The effects of climate change in the Netherlands

Netherlands Environment Assessment Agency

In collaboration with:

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Institute for Inland Water Management and Waste Water Treatment (RWS-RIZA)

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Foreword

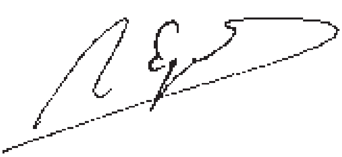
The scientifically undisputable changes in the climate and extreme weather conditions elsewhere raise questions as to the possible effects for the Netherlands. At the beginning of 2005, the State Secretary for the Environment posed a number of pertinent questions to the Netherlands Environment Assessment Agency; for example, what effects have been observed, what could be expected in the foreseeable future (within several decades) and what factors need to be taken into account?

As the report had to be short and reader-friendly, becoming available no later than the end of 2005, it would have to be based on existing and established knowledge. The time limitation made it impossible to perform new calculations. Although the results – as documented here – do not pretend to be anywhere near complete with respect to the effects of climate change on the Netherlands, they have incorporated the most important known insights in this area.

The task of providing carefully considered answers to the questions posed was daunting. Climate affects our entire environment and society. Possible effects of climate change are linked to developments in all environmental compartments, and these developments often represent the effects of several causes. It took the collective knowledge of several scientific institutions to provide the answers requested by the State Secretary.

Thus the report could not have been written without the whole-hearted cooperation of colleagues from many other institutes, to whom I would like to express my thanks for their assistance in compiling this document.

Compiling a report is only one step within a process. The institutes involved have also set up a platform to promote communication on climate change, and its causes and effects. This Platform for Communication on Climate Change (PCCC) operates in the form of a Internet portal (http://www.kimaatportaal.nl/). The information in this report can be found through this portal on the PCCC website supplemented with additional background information and links. The website will be regularly updated in response to the latest insights into our climate system.



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Contents

SUMMARY

This report provides an overview of current knowledge on the effects of climate change in the Netherlands, both at the present time and over the next few decades. No new research was initiated for the purpose of preparing this report. Existing knowledge and data have been collected from many institutes and presented in a coherent manner.

Main conclusions

The climate is changing: the sea level is rising, the discharge of rivers is increasing and nature is already responding to the temperature changes that have occurred. The observable effects in the Netherlands are, however, still limited in magnitude.

It is expected that these developments will accelerate over the next few decades.

- *Extremely warm and dry summers will occur more frequently. More frequent and heavier episodes of rainfall accompanied by floods will form part of the expected pattern. Peak discharges of the rivers will increase. If countries upstream of the Netherlands take measures to limit severe flooding, then the risks in the Netherlands will increase.*
- *The rate at which the temperature rises is likely too high to enable many species to adapt or migrate. Several plant and animal species are threatened with extinction in the Netherlands. New species will settle if they can migrate quickly enough. This will probably lead to a decreased diversity of species in the Netherlands.*
- *The agricultural and tourist sectors will undergo changes that could be both positive and negative from an economic viewpoint; this partly depends on developments elsewhere in Europe.*
- *The expected health gain due to the overall temperature rise will probably be offset to a large extent by the increased risk of mortality during extremely warm weather. Several diseases and complaints will probably become more prevalent (Lyme disease, allergies).*

Due to the delayed response of the climate system, the changes will persist for a very long period of time, even if there is a considerable reduction in the emissions of greenhouse gases. Towards the end of this century the sea level may rise 20 –110 cm. This wide range is indicative of the degree of uncertainty that still exists. Recent research points to a rise that is more towards the upper limit of this range. The combination of an ongoing rise in the sea level, land subsidence and increasing peak river discharges will become problematic for the lower-lying regions of the Netherlands towards the end of the century. Water discharge and safety will be at stake.

Over a much longer term (several hundred years), a sea level rise of several to many metres is possible. However, this time frame falls beyond the scope of this report.

The effects of climate change in the Netherlands are presently still limited

To date, climate change has not led to any serious problems in the Netherlands. However, the climate is changing:

- during the last century mean temperature has risen by about 0.7°C worldwide and in the Netherlands by about 1°C;
- the sea level along the Dutch coast has been subject to an autonomous rise of about 20 cm per century as a consequence of climate changes (melting of land ice and glaciers and expansion of seawater due to temperature rise) and land subsidence;
- the river discharges are changing: higher winter discharges and lower discharges in dry periods, with climate change playing a likely role in this;
- the average annual precipitation in the Netherlands is increasing, and there is a tendency towards more days of rain and an increased frequency of extreme rainfall;

Water policy has, to a certain extent, already taken climate change into account with technical measures and spatial planning measures. Examples of technical measures are: increasing the height of dykes, expanding the capacity of pumping stations and beach nourishment to maintain the level of sand along the coast. Spatial planning measures include the preparation of flood storage areas.

Climate change is already having consequences for the natural environment worldwide. About 80% of the observed changes in behaviour and abundance of plants and animals in all regions of the world are consistent with the expected responses to climate change. The effects of the temperature rise can be seen everywhere in the Dutch nature:

- plants and animals are migrating northwards;
- spring is beginning earlier;
- relationships in the food chain are becoming disrupted;
- the plankton, which is the basis of the food chains in the North Sea and Wadden Sea, is changing; this leads to changes higher up in the food chain: low reproduction levels in fish, decreasing bird populations, shifting porpoise populations; the changes in the North Sea and Wadden Sea ecosystems might occur abruptly.

Economic effects on agriculture cannot be demonstrated as yet. However, there are signs that the risks of agricultural damage are increasing (water logging, droughts, insects). Effects on other economic sectors are at present limited to an increase in the demand for water in dry periods, cooling water problems and limitations for navigation during low river discharges.

The effects will increase at a faster rate over the next few decades

Climate will change more quickly:

- the average global temperature will almost certainly increase further (1–6°C in 100 years); this increase is also expected for the Netherlands; the frequency of dry and extremely warm summers, such as that of 2003, will increase; the probability of extremely cold winters will decrease, although the famous '*Elfstedentocht*' skating tour will remain possible on an incidental basis;
- an increase in the average precipitation and extreme rainfall is expected throughout the world, but the regional distribution is still highly uncertain; in the Netherlands there is likely more precipitation during the winter and summers will be drier; there will be an increasing probability of extreme rainfall with local floods;
- a further rise in temperature is highly likely to lead to a more rapid rise in sea level and greater dynamics in river discharges (more than now). Towards the end of this century, the sea level will have risen by 20 –110 cm. This wide range is indicative of the degree of uncertainty that still exists. Recent research points to a rise that lies more towards the upper limit of this range or even possibly above this.

Natural environment

The ongoing climate change will have more effects on the Dutch nature in the future than those currently visible. Climate change imposes extra stress on an environment, which is already under pressure due to fishing, the spread of manure/fertilizer, drought and the loss and fragmentation of habitats. The rate of the temperature change is possibly too high to enable many plants and animals to adapt or migrate. Widely-occurring species of plants and animals are highly likely to extend their range, and more sensitive species have a much greater chance of becoming extinct in the Netherlands. This will probably result in a decreasing diversity of species in the Netherlands.

Agriculture

Climate change will likely lead to both positive and negative effects on agricultural production and the agricultural economic situation in the Netherlands. Factors that can give a positive effect are: the average higher CO_2 concentration and temperature and the extension of the growing season; the worsening situation in the southern countries of Europe may also provide Dutch agriculture with extra market opportunities. The negative effects will increase as more extreme weather and climate conditions occur more frequently or persist for longer periods (water logging and drought).

Water users

Due to the increased frequency of dry years and low river discharges, cooling water problems and limitations on navigation will increase if water management does not change (i.e. does not adapt). This effect will be enhanced by the greater demand for water in dry periods. The drinking water production and supply of irrigation water for agriculture will be confronted with penetration of saline water in dry periods, with a higher salinity of the surface water at inlet points and with higher temperatures.

Health
The temperature rise due to climate change can, in extreme situations (heat), have a direct negative influence on human health in the Netherlands. The possible health effects for the Netherlands are: problems due to heat stress, increasing spread of Lyme disease, effects of poor air quality (summer smog) and an increase in allergies. Risk groups in the population (such as the elderly, children or people with asthma) might experience stronger effects (a greater burden of disease). The size of the climate effects on health has not yet been quantified sufficiently, but these effects are probably not that considerable. There is, however, a need to remain alert.

Tourism/recreation
The temperature rise will possibly ensure an improvement in, and an extension of the summer season in northern Europe and an increase in the tourist and recreational activities that take place out of doors. The Netherlands may become more attractive to foreign tourists in terms of climate and Dutch population may also be more inclined to spend their holiday in the own country as a result of the improved weather. Climate change could lead to a strong growth in the demand for recreational and nature areas. However, the increasing temperature might lead to a deterioration in the quality of the swimming water (if no extra management measures are taken) due to, for example, an increased blooming of (toxic) blue algae; this can pose a threat to the health of swimmers.

The Netherlands can probably cope with the negative consequences of climate change over the next few decades. The positive tendencies will provide opportunities, particularly for agriculture and the recreation sector. How the water system is managed in response to the forthcoming climate changes will have considerable consequences for other (direct or indirect) stakeholders. The costs associated with adjusting our society to the changing climate and the possible benefits have scarcely been described.

Problems will arise due to the effects of climate change in the second half of this century and beyond

It is expected that climate change will proceed during the second half of the century and beyond. Present climate change will have effects for centuries, particularly with respect to sea level rise (expansion due to temperature rise and melting of ice). Over this longer time frame, a sea level rise of several to many meters is possible. The low-lying parts of the Netherlands will experience increasing problems. It is questionable whether conventional techniques can be used to maintain the current level of safety, and the effort required will increase due to the additional problems of possibly increased discharge in the rivers Rhine and Meuse and a further subsidence of the land.

The consequences of climate change for biodiversity, agriculture, recreation, other stakeholders and health in the Netherlands are difficult to state in concrete terms so far into the future. Yet it is clear that the nature in the Netherlands of the more distant future will look very different from now. Agriculture will undoubtedly adjust to the changes in terms of the choice of crops and cultivation methods. However, with respect to agriculture and other economic sectors, the effects of climate change are probably less important than those derived from other economic and societal developments. Temperature-related health effects could reach significant proportions.

The effects of climate change could be far more serious in many locations outside the Netherlands, and these changes will increasingly exert an influence on Dutch society.

Table: Overview of climate change and its effects for the Netherlands

Subject:	Aspect		Present	Future projections (about 2040 and later)
Climate and weather	Temperature	Average	+ 1°C (since 1900; particularly since 1975)	+1°C to +6°C (2100)
		Extreme, heat	3× as many warm days (since 1900)	Extra increase in extremes (number and severity)
		Extreme, cold	0.5× as many days (since 1900)	Limited decrease in extremes
	Precipitation	Average (considerable variability)	About 20% more (since 1900)	Probable decrease in summer; Highly probable increase in the winter
		Rainfall extreme, showers	>50% more days with >15, 20 or 25 mm	Uncertain probability of more heavy showers
		Rainfall extreme, drought	Probably more dry years	Probably more and longer dry periods
	Evaporation	Summer	Proportional to temperature increase	+4% to +16% (2100)
	Wind		Highly probable decrease in number of storms (since 1962)	No expectation. Uncertain probability of extreme storms
Water management	Sea level rise		+20 cm (since 1900) due to melting (land) ice, expansion seawater and land subsidence	+10 to +45 cm (2050); +20 to +110 cm (2100); uncertain probability of a much greater rise
	Rivier discharge	Winter	Average higher discharges Design discharge has risen (Rhine: from 15,000 m^3 to 16,000 m^3)	+3 to +10% (Rhine, 2050) +5 to +20% (Meuse, 2050)
		Summer	Average lower discharges	Average monthly discharge up to 50% less (2050)
	Water logging	IJsselmeer levels	Level has increased slightly	Winter higher; Fluctuations greater
		Regional	Probably more frequent (recent years)	Repeat time for daily precipitation >73 mm will change from 100 years to between 40 and 78 years
	Precipitation deficit	Drought	Highly variable	Probability of dry years occurring more frequently
Natural environment	Temperature of the atmosphere	Average warmer spring	Early spring: e.g., egg-laying date, appearance animals, flowering of spring plants	Disruption in food chain will further increase
		Average warmer temperatures and more extremes	Northwards shift of species, increase in the numbers of more southern and more widely occurring species, decrease in the numbers of northern and more specialized species	Further shift of mobile species 'Climate shifting' of 400 km per century is too fast for many species, extinction of some species

Subject:	Aspect		Present	Future projections (about 2040 and later)
	Water temperature	Seawater warmer	Change plankton composition with possible consequences for fish, birds, porpoises Decrease shellfish in Wadden Sea, resulting in mortality under shellfish-eating birds	Further shifts with possible (large) abrupt changes in ecosystems
Agriculture	Growing season		Longer season: ±3 weeks in 25 years	Further extension; higher yield; chances for other crops;
	Water logging		More frequent damage	Continued development
	Drought		More frequent damage	Continued development
	Pests and diseases		Occur more frequently	Greater potential loss of harvest
Recreation	Summer	Coast, water, wildlife	Extension Dutch tourist season; more periods with good weather	The Netherlands more attractive for holidays; Southern Europe too hot in the summer
	Swimming water	Warmth	Occurrence of infections caused by blue algae	Increase in infections
	Winter	Skating	Less cold days; probability 'Elfstedentocht'skating tour less;	Further decrease in probability of ice period (less fast than temp. rise);
		Skiing	Decrease skiing options in Europe	Further decrease in skiing season and skiing area in Alps
Commercial sector	Navigation		Incidental limitations in the case of drought	Due to increasingly lower discharges, greater limitations (costs)
	Cooling water		Temperature Rhine +3°C (since 1900); 1/3 due to climate; incidental limitation on intake	Probability of limitations during dry, warm years considerable
Health	Temperature	Average	Probable decrease in average relative mortality	Continued development
		Extremes	Probable increase relative mortality in hot periods	Heat-related mortality further increases; cold-related mortality decreases
	Lyme disease		Tick bites and red marks have doubled in past 10 years	Further increase
	Malaria		Nil	Probability small
	Allergies		Probable slight increase	Probable further increase

1 INTRODUCTION

Climate has shaped both our society and our natural environment. We build our houses and our surroundings in order to live as comfortably and as safely as possible. Farmers choose their crops and use their land so as to gain maximum benefit from the possibilities offered by the climate. We go on holiday with expectations about the temperature, rainfall and wind. Plants and animals have adapted to the climate in which they survive and reproduce. Our approach to nature conservation has also been a process requiring continual adjustment.

