

# Effects of climate change on the water table in the coastal dunes of the Amsterdam Water Supply

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## ABSTRACT

In this paper we show possible effects of climate change on both groundwater recharge and groundwater levels in the Amsterdam Water Supply dunes. Based on global climate scenarios by the IPCC, the Royal Dutch Meteorological Institute (KNMI) formulated four plausible regional climate scenarios for the Netherlands. These scenarios comprise changes in temperature, wind, precipitation and in reference evaporation. Using a KNMI-transformation procedure, historical time series of precipitation and evaporation were transformed to future time series for the two opposite most extreme scenarios (a 'wet' and a 'dry' one). Subsequently, these were used as input to AMWADU, an unsteady state groundwater model based on both MODFLOW2000 and the recently developed Unsaturated Zone Recharge (UZR) package and the Salt Water Intrusion (SWI) package. Transient simulations were carried out to determine long-term annual fluctuations of the water table in the coastal dune area of the Amsterdam Waterworks. In addition, the expected rise of the North Sea water level and effects on salt fresh water flow were included in the simulations. The results show a general rise of the water table resulting in substantial more moist and wet growing conditions for dune vegetation. Two feedback mechanisms of plants influence the effect of climate change on evapotranspiration: (1) a higher water use efficiency of plants at higher CO<sub>2</sub> levels and (2) an increasing share of bare soil and non-rooting species (mosses and lichens). We estimated the effect of these feedbacks and subsequently adapted the time series for evapotranspiration. This resulted in substantial higher maximum water tables and more pronounced seasonal water table fluctuations compared to the simulations in which the adaptation of vegetation to climate change was ignored.

## INTRODUCTION

The coastal dune water companies in the Netherlands need to consider ecological effects of climate change at coastal dune systems for their nature conservation role (Olsthoorn & Kamps, 2006). Aims of this research are to explore possible eco(hydro)logical effects of climate change and to find possible gaps in knowledge that need further investigation. The ecological part of this study was carried out by Kiwa Water Research (Witte et al., 2008); the results have been applied by Waternet to show possible effects of climate change on both groundwater recharge and water table levels in the Amsterdam Water Supply dunes (AWD) (Kamps, 2008). Obviously, the choice of time horizon strongly influences the effects of climate change. In this paper we will describe calculated effects of climate change until the year 2050. This period is sufficiently long for vegetation and hydrology to adapt to climate change, yet not being completely out of grasp for decision makers.

## CLIMATE SCENARIOS

Based on global climate scenarios by the IPPC, the Royal Dutch Meteorological Institute (KNMI) formulated four plausible regional climate scenarios for the Netherlands (Van den Hurk et al., 2006). The

	modest temperature rise +1 °C	warm temperature rise +2 °C
Air circulation patterns change	<b>G+</b>	<b>W+</b>
Air circulation patterns unchange	<b>G</b>	<b>W</b>

**Table 1. Definition of the four climate scenarios for the Netherlands, rise of temperature in 2050 relative to 1990**

scenarios comprise two variables. The first is a worldwide rise of temperature: either "modest" (+1 °C) or "warm" (+2 °C). The other variable concerns whether the general air circulation pattern, presently dominated by southwestern maritime and moist Atlantic winds, will change to a circulation pattern dominated by dryer eastern continental winds. The temperature rise has been defined for the period 1990 until 2050, 1990 taken to be representative for the period 1976-2006. Using a KNMI-supplied transformation procedure, historical time series of precipitation and evaporation have been transformed to future time series for the scenarios. This transformation influences not only changes in precipitation intensity and evaporation but the seasonal distribution as well (Anonymous, 2007). The climate scenarios also include low (+0.20 m), medium (+0.60 m) and high (+1.10 m) estimates for the rise of the average North Sea water level (MSL) in the year 2100. Because of the location of the AWD, this sea level rise cannot be neglected in climate scenarios.

## FEEDBACK MECHANISMS

Plants respond to higher CO<sub>2</sub> levels in the atmosphere by producing more biomass, increasing the Leaf Area Index (LAI). Another effect of higher CO<sub>2</sub> levels on plants is that they will sooner reach the saturation point for C demand, leading to a more swiftly closing of their stoma. These effects will result in a net reduction of water demand, which has been quantified for several types of vegetation (Witte et al., 2006; Kruit et al., 2007). Changing growing conditions will constrain the adaptation by plants to climate change.

	Climate scenario W	Climate scenario W+
<b>Ground water dependent vegetation</b>	<b>8 %</b>	<b>16 %</b>
<b>Ground water independent vegetation</b>		
north slope	1 %	2 %
south slope	7 %	26 %
dune top	2 %	9 %
average	<b>4 %</b>	<b>14 %</b>

**Table 2. Correction of the ground water recharge for climate scenarios W and W+.**

incorporate this feedback mechanisms in ground water simulations, corrections factors (c<sub>3</sub>) have been derived to be applied to calculated ground water recharge.

