Modelling the impact of climate change on drought in the Netherlands

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Introduction

The threat of flooding in the nineties of the past century has led to questions concerning the organisation and arrangement of water management in the Netherlands in the twenty-first century. Besides attention for a surplus of water, also drought is recognised as a potential threat. Climate change, land subsidence and new water demands may lead to a shortage on fresh water in summer. Therefore, a study on drought in the Netherlands has been started [1].

The study aims at making the difference between water demands and supply of water of good quality as little as possible, by reasonable means. This judgement will take into account economical aspects, quality of the natural system and social aspects. The first phase of the study focuses on assessing the drought problem in the present situation and its regional spread, effects of expected autonomous changes in the next century and distinguishing possible solutions. The second phase of the study will focus on the assessment of the goals of water management in dry circumstances and an analysis of feasible policy strategies.

In order to advise policy makers on hydrological issues on a nation-wide scale RIZA developed a set of models, which are also used in the study on drought. In addition to coupled hydrological models that simulate the entire hydrological system, there are models that translate hydrological changes to effects for several economic sectors and the natural environment.

The objective of this paper is to demonstrate how the hydrology of the Netherlands is modelled on nation-wide scale and to present hydrological implications of drought in present and future situations. As 80% of economical damage of drought is located in agriculture, effects of climate change and feasible solutions on yield reduction will also be discussed in this paper. This paper will focus on the results of the first phase and early results of the second phase of the study.

Water management in The Netherlands

The Netherlands is a highly populated delta of the rivers Rhine and Meuse. The southern and eastern part of the country consists of sandy, Pleistocene deposits. In these parts discharge takes place by natural watercourses, brooks and small rivers. In addition, ditches, trenches and artificial drains have been created to improve drainage conditions for agricultural purposes. Supply of water in dry periods is mostly limited to small regions near rivers. Irrigation mainly takes place using groundwater. The western and northern part of the Netherlands is a polder area with artificially maintained surface water levels and consists merely of Holocene deposits (clay and peat). Excess water is pumped out from the polders into larger canal systems and subsequently into the sea, rivers or big lakes. Because of the high drainage intensity, groundwater levels are influenced considerably by the surface water levels within a polder. During dry periods groundwater levels drop below the maintained surface water levels and infiltration from surface waters into the groundwater occurs. In order to maintain the surface water levels, external surface water supply is necessary. Surface level control is also important for stability

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of dikes in polder areas. Upward seepage fluxes in the Holocene areas are often fresh water, but in some cases, brackish or salt upward seepage occurs. In the latter case, polders should be flushed with fresh surface water, in order to prevent salt damage for agriculture. In polder areas the main source of irrigation water is the surface water system.

When drought occurs, the different water users are subject to rules that determine the water distribution. Water level control, to prevent irreversible drought damage and for the stability of dikes, has the highest priority. Water supply for drinking water, greenhouses and industry follows. Low priority is given to maintaining low chloride concentration, cooling water, irrigation and shipping.

The main source of water is the river Rhine, which provides 60% of the total supply. Precipitation accounts for 30% and 10% comes from other rivers. In an average year the total incoming quantity of water is 2800 mm. In 1976, which was an extreme dry year, it was 40% less. The main part of the water disappears to the sea by rivers - on average 80% but in a dry year still 60%. The other part is mostly evaporated within agriculture areas [2].

In the present situation drought can even in a relatively wet country like the Netherlands be seen as a problem. Once in 10-20 year the water demand exceeds the water supply, once in 2-5 year there is not enough cooling water. Salinisation is a threat, and some regions must accept water supply of sub-optimal quality.

To quantify the risk of drought the statistics of drought have been analysed [3]. Taking into account both precipitation deficit and trans-border river discharges, historical years can be quantified by their occurrence. To obtain sufficient insight into the problem of drought 7 characteristic years are analysed in this study. Examples are given in Table 1.

Table 1: Definition of characteristic years [3]

characteristic year	*recurrence time*	*historical year*
average	2 year	1967
dry	25 years	1949
very dry	67 years	1959
extremely dry	110 years	1976

Autonomous developments

Climate change, land subsidence and changes in land use will probably have a major impact on water management in the Netherlands. Uncertainty about these developments is high so several scenarios will be investigated to determine a range of expected changes.