Whenever a particularly unusual weather condition occurs (temperature, rainfall, wind, or a combination thereof), the question always arises whether this is an exception to the normal conditions. If it is not an exception, then it is probably advisable to modify our environment or activities to allow for this condition again in the future: this process is termed adaptation. Humans have adapted to new conditions throughout their existence, but these adaptations have occurred mostly on the basis of experiences acquired. The climate is always changing. Climate projection is a relatively new field, and we have only been making projections for a relatively short period of time and then still with a considerable degree of uncertainty. Adaptation to *expected* climate change will increasingly become a topic of discussion. Can we afford to ignore the prognosis and wait to see what happens? Is it wise to make investments if there is still so much uncertainty with respect to the changes that may occur? These and other questions will be intensively debated in the future. This report can make a contribution to the discussion. This report limits itself to the possibilities for adaptation in those cases where it is already taking place (such as flood protection measures). The Netherlands does not have a coherent adaptation policy at present. The report does not provide an evaluation of policy in this area, but a summary of the available knowledge base on climate change and its probable effects in the Netherlands.

Although the causes of climate change have been investigated extensively, the significance of this research is debated. The vast majority of the scientific world concludes (as summarized in the reports of the Intergovernmental Panel on Climate Change, IPCC) that humans have made a significant contribution to climate change over the last few decades. Yet for some, doubts remain. The processes underlying our climate and the interactions between these are not yet fully understood. This is not such an important issue for this report. The climate is changing and, in a historical sense, this is not unique because climate is always changing. Measurements can be used to determine the current rate of change to a reasonable degree of accuracy. However, future consequences of climate change can only be estimated if the human contribution to these is known. As there is still considerable disagreement about the weight of the human contribution to changes in the climate; climate predictions are intrinsically associated with a fairly large degree of uncertainty. As this report only considers the effects in the Netherlands, these uncertainties are even greater because regional and local climate expectations are less certain than climate expectations averaged worldwide. As this report is mainly concerned with the not too distant future (circa 2050), the uncertainties are not that large (see Box A). Due to the inertia in the climate system, the consequences of the highly elevated levels of greenhouse gases that are now present in the atmosphere will ensure effects in our environment for a long time to come, irrespective of how much emphasis is placed on current and future measures to reduce human effects on the climate.

The projected effects are not *predictions*, but instead are based on *scenarios*. A scenario is a set of related assumptions about how factors, that are important in the calculations, will develop in the future. Scenarios describe possible or plausible developments without stating how likely these are.

The climate system will be considered in Chapter 2. Changes in the global climate that have occurred over a considerable time period and over the past few decades will be described briefly. The focus will then switch to the Netherlands. In the expectations for the next few decades a distinction is made between summer and winter. The expectations are based on insights into the climate system and the results of simulation models, and they contain assumptions about uncertain processes, such as the Gulf Stream or about how quickly the ice caps will melt. Other, less probable, assumptions could lead to unpleasant surprises with respect to the climate. Some of these surprises and the uncertainties in climate models are presented in separate boxes. These may need to be borne in mind in the future.

The developments described in this report will affect every resident of the Netherlands. In subsequent chapters the focus is on certain groups within the population: residents of the low-lying parts of the Netherlands, water and wildlife managers, farmers, tourists, several commercial sectors and vulnerable groups in society. Many different situations associated with climate change are therefore considered in turn. In several places boxes provide a more detailed explanation of specific subjects.

This report describes a broad range of effects and is aimed at a wide readership. It therefore contains a relatively large number of illustrations and no detailed scientific explanations. Those interested in more scientific details should use the references provided on a per-chapter basis at the end of the report and to the figures. Texts have often been limited to explanations of and conclusions from the figures. Almost without exception, these figures have been taken from previous reports and have often been processed for the purpose of this report.

This report details what is currently known about the effects of climate change in the Netherlands. It could not have been realized without the collective knowledge contributed by several institutes. As the report had to be compiled within a short span, it was not possible to write it on the basis of commonly held starting points. However, as the existing reports are frequently based on the same climate scenarios of the Royal Netherlands Meteorological Institute (KNMI), there is still a considerable degree of correlation in the results. For the sake of clarity, differences in the starting points have been indicated where possible, and the influence of these different starting points on the conclusions has been stated.

Box A: Statements about the climate are always uncertain

Conclusions about climate change and the possible effects of this can only be drawn if there is a more or less coherent picture of how the complex climate system functions. Observations of parts of this system form the starting point. These observations are spread over time and space and only become meaningful in the context of models and time series analyses. The conclusions reached are in part determined by the model chosen. A wide variety of models are often used, leading to a broad range of conclusions. There is also a certain degree of uncertainty associated with the chaotic behaviour of the climate system (sensitivity for starting values in calculations) and with external influences (Sun, volcanoes, emissions).
Some of the analyses concern the *variability* of the climate in space and time. More detailed analyses tend to have even smaller data sets on which conclusions can be based, and this often leads to a greater degree of uncertainty in statements. For example, far more uncertainty is associated with a statement concerning developments related to the probability of an extremely heavy rainstorm in the Westland area of the Netherlands in July than with developments related to the average annual precipitation in the Netherlands.

To date, the predictability of the climate has scarcely been investigated in a systematic manner. In scenario studies, researchers explore how a system responds under different assumptions. In this context, a scenario is a more or less coherent set of assumptions about how factors outside of the simulation model develop. In general, the uncertainties in these analyses increase substantially the longer the time horizon and the further up in the causal chains (hence for effects). A greater distribution in the values for scenario variables increases the spread in the outcomes. This is not necessarily the same as a greater degree of uncertainty. In general, probability values cannot be ascribed to scenario outcomes.
Climate change is just one of the factors affecting developments in society and the natural environment, and it is by far not always the most important. Therefore, it can only be concluded that climate change is (at least partly) responsible for the observed changes, once the developments with and without a change in climate have been calculated and compared.

The Netherlands Environment Assessment Agency has adopted a guideline for dealing with uncertainties. This guideline is based on the work of the IPCC (Table A1). The probabilities are not solely based on calculations. The opinions of experts often play an important role and, therefore, an element of subjectivity cannot be excluded. In view of the time restriction, this report has been written on the basis of previously issued publications from various institutes. However, given that the manner in which these publications have dealt with uncertainties is not always clear, the guideline adopted by the Netherlands Environment Assessment Agency is not always strictly adhered to. Yet wherever possible due consideration is given to the terms defined in Table A1. For example, terms such as ‘likely’ have been used as consistently as possible and related to the magnitude of the calculated or estimated probability of occurrence.

Table A1: Verbal equivalents for probability intervals

Term	Probability (percentage)
Virtually certain	More than 99% probability (that objective is achieved)
Highly likely	90-99% probability
Likely	66-90% probability
Fifty-fifty[1)]	33-66% probability
Unlikely	10-33% probability
Highly unlikely	1-10% probability
Extremely unlikely	Less than 1% probability

1) The term ‘possible’ leads to confusion, as this term relates to all probabilities >0

2 HOW IS THE CLIMATE IN THE NETHERLANDS CHANGING?

Key points:

- The climate is changing. In the 20th century the temperature rose by about 0.7°C worldwide and in the Netherlands by about 1°C. It is highly likely that the temperature will further increase in the coming century.
- The annual average precipitation in the Netherlands has increased; there is a trend towards more days with extreme rainfall.
- A further increase in average and extreme rainfall is expected; the geographic distribution is uncertain. There will be a higher probability of extreme cloudbursts with local floods.
- It is highly likely that there will be more rainfall in the winter. As a result of increased evaporation it is highly likely that summers will be dryer.
- The probability of dry and extremely warm summers (as in 2003) will increase. The probability of extremely cold winters will decrease. An '*Elfstedentocht*' skating tour remains possible.

2.1 The climate system

Figure 2.1 gives a schematic overview of the climate system. This consists of the atmosphere, ocean, ice cover and land. In addition to physical processes, chemical and biological processes and the interaction between these also play an important

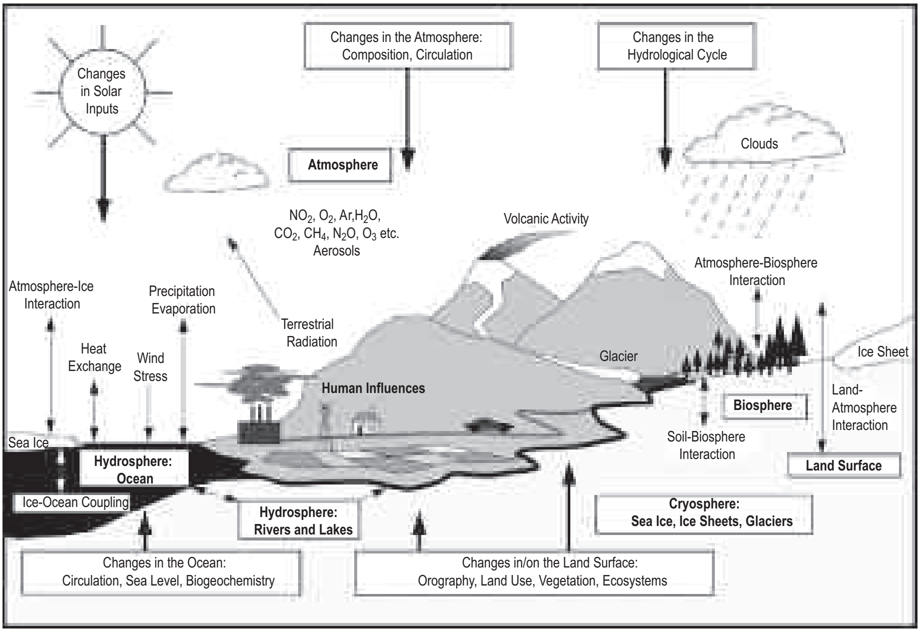

Figure 2.1: Compartments of the climate system (After: IPCC)

role. Although enormous progress has been made in the study of this complex system in recent decades, the behaviour of such a system will never be completely understood: unexpected things can always happen (see Box B: Climate surprises). Yet much is already known about how the composition of the atmosphere (and the changes in this) affects the climate. This effect is mainly exerted through changes in the climate system's energy regulation.

Box B: Climate surprises

In recent years there has been a growing awareness that the climate system can conceal a number of surprises. This knowledge is based on palaeoclimatological research and studies using models. Data from ice cores and deep-sea sediment have revealed that various rapid climate changes have occurred over the past 100,000 years. This is particularly the case for the North Atlantic area, but there are also indications for global climate changes. An overview of present knowledge has been compiled by Heij et al in the report 'Limits to warming' (Netherlands Environmental Assessment Agency, 2005).

Gulf Stream could become weaker

Studies of the North Atlantic area with various ocean models and with linked atmosphere/ocean models have revealed similar rapid changes following large disturbances in temperature and/or the influx of fresh water (due to changes in precipitation or melting land ice). The surface seawater in this region then becomes too light to sink to the sea floor. This slows down the ocean circulation, thus weakening the warm Gulf Stream so that warm water does not penetrate as far into the North Atlantic. Parts of Europe could then be subjected to periods of colder weather as the climate in these areas is strongly influenced by the warm Gulf Stream. It is estimated that if the ocean circulation were to completely come to a standstill, the climate in Europe would cool down by 2–5°C, dependent on the extent to which the ice sheet extended.
The chance of the warm Gulf Stream weakening increases as the average world temperature rises. However, the probability of it coming to a complete standstill in the 21st century is extremely small (IPCC report 2001). The consequences of such a complete standstill are dependent on when it would occur. Were the warm Gulf Stream to stop this century, then it is highly likely (90–99% probability) that this would lead to a real cooling down in parts of Europe; if this does not occur until the next century, then the effects of global warming are expected to predominate and the cooling down effect would be masked.