Based on literature and field studies an empirical relation was established between drought stress and percentage of dry sand (Bartholomeus, 2004). The vegetation coverage also depends on aspect and inclination of hill slopes. Simulations have been made with the unsaturated zone program SWAP (Dam van et al., 1997) to study the effect of

climate scenarios on the percentage of bare sands for various aspects and inclinations of dune slopes. To

## TRANSIENT SIMULATION OF THE CLIMATE SCENARIOS

### Method

Transient simulations have been carried out to assess future water table changes in the AWD. These simulations have been performed with AMWADU, an unsteady state groundwater model based on MODFLOW2000 ((Harbaugh et al., 2000). The version used here incorporates the SWI package (Bakker, 2005) to simulate fresh and salt ground water flow and the recently developed Unsaturated Zone Recharge (UZR) package (Kamps, 2006).

The two most extreme climate scenarios W and W+ have been selected for simulation with and without correction for feedback mechanisms of the vegetation (Table 1). The results will be compared with the "present climate scenario". Altogether five scenario have been simulated. The simulation periods start in 1980 with an initial fresh/salt water interface inferred from measurements, and end in 2061. The model input for the period 1980-2004 has been based on measurements; boundary conditions (other than recharge from precipitation) for the period 2005-2061 have been assumed constant and are based on average measured conditions in 2005. Transformed measured precipitation and evaporation series based on the period 1960-2004 have been used as future model input for the four climate scenarios. Obviously, for the "present" climate scenario untransformed data have been used for model input. First, the period 1980-2037 was simulated with stress periods of one year, allowing the model's fresh/salt water interface and heads to adapt to the new climate scenario conditions. The period 2038-2061 was simulated with stress periods of a month, to obtain seasonal water table fluctuations that are considered representative for the year 2050 for each climate scenario. North Sea level rises in the climate scenarios from 0.00 MSL to 0.25 MSL were applied instantaneously in 2005; the rise is not gradual because the period 2038-2061 has to be representative for the year 2050.

#### Calculation of natural recharge

Ground water recharge is calculated in advance with the 1D program ONZAT (Van Drecht, 1983). This model uses the Richards equation to translate precipitation and evapotranspiration data into groundwater recharge, depending on the vegetation type, thickness of the unsaturated zone and soil properties. ONZAT calculates time series of groundwater recharge for 192 combinations of vegetation types and thickness classes of the unsaturated zone (TUZ), using time series of rainfall and evaporation as input. The TUZ classes 50 and 150 cm provide recharge for ground water dependent areas, other classes for ground water independent vegetation. ONZAT also uses soil parameters like moisture contents for the top layer and the bottom layer. Ground water recharge has been calculated using time steps of five days for the period 1960-2004 with time series of the measurements (present climate) and also transformed time series of climate scenario W and W+. Ground water recharges were obtained for each scenario with feedback mechanisms by correcting the calculated groundwater recharge with the values of table 2.

	present climate	scenario W	%	scenario W c3	%	scenario W+	%	scenario W+ c3	%
Annual precipitation [mm]	880	943	+7	943	+7	862	-2	862	-2
Annual potential evaporation [mm]	598	633	+6	633	+6	669	+12	669	+12
Annual Recharge, TUZ 50 cm, bare sand [mm]	640	690	+8	745	+16	595	-7	690	+8
Annual Recharge, TUZ 50 cm, shrubs [mm]	375	407	+9	440	+17	314	-16	364	-3
Annual Recharge, TUZ 250 cm, shrubs [mm]	440	480	+9	499	+14	430	-2	490	+12
Wet/Moisture area [ha]	169	200	+18	222	+31	173	+2	209	+24

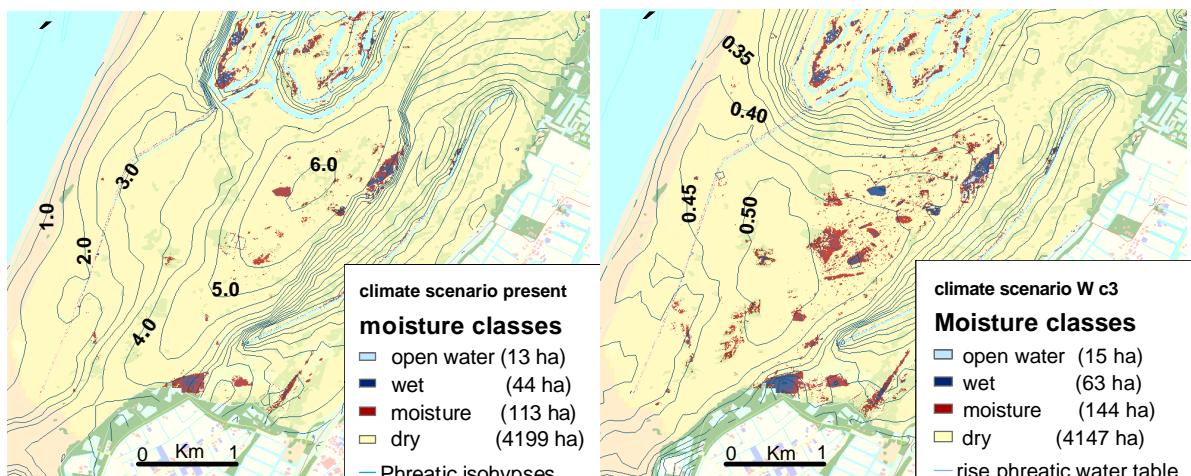
Table 3. Mean values period 2038-2061 of climate scenarios, difference with present climate is given in %.