Global Climate Models predict that global warming will result in higher temperatures and wetter conditions in Western Europe, especially during winter. Increased precipitation in The Netherlands and neighbouring countries will alter trans-border river discharge. In addition a significant sea level rise is predicted. Table 2 summarises the assumed effects of climate change that are calculated for the Netherlands [3]. A central, upper and extra dry scenario are given for the year 2050.

Table 2: Summary of characteristics of the climate scenarios [3]

	central estimate 2050 summer	central estimate 2050 winter	upper estimate 2050 summer	upper estimate 2050 winter	dry scenario 2050 summer	dry scenario 2050 winter
Temperature	+ 1 °C	+ 1 °C	+ 2 °C	+ 2 °C	+ 3.1 °C	+ 2.0 °C
Precipitation	+ 1.4 %	+ 6 %	+ 2.8 %	+ 12 %	– 20 %	+ 13 %
Evaporation	+ 3.3 %	+ 5.6 %	+ 6.6 %	+ 11.2 %	+ 24 %	+ 8 %
sea level rise	+ 25 cm	+ 25 cm	+ 40 cm	+ 40 cm	+25 cm	+25 cm

River discharge	- 3 %	+ 4 %	- 6 %	+ 8 %	-3 %	+ 4 %

A great part of the Netherlands, especially the polder and river areas, are subjected to land subsidence, due to oxidation of especially peat soils, mining activities and tectonic movements. Estimates for 2050 resulted in a local subsidence of 60 cm to a rise of 5 cm in the southeast part of the country [5]. Significant changes in land use are foreseen. Most likely scenarios include shifts from agricultural (-17%) to urban (+25%) and natural areas (+32%) [5].

Measures

In the first phase of the study a sensitivity analysis of possible measures to reduce the negative effects of drought are investigated. In the second phase packages of these measures will be constructed in more detail. Different measures, such as a change in water distribution, or changing land use, are combined in a package of measures. Two types of measure packages are distinguished in case of drought: reactive measures and preventive measures.

Reactive measures
Two packages of reactive measures are distinguished. The first package consists of distribution measures in the national network. Local problems with cooling water are solved and Rhine water is send to the northern part of the country for shipping and agricultural demand. The second package addresses priority ranking of water users. As nature is not included in the present priority ranking it is added behind supply for drinking water and before supply for greenhouses.

Preventive measures
In the preventive packages more structural and permanent measures are included to prevent major drought damage.

The first preventive package includes retaining groundwater in regional water systems by reducing the drainage capacity. Retaining ground water in springs will increase the availability for crops in dry periods. In addition capital-intensive agriculture is reallocated to areas without drought problems. The cultivation of flower bulbs and ornamental trees is highly demanding towards water management and is situated in the present situation in the western part of the country. A third measure in this package is the replacement of coniferous forest that has a high evaporative demand by deciduous forest.

The second preventative package assumes measures taken upstream in the rivers Rhine and Meuse (in Germany and Belgium) that raise the discharge by 10% in dry periods.

Modelling approach

Three coupled hydrological models simulate the hydrological system of The Netherlands. The NAGROM-model [6,7] simulates the entire saturated groundwater system. The MOZART-model [8] simulates the unsaturated zone and regional surface waters. Nation-wide distribution of surface water is simulated with the Distribution Model (DM) [9]. Among models for other sectors, RIZA developed the AGRIcultural Cost Model (AGRICOM) [10] to determine the economic effects of hydrological changes for agriculture.

NAGROM is a steady state model, based on the Analytic Element Method (AEM). The groundwater system is modelled using different aquifers and aquitards, underlain by an impermeable base (Tertiary deposits). The hydrological top system, which is defined as the layer above the upper semi-permeable layer, is modelled as an area with one or two drainage systems. The upper boundary condition of the hydrological top system is given by the groundwater recharge. The behaviour of the hydrological top system is modelled in a lumped manner, using a linear relation between groundwater heads in the first aquifer and the flux towards the different drainage systems [11].