Icecaps could melt

A second possible outcome of unpredictable climate change is that a large proportion of the ice cap in West Antarctica could become unstable and then melt. This would lead to a 6-m rise in sea level. The IPCC expects that it will take about five to seven centuries before the entire ice cap of West Antarctica disappears into the sea. Translated into a sea level rise, this is about 1 m per century over and above the effects of the expanding ocean water.
The Greenland ice cap is more than 3 km thick in places and contains almost 3 million cubic kilometres of ice. If this large quantity were to completely melt, the world sea level would rise by 7 m. Each summer a small part of the Greenland icecap melts – which is a normal process – and in the winter, it grows again. In recent decades, however, the melting process seems to have accelerated. According to the IPCC, a local average temperature increase of about 3°C could lead to the start of an irreversible melting of the Greenland ice cap over a period of 1000 years or more. This local warming up could be achieved with a global warming of 1-3°C. The rate of melting is dependent on the temperature, but the underlying mechanism is still not clear. It has been observed that glaciers are moving into the sea at an increasingly faster rate. The melt water possibly acts as a lubricant in helping the glacier to slide into the sea, thereby increasing the rate at which the ice cap is breaking up. Consequently, the contribution of the Greenland ice cap to a rise in sea level rise this century could be much greater than has been assumed to date.

Permanently frozen areas defrost

Due to global warming permafrost areas will defrost, and a possible result of this is the escape of a large amount of greenhouse gases into the atmosphere. The chance that the permafrost areas will actually defrost increases as the average world temperature rises. Such processes determine in part the predictability (or the reverse) of the climate.

The energy in the climate system originates from the Sun. Clouds, aerosols (small particles in the air) gases and the Earth's surface reflect back 30% of the incoming shortwave radiation directly, and because this energy disappears into space, it does not affect the climate. The atmosphere absorbs one-third of the remaining radiation and the Earth's surface two-thirds. As a result, both the atmosphere and the Earth's surface warm up and emit long-wave heat radiation (infrared radiation) which eventually disappears into space. This leads to a balance between incoming and outgoing radiation. The majority of the heat radiation from the Earth's surface is absorbed by greenhouse gases in the atmosphere, which in turn reflect part of the heat radiation back to the Earth's surface. As a result of this process, the surface temperature is higher than it would be in the case without greenhouse gases. This is the natural greenhouse effect. Without this natural greenhouse effect the surface temperature on Earth would be –18°C and it would be a dead planet. The naturally occurring greenhouse gases increase this temperature by up to +15°C and are therefore crucially important for life on Earth as we know it.

Energy exchange between the Earth's surface and the atmosphere not only takes place by means of radiation, but also through the evaporation and condensation of water (cloud forming) and the upper air streams (also well-known as thermals of turbulent air movements). Over the year and throughout the world these processes have a net cooling effect on the Earth's surface.

2.2 Climate changes: the global perspective

The distant past: rapid climate changes

Since the world was formed, about 5 billion years ago, climate variations have been a natural phenomenon. A well-known example of naturally occurring climate varia-

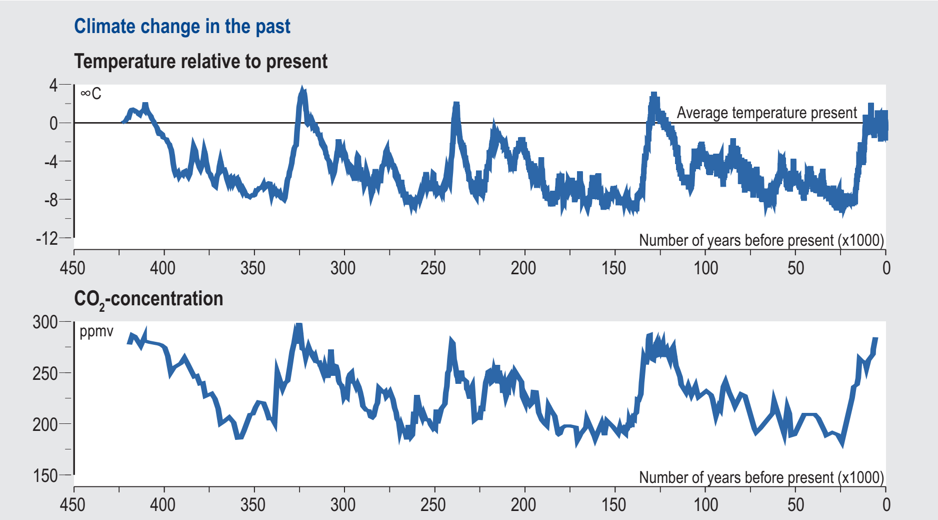

Figure 2.2: Climate changes in the distant past (Source: IPCC, 2001)

tions is the occurrence of a number of ice ages separated by interglacial periods of about 100,000 years, which were accompanied by variations in the average temperature on Earth of about 5°C. In this distant past, changes in the concentrations of greenhouse gases and global temperature largely kept pace with each other (Figure 2.2). Following the end of the last ice age about 12,000 years ago, several rapid climate changes occurred that were probably associated with changes in the ocean circulation caused by melting ice. Thereafter, the climate was strikingly stable with variations in the order of 1°C. In this stable climate, humans became farmers and many civilizations subsequently flourished before modern society finally emerged.

The recent past and now: the Earth is becoming warmer

The Earth is becoming warmer as shown by the rise in the global average temperature of the Earth's surface by about 0.7°C during the 20th century (Figure 2.3). This has not been a gradual process but has occurred mainly in the periods 1920–1945 and 1980–2000, with the years 1995, 1997, 1998, 2001, 2002 and 2003 being the warmest since 1860.

Since the advent of the Industrial Revolution, the concentration of greenhouse gases in the atmosphere has increased. The concentration of CO_2, the most important greenhouse gas, has increased from 280 ppm (= parts per million parts of air) pre-1800 to 380 ppm at the present time (Figure 2.4). This increase has mainly been caused by the combustion of fossil fuels, the production of cement and large-scale deforestation. Other human activities, such as agriculture, livestock husbandry and gas extraction, contribute to the emission of various other greenhouse gases, such as methane (CH_4) and nitrous oxide (laughing gas) (N_2O). Air pollution leads, via chemical reactions, to the formation of ozone (O_3 is also a greenhouse gas) at the Earth's sur-

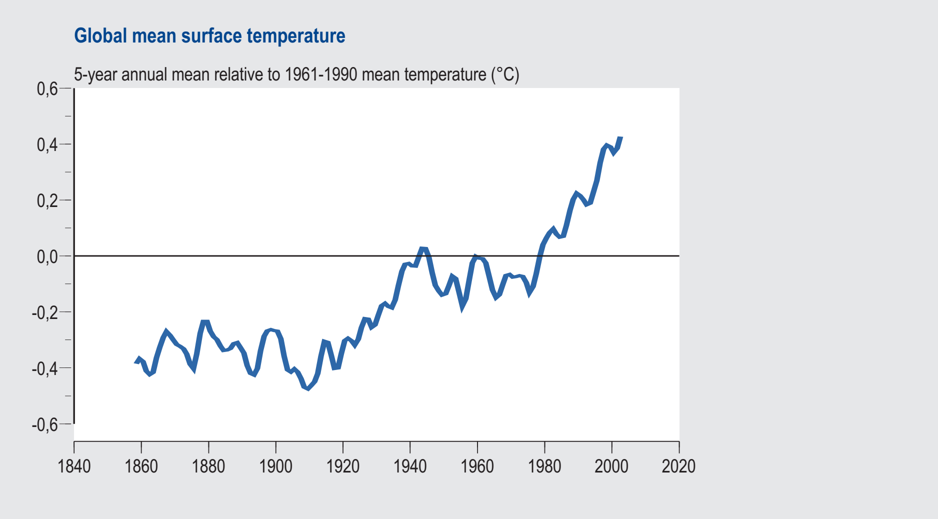

Figure 2.3: The Earth's temperature rose during the 20th century (Source: Climate Research Unit, http://www.cru.uea.ac.uk/cru/data/)

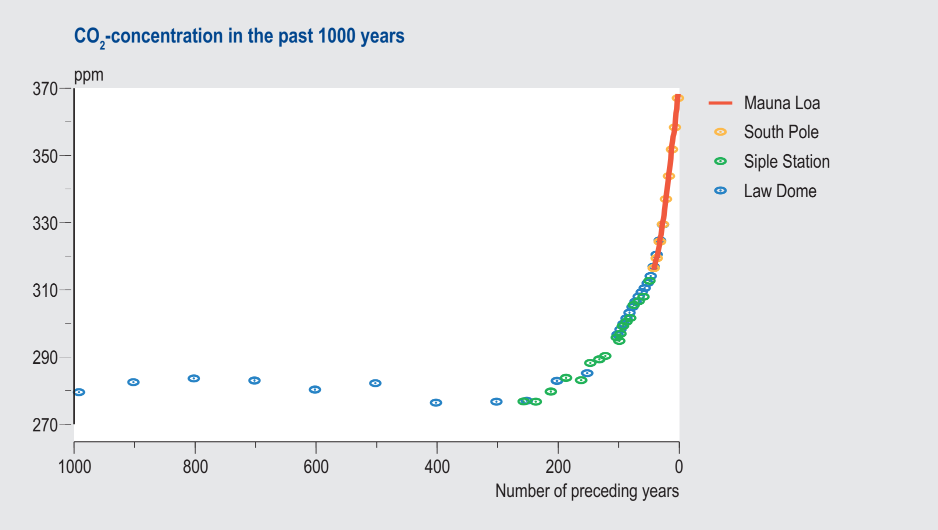

Figure 2.4: Trend in CO_2 concentrations in the atmosphere over the past 1200 years at various locations in the world (After: IPCC)

face. Although these other gases are released into the atmosphere in much smaller quantities than CO_2, their overall greenhouse effect is much stronger. The actual location of the emissions makes little difference with respect to their effect as greenhouse gases mix rapidly in the atmosphere and remain there for a long time. These higher concentrations of greenhouse gases cause an enhanced greenhouse effect; in other words, they contribute to the increase in the average temperature of the Earth's surface.

2.3 Causes of recent climate changes

The observed climate variations in the 20th century can be explained by a combination of natural and human causes. There are three distinct natural causes of climate variations: volcanic eruptions, variations in solar activity and El Niño (Figure 2.5).

Strong volcanic eruptions, such as those of Mt. Pinatubo in the Philippines in 1991, expel enormous quantities of dust high into the air. This dust remains in the atmosphere for several years and reflects sunlight back into space. As a result, the Earth's surface becomes cooler. The second natural factor, solar activity, is not constant and, consequently, the quantity of energy which reaches the Earth from the Sun varies slightly over time. This will in turn affect the temperature on Earth. The third natural factor is El Niño. The temperature of the seawater in an area to the west of Peru is abnormally high once every 3–7 years, which causes changes in the ocean circulation patterns. This change eventually leads to abnormal global weather patterns and affects the average global temperature.