#### Results of climate scenario simulations

The results of the simulations are shown in Table 3. A temperature rise of 2 °C without change of air circulation pattern (scenario W) will lead to an increase of precipitation of 7 % and of potential evaporation with 6 %. Despite the higher potential evaporation, recharge in areas with bare sand will increase with 8 % and with 9 % in areas with shrubs. This is not only because of the increased precipitation, but also because plants reduce their transpiration when the soil becomes too dry. When also adaptations of the vegetation taken into account (scenario Wc<sub>3</sub>) the increase of recharge will almost double. The average water table levels in April, a dominant factor for dune vegetation development, would rise with 0.35 m in scenario W and with 0.50 m in scenario Wc<sub>3</sub> (figure 1). The relatively small rise of ground water table would cause an increase of the area of moist and wet dune valleys with 18 % for scenario W and 31 % for

scenario Wc<sub>3</sub>. In addition the average amplitude of the seasonal fluctuation of the water table will change from 0.6 m to 0.7 m (scenario Wc<sub>3</sub>).

A temperature rise of 2 °C with change of air circulation pattern (scenario W+) will lead to a slight decrease of precipitation (-2 %) and a significant increase of potential evaporation with 12 %. When the ground water reaches the root zone (ground water depending condition), natural recharge will decrease with 16 %, whenever ground water is beneath the root zone (ground water independent condition) recharge will only decrease 2 %. As in the present situation most of the dune area has mainly ground water independent conditions, the effects in terms of a declining water table are limited and partly compensated by the rise of the North Sea level. Introducing feedback mechanisms in this scenario leads to opposite effects: the net recharge would increase with 12 % (shrubs). While in scenario W+ the total area with wet and moist conditions remains constant, in scenario W+c<sub>3</sub> moist and wet areas will increase with 50 hectare (24 %). The average amplitude of the seasonal water table fluctuation will increase from 0.6 m to 0.8 m in scenario W+c<sub>3</sub>.



**Figure 1. Southern part of AWD. Left; climate scenario present, average (period 2038-2061) water table of April [m MSL] with moisture classes. Right; climate scenario Wc3, contours of rise phreatic water table (compared with climate scenario present) and moisture classes.**

## SUMMARY

All adopted future climate scenario for the Amsterdam Water Supply dunes lead to an increase of net recharge and as a consequence, higher water tables. The maximum computed average water table rise would be 0.35 m in scenario W. If vegetation feedback mechanisms are taken into account too, the water table will rise 0.15 m extra. This water table rise will lead to a larger percentage of moist and wet dune valleys area in all future climate scenarios, with the largest increase in the Wc3 scenario.

Vegetation feedback mechanisms induce a significantly higher water table rise and therefore cannot be ignored. Nevertheless to our knowledge no ground water model exists yet that can take this vegetation feedback mechanism directly into account.

The expected rise until 2050 of the North Sea level by 0.25 m causes a large part of the water table rise up to 1.5 km inland of the sea shore. Therefore in all future climate scenarios for coastal areas the sea level rise should be taken into account as well.

In addition the water table is expected to rise still higher due to slow but persistent adaptation of the salt/fresh interface to the new hydrological situation by the Badon-Ghyben-Herzberg principle. A new equilibrium will be approximated only after a period in the order of 75 years. The current salt/fresh interface is not in an equilibrium position because of a number of major hydrological events in the past century. Because of this, future changes in water table elevation will not only be due to climate change but are also a consequence of historical events.

As regards hydrological effects, the uncertainty associated with future climate scenarios themselves is amplified by uncertainty associated with vegetation feedback mechanisms. In addition, uncertainties associated with the inferred initial position of the fresh/salt interface position can have significant effects on the outcome of future climate simulations.

In summary, the most important conclusion is that at least in coastal areas, climate change cannot be ignored for any long-term (> 30-50 years) hydrological simulation of future situations.

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