MOZART is a transient model, which simulates one-dimensional vertical water transport in the unsaturated zone for unique hydrological units (plots). A plot is a one-dimensional system, consisting of an effective root-zone and a subsoil (Figure 1). Resolution in time is 10 days; the spatial resolution is 500 x 500 m. Linear relations between drainage fluxes and the groundwater table describe the interaction between groundwater and surface water (Figure 1, right). When the groundwater level drops and consequently the capillary rise decreases or when there is a deficit of precipitation, evapotranspiration reduces. This is locally prevented by the possibility of irrigation. Each time step (decade) drainage fluxes are assembled in regional surface water systems that are included in MOZART. Inside the surface water system the available water quantity can be distributed over several users (irrigation, drinking water, industry). In addition to water quantity MOZART also takes into account the salt balance in both groundwater and surface water.

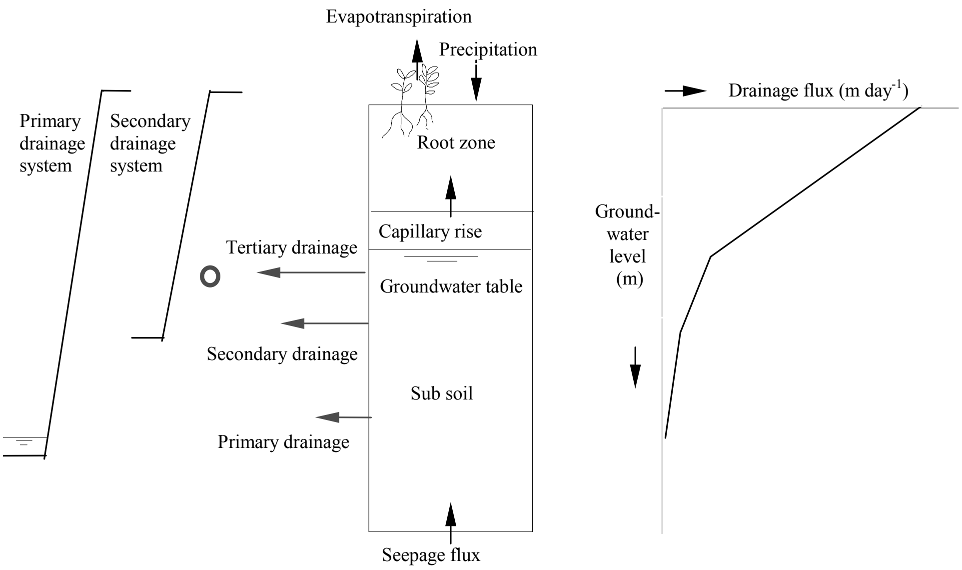

Figure 1: Plot schematisation and drainage relations within MOZART

The concept that couples NAGROM and MOZART provides both spatial and temporal scaling [11]. NAGROM generates the lower boundary for MOZART by calculating the groundwater head in the first regional aquifer. Subsequently, seepage fluxes can be computed using grid-data on feeding resistances, drainage levels, groundwater recharges and groundwater heads. MOZART-computations are carried out, resulting in new values for the year-averaged groundwater recharge that is part of the upper boundary condition of NAGROM. The final lower boundary for MOZART is determined in two iterative steps (Figure 2).

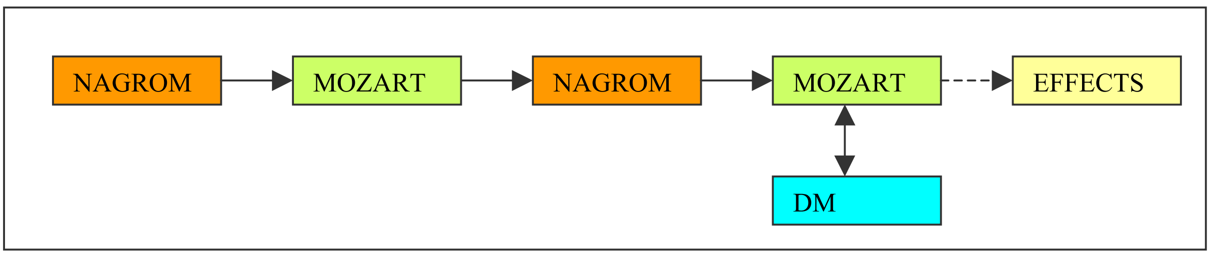

Figure 2: The calculation procedure (simplified)

The surface water distribution model DM, simulates the major components of the surface water management system in the Netherlands such as rivers and canals. DM considers two kinds of subsystems:

1) the large rivers, canals and lakes that comprise the national system (Figure 3)

2) the network of waterways, such as small rivers, canals and lakes that transport water from the national system into the regions, the regional system.