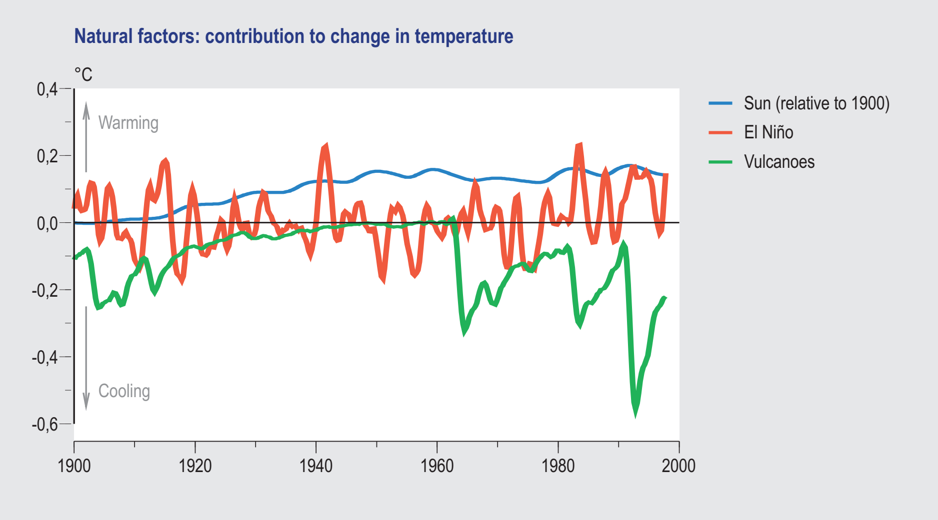

Figure 2.5: Estimate of natural climate variations in the 20th century (Source: Van Ulden and Dorland, 2000)

From 1950 until the mid-1990s these three natural factors had a net cooling effect on the climate. Nevertheless, the average global temperature has increased considerably since the 1980s, mainly due to the emission of greenhouse gases. Humans are also influencing the climate in another manner. Aerosols have a predominantly cooling effect and mask some of the warming effect of the rising concentrations of greenhouse gases (Figure 2.6). However, there are also aerosols which have a warming effect (mainly soot); these absorb heat and then emit this to their surroundings. With

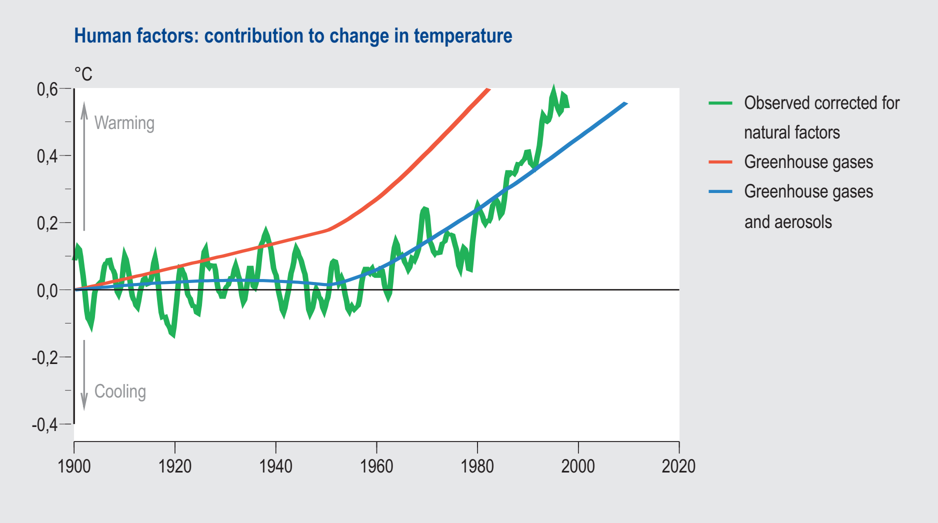

Figure 2.6: The human influence on the climate increases in the 20th century (Source: Van Ulden and Dorland, 2000)

increasingly stringent air pollution control measures, the predominantly cooling effect of aerosols has decreased over the course of time.

2.4 Climate changes in the Netherlands

Temperatures in the Netherlands have increased more than the worldwide average

Taken periods of 10 years or more, the temperature in the Netherlands is generally in line with the average global temperature (Figure 2.7a). In recent decades, however, the temperature rise in the Netherlands has been more than the world average (1.5 times). This difference is mainly due to changes in the prevailing wind direction. Wind determines the temperature variation from year to year and even from day to day. For example, in the winter, an easterly wind originating over land masses brings cold air over the Netherlands, and a westerly wind originating over the sea brings mild sea air. In the summer, the reverse is true. The direction of the wind is correlated

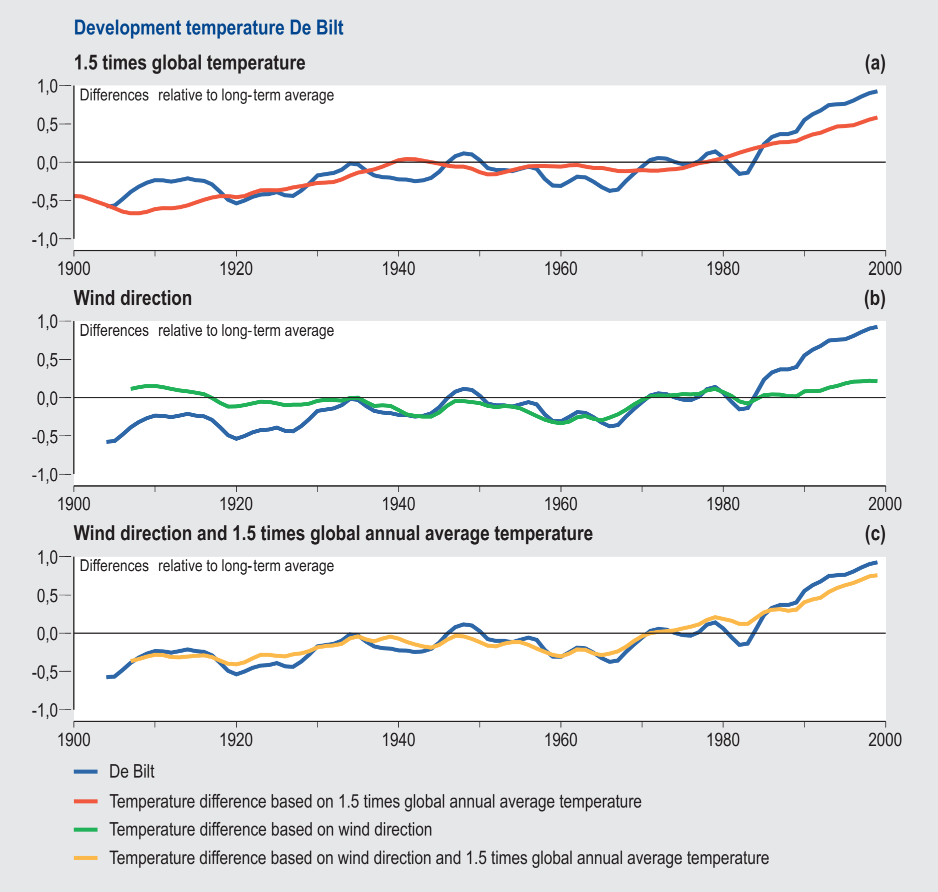

Figure 2.7: Temperature change in the Netherlands (Source: KNMI, 2003)

to developments in high and low pressure areas above the North Atlantic Ocean, the so-called North Atlantic Oscillation (NAO): the changes in air pressure differences between Iceland and the Azores. This determines airflow patterns above the North Sea and the European mainland. These patterns cannot be predicted far in advance.

Relatively colder weather predominated between 1940 and 1970. Due to the effects of the wind, the first 10 years and last 30 years of the 20th century were significantly warmer than the average global trend (Figure 2.7b). In particular, the late winter/early spring period has been noticeably warmer since the 1980s due to the increase in south-westerly winds. It is still not clear whether this increase in 'warm' winds in this season is correlated with a human effect on the climate. When the effects of winds are considered over longer periods of time, they become less distinct but are still not negligible. Consequently, the change in temperature pattern which has occurred can largely be clarified by the worldwide trend and the effect of the prevailing wind direction (Figure 2.7c).

In Europe, including the Netherlands, there are trends in the occurrence of extreme temperatures (Figure 2.8). For example, the number of cold days in the Netherlands has decreased, while the number of warm days has increased, particularly since 1975. However, these trends are not keeping pace with each other. The strongest warming effect in recent decennia has mainly been associated with an increase in the number of warm days and to a lesser extent with a decrease in the number of cold days.

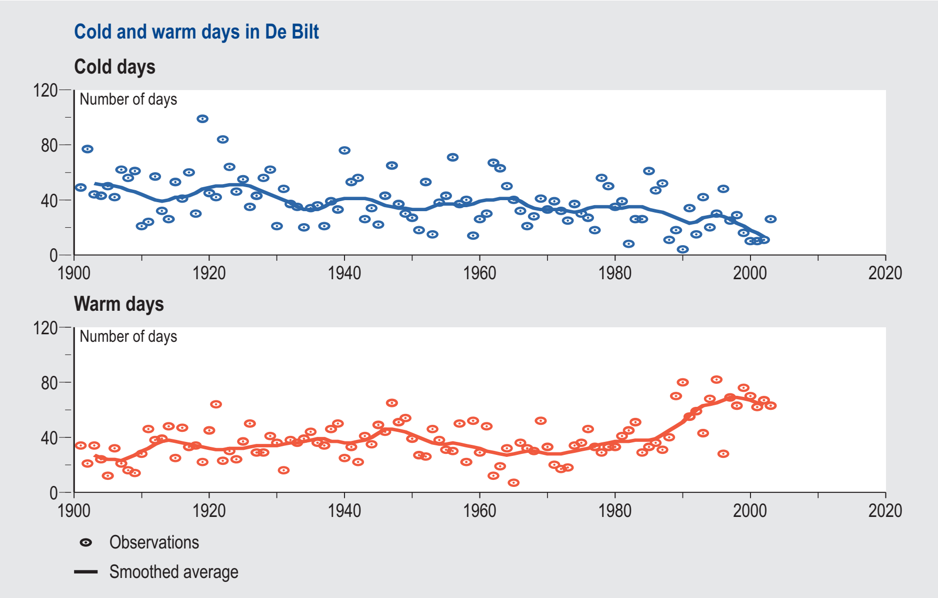

Figure 2.8: Trends in cold and warm days during the course of the 20th century, measured in De Bilt. For each calendar day the boundary for both cold and warm was set at the temperature which was exceeded on only 10% of the days between 1961 and 1990. (Source: KNMI, 2003)

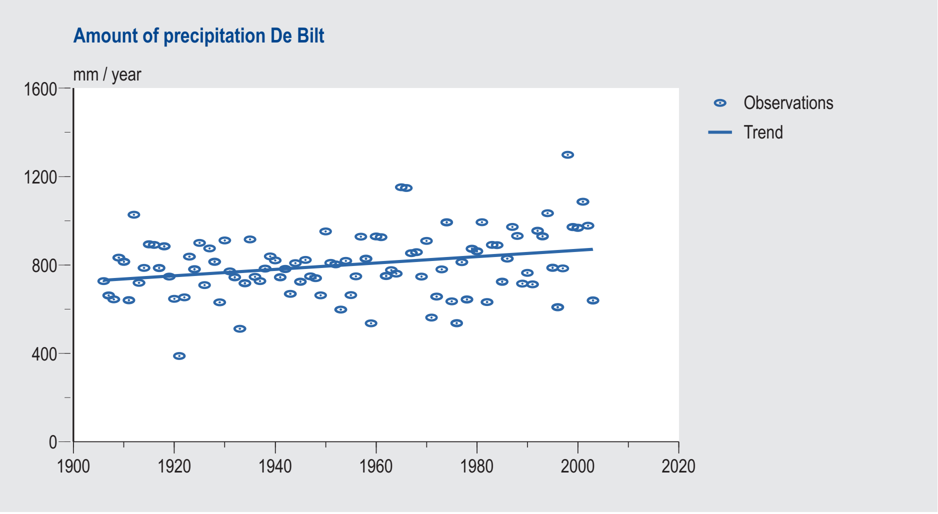

Figure 2.9: Annual precipitation in De Bilt during the period 1906–2003; the black line shows the trend (Source: Smits et al., 2004)

Precipitation is increasing, especially in the winter

Precipitation has an intrinsically unpredictable character – i.e. considerable variations can occur in space and time. Measurements recorded at De Bilt, the Netherlands indicate that the highest annual precipitation is about threefold more than the lowest (Figure 2.9). Despite this variability, there is a trend towards an increase in the annual precipitation. This trend is also visible at the national level and is mainly due to an increase in the average amount of precipitation between October and March. The rainfall between April and September has not changed.

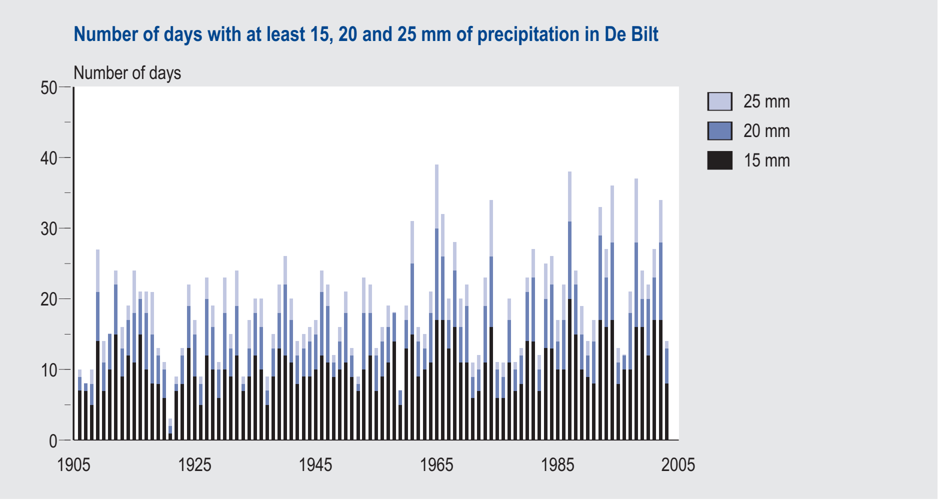

Figure 2.10: Days with at least 15, 20 and 25 mm of precipitation (±11-, 6- and 3-fold more precipitations a year, respectively) at De Bilt for the periods 1906–1954 and 1955–2003 (Source: Smits et al., 2004)

