase upward seepage.
- Climate change will result in a changing water balance, with dryer summers (Figure 4). Typical dry years like 1996 will occur more frequently.
- Climate change will also result in an increasing saltwater intrusion of the Hollandsche IJssel. This is related to the discharge regime of the river Rhine. When Rhine discharge gets below 1000 m3/s salt water intrusion occurs in the Hollandsche IJssel, and the intake at Gouda is not possible anymore. Analyses of Rhine discharges at present and in the future made by Middelkoop et al. (2000) indicate that in the future the frequency of low Rhine discharge will increase (see table 3).
- Furthermore, plans of the national government also thread the availability of fresh water and advance the inflow of chloride. In the south of the Netherlands, there are plans to open the Haringvliet Sluices in order to restore ecology in the Haringvliet estuary. The Haringvliet sluices currently act as a barrier to keep salt water out of the lower delta of the River Rhine. Opening them will result in salt water intrusion, not only in the vicinity of the Haringvliet but also in the northern part of the Rhine delta. Opening the Haringvliet sluices will jeopardize the availability of fresh water to waterboards in the western part of the Netherlands. There are 3 options: ´De Kier´, ´Getemd Getij´ and ´Stormvloedkering´. In each option the opening in the sluices will be larger. The Kier will commence in 2005. Most probably Getemd Getij will follow in 2015. Table 3 shows the expected number of days that intake is not possible at Gouda from the Hollandsche IJssel during the period April – September due to high chloride levels for each option. Much research is going on at present to investigate how to proceed with these plans. In the north, there are plans to enlarge the sluices at IJmuiden to further develop the harbour of Amsterdam. If continued this will about double the chloride levels in the Noordzeekanaal and, without countermeasures, double the input of chloride through the shiplock at Spaarndam.

		2050		
	present	minimum	Mean	maximum
Sea level change (cm)		10	25	45
Land subsidence (cm)		50	50	50
Climate change P (%)		1,5	3	6
T (°C)		1	1	2
Nr of days that intake is not possible at Gouda from the Hollandsche IJssel during the period April – September due to high chloride levels				
• Due to low Rhine discharge	4	4	5	11
• Due to the opening of the Haringvliet Sluices	4	5 (de Kier)	81 (Getemd Getij)	77 (Stormvloed kering)

Table 3 *Expected changes of climate, sea level rise and land subsidence in the Netherlands in 2050.*

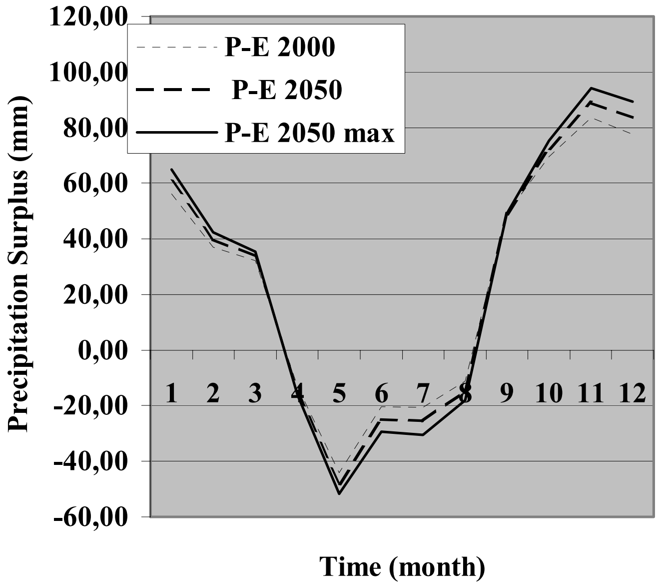


Figure 4 *Changing water balance due to climate change*

Together with Kiwa Water Research, The water board Rijnland will assess the impact of these changes on Rijnland. Three scenarios were developed, in which we defined minimums, means, and maximums of the salinization of the various future inputs to the water system of Rijnland. To compare the scenarios, the present situation was also calculated. Other aspects were maintained as they are at present, i.e. land use and water levels were kept the same. *Oude Essink* (2002) and *Schaars and Maas* (2002) go into the technical details of the models used to calculate the effects of these scenarios.

Preliminary results indicate that due to autonomous salinization, sea level change, land subsidence and increased precipitation, upward seepage will increase by about 5 %. Mainly due to the autonomous salinization this may result in a 26% increase of chloride reaching the surface under the maximum scenario for 2050. Altogether, Rijnland may be facing the facts presented in table 4.

	2000	2050, max	%
Autonomous salinization	97.000	111.000	+14
Autonomous salinization, climate change, sea level rise and land subsidence		124.000	+26
Shiplock Spaarndam	32.000	64.000	+100
Gouda	7500	++	??

***Table 4** Assessment of changing salinization in terms of yearly chloride mass in tons of chloride per year on the boezem of Rijnland*

POSSIBLE MEASURES TO BE TAKEN

The results presented here have not yet been integrated. Further research will be done, to quantify the effects at different locations in Rijnland. We also have to decide how to proceed, depending on other developments in the region. More research is needed, especially because measures will have to be weighted against their costs and benefits at a scale probably larger than Rijnland.

Possible measures to be taken can be divided into measures that can be performed by the water board alone, and those that can only be performed by or together with other parties. Measures to be taken by the waterboard are: optimization of water flow within the boezem, higher water levels in polders and adaptation of the shiplock at Spaarndam. By optimising the water flow in the boezem, it may be possible to separate, more than now, fresh water from brackish. Higher water levels may reduce upward seepage, especially in the deep polders where surface water is about 1 meter below soil surface. Preliminary results in a polder show that this is possible without affecting the agriculture too much. Analyses of the operation of the shiplock shows that a reduction of chloride intake of 30-50% is possible by reducing the opening time of the doors and by increasing the number of ships per lockage.

Measures to be taken together with other parties are more rigorous and difficult to achieve. Depending on the need for fresh water it may be cost effective to create new lakes in deep polders, with flexible water levels, to store fresh water and to (locally) reduce seepage. Another measure might be to move the intake of fresh water more to the east. A combination of both is also possible. On the other hand, when fresh water is not available in the future, due to climate change for instance, it may be necessary to change land use in this part of the country such as to become less dependent on fresh water.

REFERENCES

Middelkoop et al., 2000. The impact of climate change on the river Rhine and the implications for water management in the Netherlands. RIZA report 2000.010.

Oude Essink, Gualbert, and Frans Schaars, 2002: Impact of climate change on the groundwater system of the Waterboard of Rijnland, the Netherlands, to be presented at the 17th Salt Water Intrusion Meeting, Delft 2002.

Schaars, Frans, and Kees Maas, 2002: Forecasting the dynamical salt concentration of the surface waters of the Rhineland Waterboard, to be presented at the 17th Salt Water Intrusion Meeting, Delft 2002.