Figure 3: The most important routes for water distribution schematised in DM

Both systems are schematised in DM, as a single network. This network consists of links, indicating a river or canal, and nodes, which represent locations where waterways join or water is stored or supplied. Several management rules and pumping capacities obtained from Dutch water are input for the model, as well as trans-border discharge of the major rivers and water extractions for drinking water and industry. The demand for surface water from other users in the districts is derived from MOZART. Each of the 130 MOZART districts are coupled to one ore mores nodes in DM.

The coupled computation of MOZART and DM is an online iterative procedure (Figure 2). For each time step MOZART determines the water demand for each district. DM simulates the distribution in the network according to this demand and determines the supply to each district. Subsequently MOZART recalculates hydrological processes in the same time step using this water supply. The final results of MOZART are used in models such as AGRICOM to determine impact on agriculture and nature.

Agricom

AGRICOM calculates benefits and sprinkling costs for agriculture in the Netherlands. The model considers three types of sources for crop damage: drought, water logging and salt. The agricultural damage is based on the crop damage (evapotranspiration reduction, inundation period of salt damage) calculated in MOZART. For every period of time MOZART estimates the fraction of the total crop production that is lost due to salt, drought and water logging and the cumulative damage. Subsequently, AGRICOM calculates the annual actual physical crop yield by multiplying the annual potential physical crop yield with the cumulative damage derived from MOZART. The crop damage is estimated in terms of money using either a standard crop value or calculating the crop value using actual yield and price-elasticity of the crops.

Results

Magnitude of drought in the present situation
Part of the study is to determine the shortage of water in The Netherlands in the present situation. Shortage of water is expressed as the difference between the demand of water and the available quantity. In this paper shortage is defined in two possible ways:
1) The difference between demand of surface water users and the allocated quantity. Among the water users are surface water level control, irrigation, flushing and drinking water. This type of shortage is only determined for the part of the country were water supply is possible using the present infrastructure.
2) The shortage for crops can be expressed as the reduction of the evapotranspiration of plants due to a lack of water in the root zone. A reduced evapotranspiration leads to a diminished growth and eventually to yield reduction.

A comparison between the two types is presented in Table 3. Shortages in the present situation are presented here as the volume of the shortage divided by the area of the country. It shows us that evapotranspiration reduction is of greater magnitude than the shortage of surface water supply to the regions.

Table 3: Water shortages in present situation in mm
(expressed as a volume divided by the total area of the Netherlands)

year	*evapotranspiration reduction*	*surface water shortage*
average	25	0.2
dry	75	0.4
very dry	137	0.6
extremely dry	151	1.3

Surface water shortage in an average year is caused by low capacities for inlet of water at some locations. In an extremely dry year however, in addition to low inlet capacities, the availability of water in the main rivers and canals is limited.

Impact of autonomous developments
Autonomous developments such as climate change, land subsidence and changes in land use will effect shortages, especially in an average year (Table 4). Shortages in the root zone will increase 10% in an average year for the upper scenario. This is largely caused by an increased precipitation deficit in summer. Surface water shortage increases with about 100, but shortages remain small compared to evapotranspiration reduction. The effect of sea level rise on seepage is limited to a small coastal zone. However, salinisation of river branches near the sea might have a significant effect on fresh water supply to agricultural regions. Further research on salinisation is scheduled in the second phase of the study.

Table 4: Impact of autonomous developments, 2050 central estimate

characteristic year	*evapotranspiration reduction*	*surface water shortage*
average	27 (+10%)	0.3 (+113%)
dry	81 (+7%)	1.0 (+118%)
very dry	146 (+7%)	1.1 (+80%)
extremely dry	161 (+7%)	2.6 (+98%)

Sensitivity analyses for among others the upper estimate and the dry scenario show that increases of shortages may roughly double or triple comparing to the central estimate.