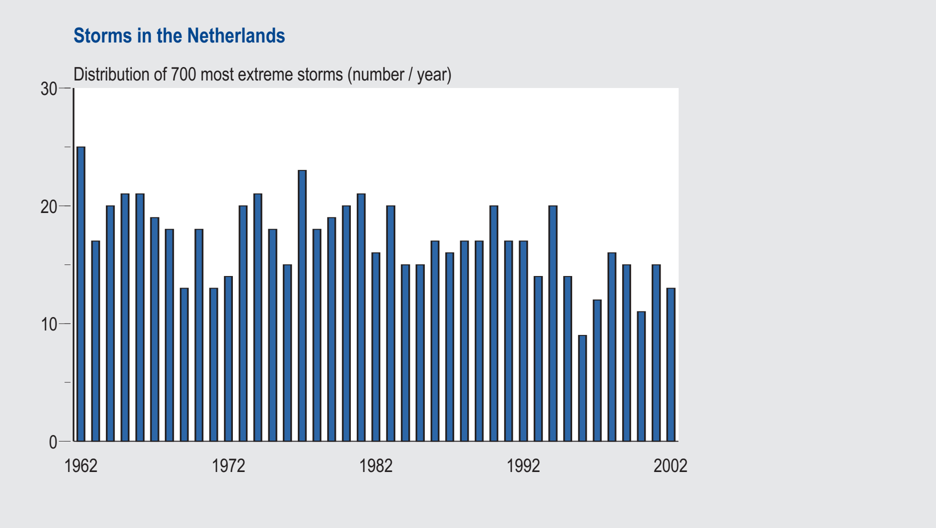

Figure 2.11: Distribution of the 700 most extreme storms in the Netherlands over the past 41 years (Source: KNMI)

For precipitation, even more so than for temperature, the effects are mainly determined by extremes. In De Bilt, the total number of days with considerable precipitation is clearly increasing (Figure 2.10). However, when measurements are extrapolated over the entire country, the trend towards highly intensive precipitation (>50 mm per day) is not yet observable. This is due to the unpredictable nature and spatial distribution of the showers. The Royal Netherlands Meteorological Institute's (KNMI) opinion is that it is highly likely that very extreme rainfalls have also increased in the Netherlands.

Fewer storms in the Netherlands

Since 1962 the number of storms per year has decreased. Figure 2.11 shows the distribution of the 700 most extreme storms in the Netherlands over the past 41 years. The wind speed associated with these storms was, depending on the location within the country, more than 11–16 m/s; this is equivalent to a wind force of 6–7 on the Beaufort scale. Moreover, even if only the 300 or 500 most exceptional events are considered (heavier storms), the picture does not change: the number of storms in the Netherlands is decreasing. To what extent this decrease is correlated with rising temperatures is not clear.

2.5 Climate projections for the 21st century: global

That the world's climate is changing is a generally accepted fact. Less well known is how this change will unfold in the distant future. Climate projections for the 21st century can only be made if a picture of the future emission of greenhouse gases and particles is available. Due to the intrinsic characteristics of climate change, such a picture is highly uncertain. Therefore, in climatology, scenarios are used that describe alternative pictures of possible developments, which together form the contours of a conceivable future. In 2000, the IPCC developed six groups of scenarios for worldwide population, social economic and technological developments in the 21st century. All of these scenarios were developed without including climate policy and resulted in the prediction of different emissions of greenhouse gases and patterns of climate change. Despite this variation, all of the scenarios predict a considerable increase in the quantity of greenhouse gas emissions. It is expected that the cooling effect of dust particles will eventually decrease.

The IPCC states that the scenarios could lead to a rise in the average global temperature of 1.4–5.8°C by 2100 compared to 1990. The temperature range is associated with the uncertainty in the predictions regarding future human emissions of greenhouse gases and dust particles as well as an incomplete knowledge of the climate system (see Box C). These two uncertainties are similar in size. In the Netherlands, a large number of calculations on changes in extreme weather situations over the period 1940–2080 have been carried as part of the Dutch Challenge Project (Centre for Climate Research – CKO). A detailed climate model was used for this, parts of which are distinctly different from other models (Figure 2.12). The study revealed a rise in the global temperature of 1.5°C, which is at the lower limit of the IPCC range of values. The difference lies in the scenario used here (the so-called A1b scenario of IPCC, which is a middle scenario in terms of emissions) and the low sensitivity of the climate model (see Box C).

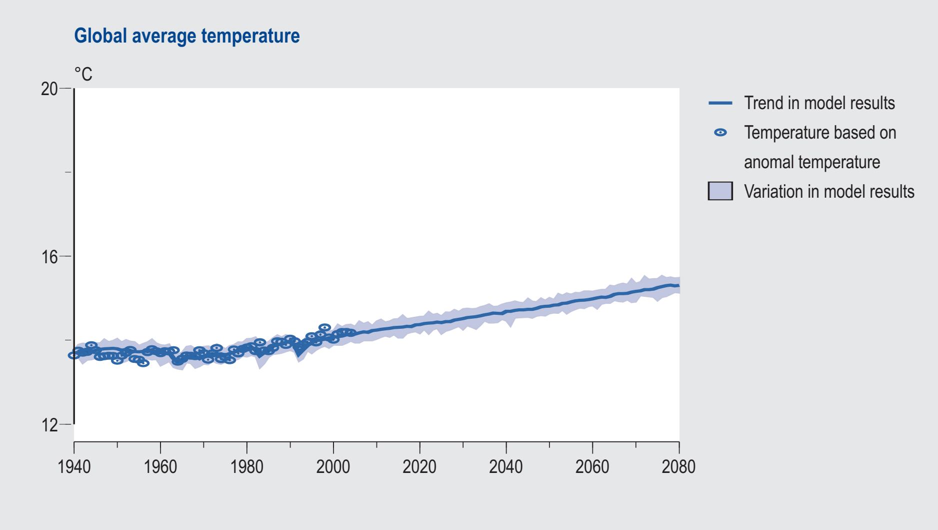

Figure 2.12: World average temperature pattern for the period 1940–2080 (Observations dark dots; simulations light crosses) and the average of the simulations (black line). The effects of large volcanic eruptions are clearly visible (Source: http://www.knmi.nl/onderzoek/CKO/Challenge_live/).

Box C: Climate sensitivity and model uncertainty

The sensitivity of the climate system for a change in the concentrations of greenhouse gases in the atmosphere is termed the climate sensitivity (expressed in °C global temperature increase due to a doubling in the equivalent CO_2 concentration in the atmosphere).

The value of the climate sensitivity is uncertain and its determination complex. It cannot be clearly defined on the basis of observations. The IPCC (2001) gives a probability range of 1.5°C–4.5°C for the climate sensitivity, with 2.5°C as the central estimate (Curve of Wigley and Raper). Since the publication of the last IPCC report (2001), various new studies have appeared that have constructed probability distributions for the climate sensitivity value on the basis of various models. These distributions show that the climate sensitivity has a greater range of possible values than the IPCC range and that in particular there is a higher probability of greater climate sensitivity.

The uncertainty in the climate sensitivity is due to the complexity of the climate system. The determination of the final temperature effect of the increase in greenhouse gas concentrations requires a very detailed knowledge of the climate system. For example, purely on the basis of the radiation effect, a doubling of the CO_2 concentration leads to a temperature rise of about 1.1°C. Many processes in the atmosphere are temperature-dependent and can counteract or magnify such a temperature change. These mechanisms are termed negative and positive feedback, respectively.

In particular, possible changes in the water cycle (hydrological cycle) exhibit a strong feedback. For example, it is expected that the temperature rise will lead to an increase in the quantity of water in the atmosphere. This magnifies the original greenhouse effect of water vapour by a factor of 1.8. The temperature rise due to a doubling in the CO_2 concentration would therefore be about 2°C (= 1.1 × 1.8). However, if in a warmer climate the increase in water vapour mainly occurs in the clouds, this positive feedback is much weaker.

A second feedback mechanism associated with the water cycle is the so-called ice-albedo feedback. In the event of a temperature increase, the total surface area of land and sea ice decreases, with the result that less solar radiation is reflected by our planet. This also gives rise to an extra temperature increase.

A third feedback mechanism is possibly caused by changes in cloud characteristics, such as changes in the average height of the base and/or top, the quantity of water in the cloud and the average drop and ice crystal size. However, there is enormous uncertainty about these feedback mechanisms. Some models reveal an attenuation in temperature response and others an amplification.

Finally, interactions with the ocean currents and the biosphere are possible, such as shifts or changes in the vegetation.

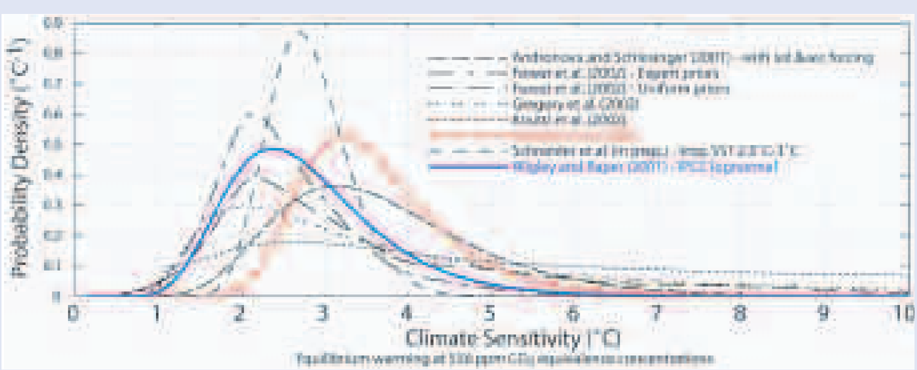

Figure C1: Probability distribution functions for climate sensitivity. (Source: Hare and Meinshausen, 2004)

The warming of Earth will almost certainly intensify the water cycle, with the result that more frequent and heavier rainfalls are predicted worldwide. Again, however, the unpredictable nature of the changes in rainfall patterns means that these expectations are uncertain. The expected increase will most likely mainly occur in temperate regions, whereas in the subtropics a decrease in rainfall is expected. In Europe, the chances of drought and more extreme heat will increase. Southern Europe in particular will be affected by this with, for example, an average decrease in summer rainfall of 20%. Furthermore, the higher summer temperatures in southern Europe will also lead to an increase in evaporation, which will exacerbate the drought.

Such changes are associated with increasing differences from year to year. Sea ice, glaciers and icecaps will probably retreat further, whereas the ice mass of Antarctica may expand due to the increasing amount of precipitation. The sea level is expected to rise by 9–88 cm. The rise could be higher than the projections if large ice masses such as those on Greenland begin to melt. There are indications that this could happen if the average world temperature were to rise by just 1–3^{o}C. Furthermore, even after the 21st century, the sea level could continue to rise for many more centuries to come even if greenhouse gas concentrations were to remain at the same level. The final conclusion is that, depending on the temperature rise, a sea level rise of several metres is projected over a period of thousand years.

2.6 Climate expectations for the Netherlands

Predictions on climate change in the Netherlands require insights into regional climate expectations as well as global trends. Regional trends are even more uncertain because small spatial shifts in climate patterns can make a considerable difference. This is particularly the case for changes in precipitation patterns and changes in extremes. Consequently, improvements in regional climate projections and insights into the shifts in extremes have been given a high priority on the research agenda for the next few years.

The increase in the average temperature is set to continue

Current climate models indicate that the expected rise in temperature in the Netherlands will effectively be in line with the average global increase in temperature.
Measurements taken at the De Bilt meteorological station within the framework of the CKO project reveal that there are considerable yearly fluctuations in both the measured and calculated temperature series (Figure 2.13). Since the 1990s there has been a visible rise in both the calculated and measured time series. Calculations predict that the temperature in the Netherlands is rising just as rapidly as the average world temperature, namely, 1.5^{o}C over the next 80 years. The rise could be much bigger if other assumptions are made for the increasing concentrations of greenhouse gases and other climate models are used.

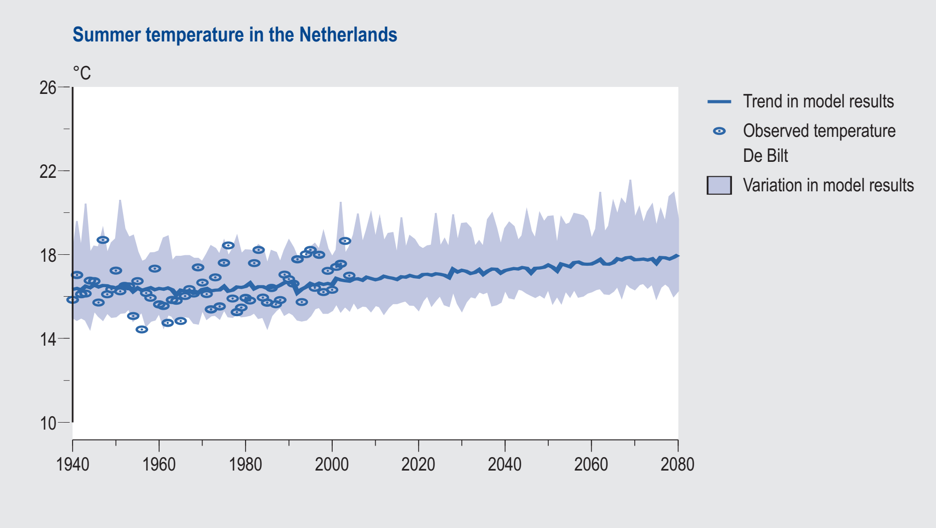

Figure 2.13: The average summer temperature in a specific time point of the model that covers part of the Netherlands (Source: http://www.knmi.nl/under/CKO/Challenge_live/).

Expectations for the average precipitation: more rain

Based on the world average temperature projections from the IPCC, the Royal Netherlands Meteorological Institute KNMI has developed three scenarios for the precipitation in the Netherlands in the year 2100 (Table 2.1). These climate scenarios were the starting point for exploratory studies into the consequences of climate change in the Netherlands, such as possibilities for drainage. For example, the national water policy for the 21st century is partly based on these insights (see also later in this report). These scenarios reveal an increase in both summer and winter precipitation. The KNMI has also recently developed a dry scenario based on new insights and model studies that indicate that summer droughts can become worse as a result of extreme

Table 2.1: 'Wet' climate scenarios for the Netherlands (for 2100), after Kors et al. (2000), and a dry scenario (for 2050)

	Low (2100)	Middle (2100)	High (2100)	Dry (2050)
Temperature	+ 1°C	+ 2°C	+4 to +6°C	+4 to +6°C
Average summer rainfall	+1%	+2%	+4%	–15%
Summer evaporation	+4%	+8%	+16%	+19%
Average winter precipitation	+6%	+12%	+25%	n.c.
Annual maximum 10-day winter precipitation sum	+10%	+20%	+40%	n.c.
Repeat time 10-day precipitation sum*	47 years	25 years	9 years	n.c.
Sea level rise	20 cm	60 cm	110 cm	n.c.

*: sum as this now occurs once in every 100 years: ≥140 mm
n.c.: not calculated

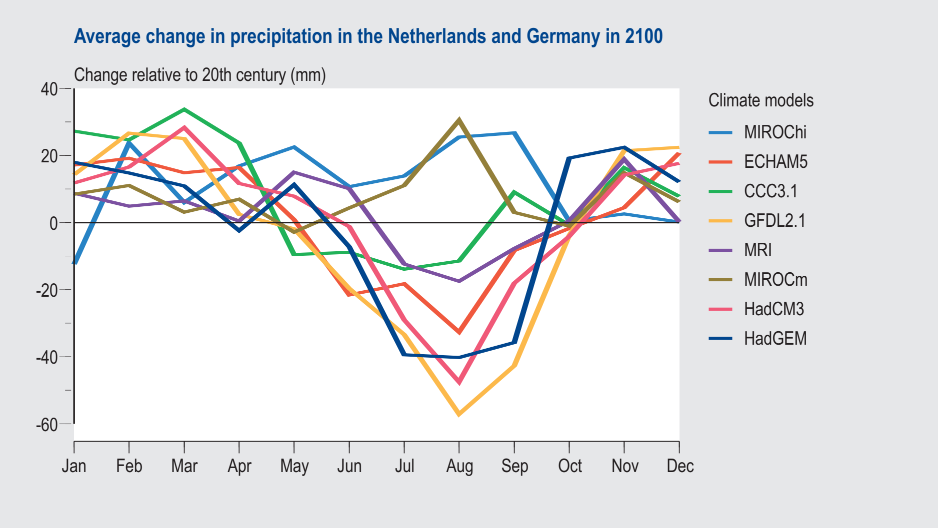

Figure 2.14: Monthly average change in precipitation in 2100 in the Netherlands and Germany calculated with eight climate models (presented as % precipitation change for the period 2070–2100 with respect to the average of the 20th century) (Source: http://www.knmi.nl/under/CKO/Challenge_live/)

heat and circulation changes. This dry scenario (calculated for 2050) combines high estimates in temperature changes and a decrease in frontal precipitation. The frequency of rainfall extremes will not change compared to the present situation. Note that these scenarios are not predictions. They are calculations based on more or less consistent assumptions about developments in the climate system and how these could be influenced (see also Box A on uncertainties).

The uncertainty in the expected summer rainfall can be derived from Figure 2.14, which presents the results from eight different climate models with respect to the expected monthly average change in precipitation in and around the Netherlands. This figure shows that the average precipitation will increase during the winter season. In the summer, however, while the majority of models reveal a decrease in the average precipitation, two models predict an average increase. This variation in modelling results reflects the uncertainty which exists with respect to the development of regional circulation patterns. It also indicates the likelihood of the scenarios from Table 2.1. In the KNMI scenarios and the model studies, the expectation is that, all things being equal, the Netherlands will become drier in summer, mainly as a result of the strong increase in evaporation.

Changes in storms are very uncertain

The large uncertainty in the effect of climate change on the storm patterns in the Netherlands means that an understanding of changes in the likelihood of storm floods is far from complete. Recent research with large-scale models indicates a possibility of ‘super storms’ occurring within our borders, with the chance of significantly

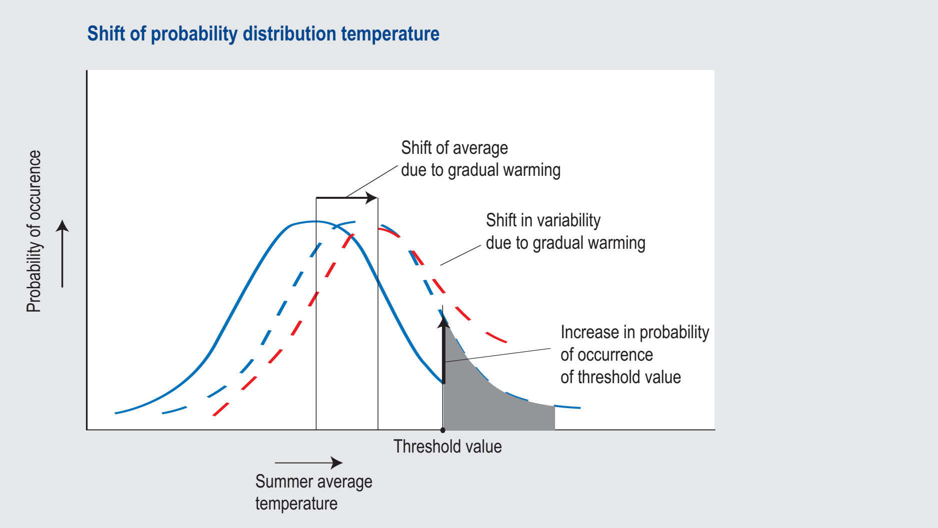

Figure 2.15: Shifting averages leads to a disproportional increase in extremes

higher wind speeds than we have experienced in the 20th century. Further research with more refined models is necessary in order to understand the underlying processes.

Expectations for climate extremes: more heat waves, less cold waves

Projections of possible shifts in extreme weather are extremely uncertain. Figure 2.15 shows, however, that just a limited shift in the frequency distribution of temperature (and also precipitation) can lead to large changes in weather extremes. A similar finding was also obtained from the CKO project, which main objective was to evaluate changes in extreme weather situations. The latter study revealed that on average the August temperature might increase by 1.4°C in 2080. However, the temperature from the extremes in warmth that occur once every 10 years is increasing twice as much. This is because the cooling effect of the evaporation process disappears due to a greater chance of low moisture content in the soils. The calculations also reveal a more frequent circulation from the southeast. A more frequent occurrence of the 'summer of 2003' will therefore be highly likely (see also Box D). The British Hadley Centre even claims that such a summer could become quite normal around the middle of this century.

It is expected that the chance of extremely cold winters will decrease less quickly than would be expected on the basis of the average temperature increase (Figure 2.16). This is because the cold extremes are strongly dependent on the wind direction (easterly wind). In concrete terms this means, for example, that in the future the famous '*Elfstedentocht*' skating tour is less likely but still possible.

Box D: The extremely dry and hot summer of 2003

In central and northwestern Europe the summer of 2003 was the hottest in more than 500 years. The average summer temperature in Europe was almost 2ºC higher than the long-year average of 17.5ºC over the period 1901–1995. The central part of Europe and, in particular, the Alps had the largest temperature aberration: more than 5ºC above normal. Up until then the warmest European summer had been that of 1757 when it was particularly warm in southern Scandinavia, eastern Europe and western Russia. The summers of 1947, 1976 and 1994 were also particularly warm in various European countries. In the Netherlands, it was less extreme. The Dutch summer of 2003 was – with an average temperature of 18.6ºC – about as warm as the summer of 1947, which was the warmest summer of the 20th century in the Netherlands.

The summer of 2003 was also extremely dry in large parts of Europe. Extreme drought enhances the heat. In the Netherlands the drought was somewhat less extreme: such a dry year occurs on average once every 10–20 years.

Due to the low supply of water in the Rhine, the brackishness from the sea gradually spread inland, with the result that in the middle of August the inlet points of the Rhineland and Schieland Water Boards became brackish. In normal situations fresh water is let in here in order to (i) maintain the water level in the polder reservoir system of Mid-Holland within margins of 10–20 cm and (ii) counteract internal brackishness (seepage of brackish groundwater). The two inlet functions could no longer be combined in mid-August.

As a result of the high water temperatures and low river level the cooling capacity of several power stations was threatened. The discharge requirement that cooling water may be no warmer than 30ºC meant that several companies could only satisfy this criterion by reducing their production capacity. The three hydroelectric power stations on the Meuse, Nederijn and Vecht also had to run on a very limited capacity for several weeks (10–25% of normal). The combined result was a threatened shortage of electricity in the Netherlands.

A number of dykes also collapsed as a result of the drought (Wilnis, Rotterdam, Stadskanaal). There are about 3500 km of peat dykes in the lower regions of the Netherlands. Due to the persistent drought a number of these dykes lost a critical amount of water. This resulted in their becoming lighter, shrinking, cracking and, ultimately, collapsing. The relatively dry winter of 2003–2004 resulted in the peat dykes not regaining their resilience by the summer of 2004.

The heat wave in 2003 lead to the premature death of about 500 people in the Netherlands. This number has been estimated to be 27,000 people throughout all of Europe, more than one-half of whom were in France.

In large parts of Europe the grain harvest was much lower than normal due to the drought (not in the Netherlands). When the EU-15 is considered as a whole, the harvest was the worst since the start of record keeping in 1961.

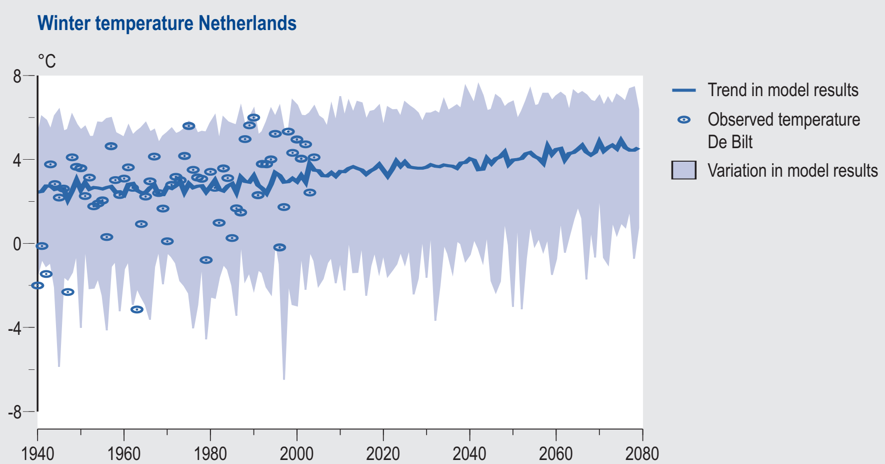

Figure 2.16: The average winter temperature in a time point of the model that covers a part of the Netherlands (Source: http://www.knmi.nl/under/CKO/Challenge_live/)

3 WHAT DO RESIDENTS IN LOW-LYING AND RIVER AREAS NEED TO BEAR IN MIND?

Key points:

- A rising sea level as a consequence of climate change has already been demonstrated; further temperature increases will inevitably lead to a continued and more enhanced sea level rise and a greater variability in river discharges.
- The chances of floods will likely increase further due to an expected increase in the number of episodes of extreme rain.
- The observed annual precipitation deficit does not yet demonstrate a clear trend. The chance of drought during the summer is expected to increase; whether extremely dry summers will occur more frequently is not yet known.
- Adaptation to climate change already affects water policy. Spatial measures play an important role in the plans but have only been deployed to a limited extent to date.

Climate change already plays a role in water policy

The climate is changing and the consequences (see, for example, Chapter 2) of this are: increased precipitation and evaporation, a rising sea level, higher river discharges in winter and a greater chance of floods and drought in the summer. A rising sea level and increasing river discharges together imply that without additional measures there will be an increased chance of severe flooding in the low-lying parts of the Netherlands. Higher chances of floods and droughts are predicted for the entire country, even for the higher parts.

Current water policy takes the possible effects of climate change into account. With the objective of realizing a safer and more robust water system, these considerations involve not only technical measures but also spatial planning measures.