Impact of measures
Water shortage reduction by measures is largely limited to the surface water system. In Table 5 the results of the most promising measures in hydrological sense are presented. Evapotranspiration reduction is hardly reduced by the measures that are included in the computations, even though the

availability of surface water has increased. Infrastructure for bringing water to the root zone seams to be the weak link in the water system. Retaining groundwater has the largest impact on evapotranspiration reduction. This shortage is reduced by up to 10% in an average year.

Table 5: Impact of measures on hydrology

	evapotranspiration reduction	*surface water shortage*
average year (2050-central)		
water distribution	0%	-17%
increased river discharge	0%	0%
retaining groundwater	-10%	-2%
extremely dry year (2050-central)		
water distribution	0%	-20%
increased river discharge	0%	-1%
retaining groundwater	-4%	-3%

Agriculture

Drought damage in agriculture is determined in this study by using the relation between evapotranspiration reduction and yield reduction. Damage to crops by salinisation and inundation is not included in this phase of the study and therefore it can only be seen as a rough estimate of the impact of drought, future developments and measures.

Computed damage for the present situation, future and after including measure packages are presented in Table 6 as the annual-expected yield reduction. For instance, in the present situation the damage varies from 200 in an average year to 1.800 million Euros in an extremely dry year. Taking into account the occurrence of the characteristic years the annual-expected yield reduction is obtained. It appears that there is only a slight increase of damage in 2050. The increase in 2050 is remarkably low for the country as a whole. However, the damage per hectare increases 25% as agricultural area decreases. Corresponding to the effect on evapotranspiration reduction, the only package of measures that decreases the damage significantly is the one that includes retaining the groundwater.

Table 6: Yield reduction expressed in million Euros per year

present situation	2050 central			
	without measures	distribution	increase river discharge	retaining groundwater
420	+3%	0 %	0 %	-16%

Continuation of the study

The second phase of the study on drought will focus on the assessment of the goals of water management in dry circumstances and an analysis of feasible policy strategies. Prior to this phase the hydrological models are extensively calibrated and verified.

The NAGROM model is optimised using automatic optimisation techniques (PEST) [12]. For optimisation, nation-wide measurements of groundwater heads have been used. For the MOZART model sensitivity analysis and optimisation has been carried out [13]. For calibration of MOZART, images that originate from satellite data have been obtained that provide information on evapotranspiration during a year. In addition nation-wide measured phreatic groundwater levels have been used for optimisation.

In a regional study on drought in the western part of the country the hydrological results were verified [14]. Verification on a regional scale led to acceptable hydrological results, concerning groundwater levels, evapotranspiration, discharge and water shortage in dry periods. Besides water quantity also salinisation and salt damaged were considered in the verification.

Conclusions

The hydrological models used to assess the problem of drought in The Netherlands have been presented. As this set of instruments comprises the whole hydrologic system, ground- and surface water, it gives an integral view of the impact of climate change on nation-wide scale. In the first phase of the study on drought indicative model simulations were applied.

Shortages expressed as evapotranspiration reduction or surface water shortages are common in the present situation. The model application shows that climate change has a significant impact on shortages in groundwater in dry periods. This evapotranspiration reduction of agricultural crops, translated to yield reduction, results in a 25% increase in the annual-expected damage per hectare. Yield reduction and the resulting agricultural damage is the most important economic consequence of drought in The Netherlands.

Prevention from water shortages in an extremely dry year is impossible in an acceptable manner. A certain degree of acceptance of water deficits will probably be part of the water policy in the future because some problems are just not solvable. Retaining groundwater is the most promising measure to decrease agricultural drought damage and therefore the economical damage. Other measures are alternative distribution of water, water retention, alternative use of land and other priorities for water distribution during drought periods. All measures need to be optimised at a regional level and an appraisal has to be made of financial, ecological and social considerations.

In previous studies the results of hydrological models appeared to be sufficiently reliable on the nation-wide scale. To be able to pronounce upon effects on regional scale however thorough calibration is required. Using calibrated and adjusted hydrological models, the second phase of the study on drought will focus on the assessment of the goals of water management and an analysis of feasible policy strategies.

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