3.1 Protection from severe flooding

The term 'severe flooding' describes a situation which is life-threatening, possibly with casualties; the term 'light floods' is used when there may be damage to buildings and/or the agricultural infrastructure but the situation is not life-threatening (see Section 3.3).

Safety measures against severe flooding mainly play a role in the low-lying areas of the Netherlands: along the coast, in the Rhine/Meuse area and in the Lake IJssel area. The standards for the safety level in the coastal provinces and the Rhine/Meuse area have been established in the Flood Defences Act of 1996 (see also Box E). The severe flooding along the Meuse and the near-serious flooding along the Rhine in 1993 and 1995 have led to a renewed consideration of safety measures against severe flooding.

Box E: Is the Netherlands sufficiently protected against severe flooding?

In 2003/2004, the Netherlands Environmental Assessment Agency (MNP) carried out an evaluation of the policy on safety measures against severe flooding, at the request of the Ministry of Transport, Public Works and Water Management. The results were presented in a report 'Risico's in bedijkte termen' [Dutch dikes, and risks hike (MNP-RIVM, 2004)]. The most important results from the report are summarized below.

From an international perspective the Netherlands has the highest safety standards with respect to severe flooding, and the strength of the dykes has increased substantially since the last severe floods (1953). The standards for the safety level are legally established in the Flood Defences Act of 1996 and in order to maintain a safe situation, the measures that need to be taken to ensure that the dykes still satisfy the standards are reviewed every 5 years. Consequently, the probability of severe floods remains more or less the same.

However, current measures to protect the Netherlands against severe floods are not sufficiently safeguarded. Firstly, only 50% of all primary dykes have been clearly shown to satisfy the standard set for these dykes; of the remaining 50%, 15% do not satisfy the standard, while the information needed to make the assessment is lacking for the last 35%. Secondly, the economic value that must be protected by the dykes and dunes has increased substantially since the year (1960) in which the standards were established: in the intervening period the economic value has increased by more than a factor of six, and there has also been a strong increase in the size of the population. Consequently, the potential for damage has increased substantially. The probability of a considerable number of casualties (the 'group risk') as a result of severe flooding is therefore higher than all of the other external risks taken together (air traffic, train derailments, LPG transport, industrial complexes).

Unless additional measures are taken, the risks of damage will further increase due to the increasing well-being of the inhabitants, the increase in river discharges and the rising sea level. A number of suggestions are made in this report which can reduce the risks, such as adjusting and differentiating safety levels, compartmentalizing dyke rings and taking risk situations into consideration in spatial planning policy (e.g. not building in (potentially) dangerous places).

Sea level at the Dutch coast has risen over the past century

The sea level along the Dutch coast has risen by about 20 cm as an average during the past century (Figure 3.1). As the level markers of NAP (Normal Amsterdam Level) move with the tectonic movements of the Earth's crust, measurements compared to NAP always provide a *relative* rise in sea level: the combined effects of the *absolute* rise in sea level and subsidence of the land.

Part of the observed relative rise in sea level is the effect of land subsidence in the coastal zone due to time-lag effects from the last ice age (isostatic movement). Whereas Scandinavia is still moving upwards due to the melting of ice, large parts of the northern and western areas of the Netherlands are experiencing a land subsidence of several centimetres per century. In addition, the land in many places in the low-lying parts of the Netherlands is subsiding compared to NAP due to a settling of the clay and peat layers and oxidation of peat; this results in an even greater relative sea level rise compared to ground level.

The temperature rise of the atmosphere (see Chapter 2) causes on the one hand the melting of glaciers and polar ice and on the other the warming up and subsequent expansion of ocean water. Both of these processes contribute to an absolute rise in sea

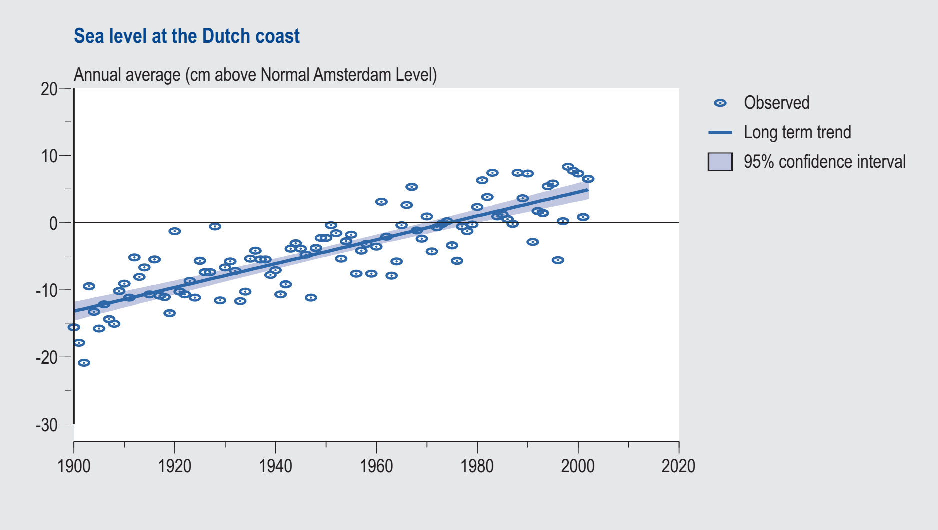

Figure 3.1: The sea level at the Dutch coast has risen by an average of 20 cm over the past century (Source: RIKZ)

level. On a global scale these two factors are probably the main causes of the observed world average sea level rise of 10–20 cm. Climate change is also the most important cause of the rise in sea level at the Dutch coast.

The predicted sea level rise necessitates extra measures against severe flooding

The expectation for 2100 is that climate change will lead to a further rise in sea level at the Dutch coast in the order of 20–110 cm relative to ground level (see Climate Scenarios Table 2.1). This prediction is based on an average land subsidence of 10 cm per century and takes into account both land subsidence as a consequence of time lag effects from the last ice age – to which the NAP is also subjected (see above) – and the average value for fall in the ground level due to the settling of clay and peat. However, considerable local differences in ground subsidence can occur.

Note that there is a large time lag between the warming up of the oceans and the temperature rise in the atmosphere. This implies that if the average temperature of the atmosphere would be limited as a result of reduced emissions, an effect on sea level would only be realized after many centuries.

One consequence of the expected rise in sea level is the need for more and larger volumes of sand to be added as beach nourishment to the coastal system to compensate for the losses of sand that now occur and to maintain current safety levels. The addition of sand to the coastal system will also ensure that the coast, estuaries and the Wadden Sea keep pace with the rise in sea level. In the future, stronger and wider dykes will be needed to offset the greater pressures arising from the rise in sea level.

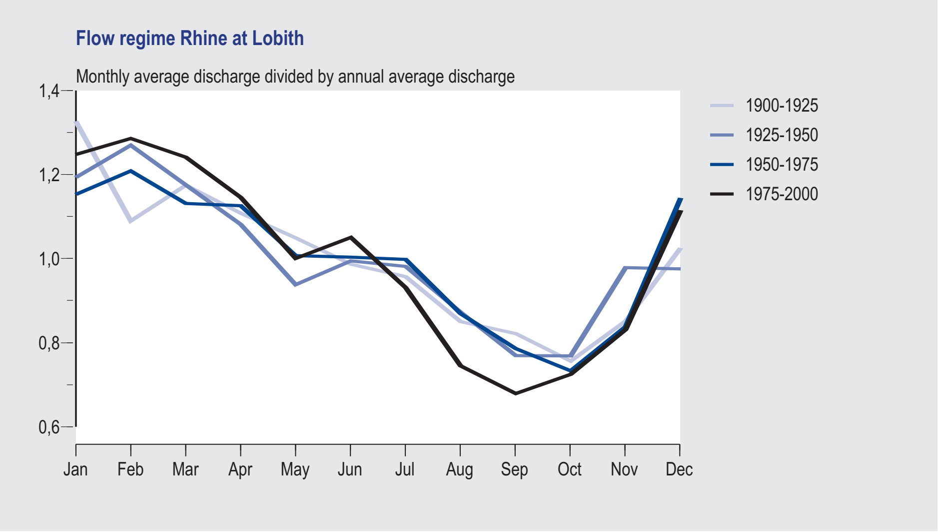

Figure 3.2: In recent decennia the winter discharge from the Rhine has increased and the summer discharge has decreased (Source: Buiteveld, H., 2005)

Over the next 50 years, the additional costs for coastal management are expected to be no more than 0.13% of the gross national product. In the case of a further rise in sea level after 2050, the costs for coastal management could increase to (much) more than the present spending level.

Next to the influence of sea level rise, the occurrence of flood levels is strongly determined by the occurrence of storms on the North Sea. However, it is not yet clear how the frequency and intensity of storms will change in the future.

Discharge measurements from the Rhine over the past few decades are higher in the winter and lower in the summer

The discharge of the Rhine since 1900 shows an apparent trend which is expected to continue in a more pronounced form in the future. Figure 3.2 shows monthly average discharges at Lobith, expressed relative to the annual average discharge. During the last few decades in particular there has been an observable shift towards higher average discharges in the winter and lower average discharges in the summer. While there is no direct evidence that this shift is due to climate change, it does fit in with the total picture of climate change.

It is expected that river discharges will increase even more in the winter and decrease even more in the summer

Due to global warming, changes will occur in the precipitation pattern in the Rhine basin area. It is expected that the Rhine, at present a combined rain and melt-water river, will increasingly become a rain river with high discharges in the winter and low discharges in the summer. The increasing winter precipitation will affect an increase

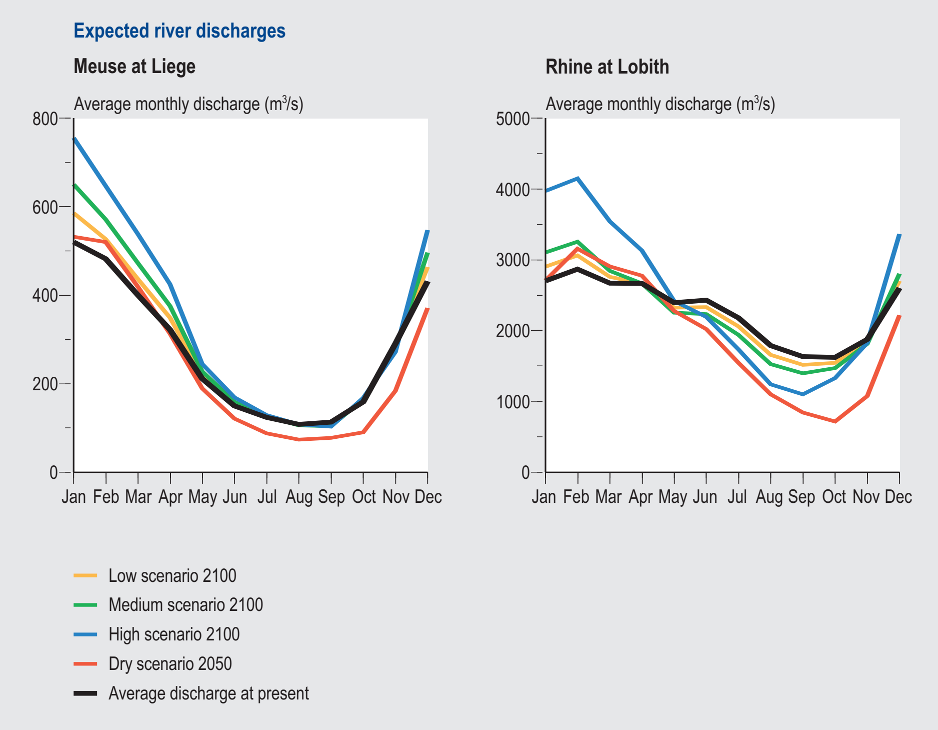

Figure 3.3: In all four of the climate scenarios considered, the winter discharge increases even more in the future; the summer discharge decreases for the Rhine in all of the scenarios and for the Meuse, only in the drought scenario (Source: Beersma et al., 2004)

in the discharge of the Rhine in winter. Summer discharge will decrease as a result of a reduced amount of melt water and a strong increase in evaporation, the latter outweighing the effect of the smaller increase in the average rainfall in the summer (see Climate Scenarios Table 2.1).

Figure 3.3 shows that in all of the climate scenarios (low, medium, high and dry, see Chapter 2) the expected winter discharge of the Rhine will increase even further and the summer discharge will decrease even further relative to the present discharge. Similar to the expectation for the Rhine, the winter discharge of the Meuse will also be higher in the future than it is at present. For the dry climate scenario in particular, the summer discharge will be even lower than is currently the case. In the present situation a low water level on the Meuse is already a problem, and only a slight change is enough to make the situation in the summer worse.

Expected extreme river discharges will also increase

The design discharge which is used as the basis for the legal safety standards in the Flood Defences Act is indicative for extreme discharges. In the Rhine/Meuse area, the design discharge is based on a discharge quantity which occurs on average once every 1250 years. In legal terms, this is the maximum quantity of water the river must be

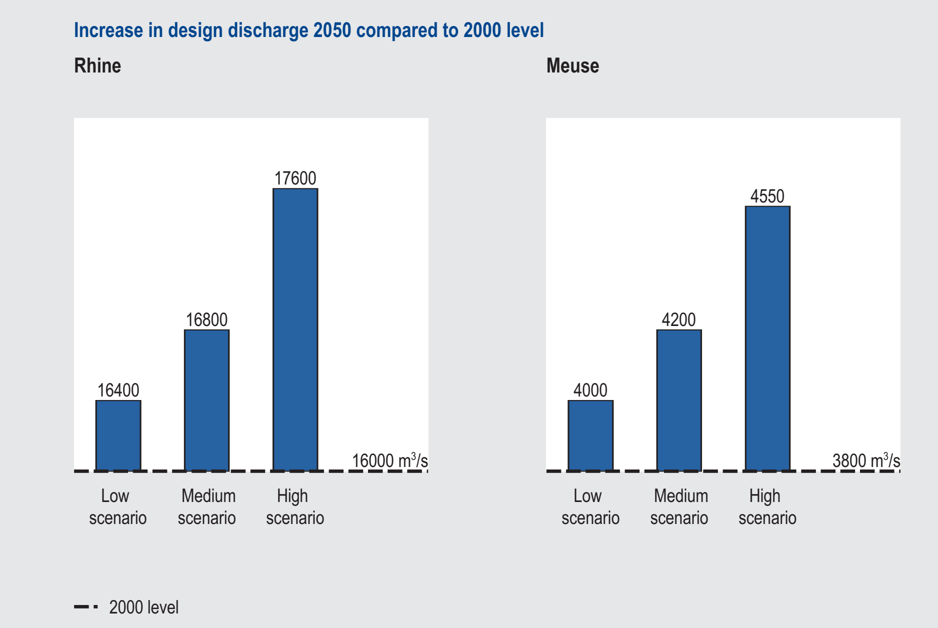

Figure 3.4: The design discharges of both the Rhine and Meuse increase in 2050 in three of the climate scenarios considered (low, medium, high) (Source: Buiteveld and Schropp, 2003)

able to discharge without the hinterland becoming flooded. The dykes, flood plains, main channel and other related factors are dimensioned on this discharge.

Following the high water levels in the Rhine/Meuse system in 1993 and 1995 the design discharge for the Rhine was adjusted from 15,000 m^3/s to 16,000 m^3/s. The direct consequence of this adjustment is that the current situation in the Rhine/Meuse area no longer satisfies the legal safety standards. In the Spatial Planning Key Decision Document: 'Room for the River' the Dutch Cabinet presented a package of measures which would ensure that the flood protection measures for the Rhine/Meuse area would once again meet the legal safety requirements by no later than 2015.

According to the climate scenarios, in 2050 the design discharges of both the Rhine and the Meuse will have increased (see Figure 3.4): the Rhine by 3–10% and the Meuse by 5–20%. This means that additional measures in the Rhine/Meuse area will be necessary to ensure that the legal standard is still met.

Adaptation: measures in the Rhine/Meuse area

In the future the expected rises in sea level together with the higher discharges of the Rhine/Mass system will result in higher extreme flood levels. By 2050 these increased water levels are expected to cause problems in the Rhine/Meuse area as well as in the area downstream (Figure 3.5). Additional measures in this area and/or upstream of it will be needed to maintain the current safety level.

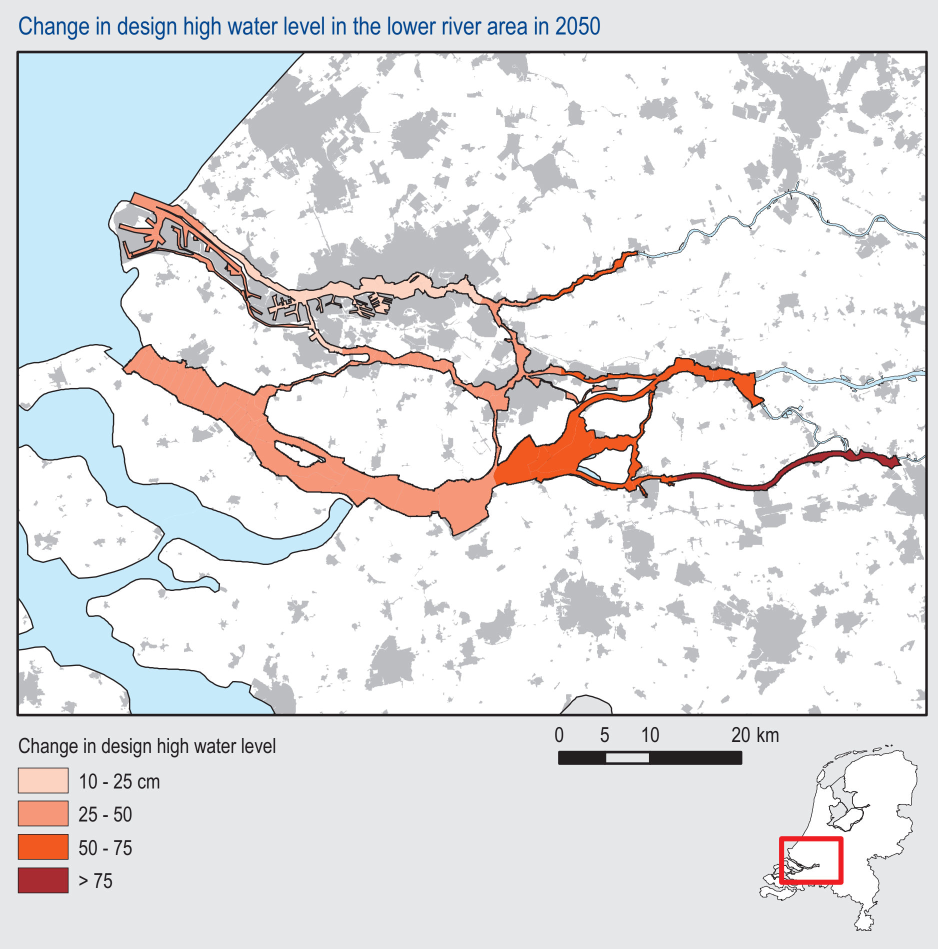

Figure 3.5: Example: in 2050 problems can be expected in large areas downstream in the Rhine/Meuse area (middle scenario) as a result of extreme water levels (After: Blom, 2001)

In the Spatial Planning Key Decision Document 'Room for the River', additional to the measures to ensure the safety level associated with 16,000 m^3/s (see above), measures for preserving space over the long term have been included to compensate for the future effects of increases in river discharges and the sea level. To this end, about 7000 hectares have been reserved along the Rhine. This space will allow for a possible increase in the design discharge of the Rhine of up to 18,000 m^3/s. The actual measures still need to be taken in these reserved areas.

As the Rhine and the Meuse are both transboundary rivers, protection against floods requires an international approach. Therefore, France, Germany, Luxembourg, Belgium and the Netherlands cooperate on measures to limit the risks of floods. There are joint Flood Action Plans for both Rhine and Meuse. The European Union has financially supported the implementation of these plans with a contribution of 140 million euros. Joint research projects on floods in the Rhine by the German state of Nordrhein-Westfalen, the Dutch province of Gelderland and the Directorate General for Public Works and Water Management form an integral part of these plans.

Lake IJssel area: expected winter water levels are higher and more variable

As a consequence of the increasing discharges from the Rhine in the winter and the increasing discharge problems into the Wadden Sea due to the rise in sea level, the water level of the Lake IJssel will show a tendency to follow the discharge pattern of the IJssel river, a branch of the river Rhine. The average winter level will increase and, after 2050, it will be higher than the summer level. If current management measures remain the same, greater fluctuations in the level will occur (Figure 3.6).

According to the middle climate scenario, the average winter levels in the Lake IJssel, Lake Marken and Border Lakes will increase by several decimetres in 2100 (Figure 3.7), with the consequence that water discharge from the so-called 'natte hart' ('wet heart'; Lake IJssel, Lake Marken, Border Lakes, Amsterdam-Rhine Canal and North Sea Canal) could become problematic. The intended expansion of polder drainage pools, pumping stations and discharge capacity of the Lake IJssel is expected to be sufficient to maintain the current levels until well into this century. The water supply in dry summers would seem to be more favourable as a result of the increasing summer levels; however in extremely dry years the rise in level is insignificant.

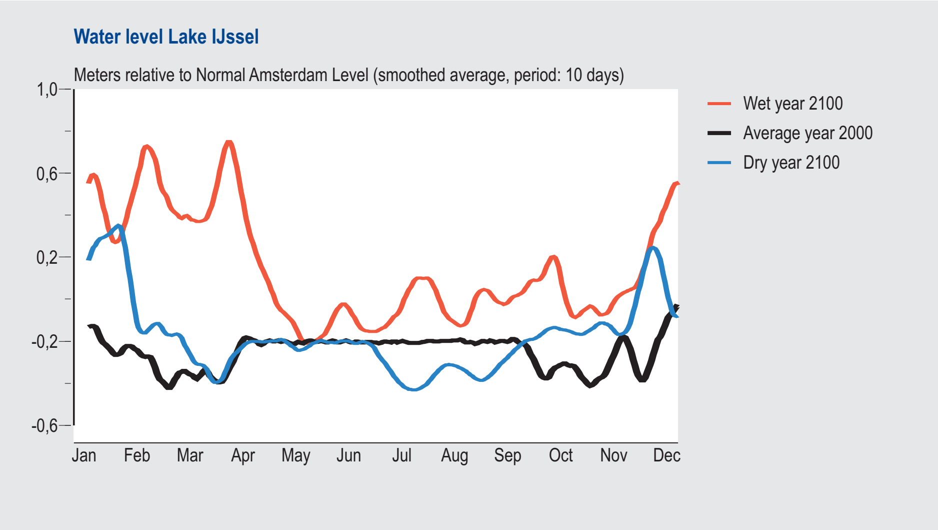

Figure 3.6: According to the middle climate scenario, if current management measures remain the same, the winter levels in the Lake IJssel will in future rise above the summer level and fluctuations in water levels will further increase (Source: Rijkswaterstaat, 2000)

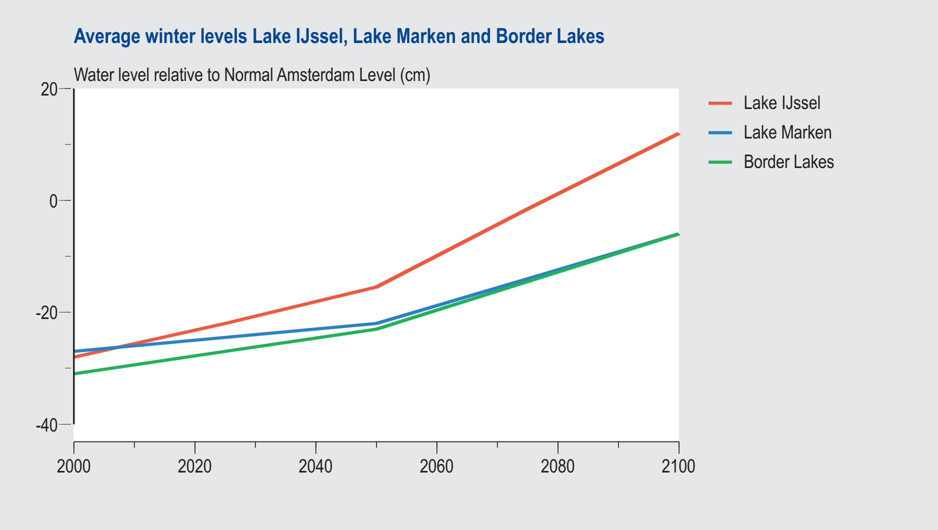

Figure 3.7: According to the middle climate scenario the average winter levels in the Lake IJssel, Lake Marken and Border Lakes will increase in the future if current management measures remain the same (Source: Rijkswaterstaat, 2000)

3.2 Floods and droughts

Unlike ‘severe flooding’, ‘light floods’ are not a life-threatening situation although damage to buildings and agriculture can occur. Light floods can take place in both the lower- and higher-lying parts of the Netherlands. While it is mostly caused by heavy precipitation, it has become apparent that in extremely dry years (for example, in 2003) light floods can be the result of a collapse of the peat dykes (see Chapter 2, Box D).

Increasing droughts in the summer can, to a greater or lesser extent, lead to problems for nature (Chapter 4), agriculture (Chapter 5) and utilities like energy production and navigation (Chapter 7).

Chance of (light) floods will increase

Over the past few decennia the Netherlands has been repeatedly confronted with floods that led to considerable damage to individuals and businesses: for example, the damage to horticulture under glass and houses in the Westland area, to the flooded museum in Groningen and to the many flooded streets in various parts of the Netherlands. Figure 3.8 utilizes the extreme rainfall events of September and October 1998 to illustrate that even on the small scale of the Netherlands, large regional differences in rainfall intensity and, therefore, floods can exist.

The increase in flood events is in line with the changing precipitation pattern. In the period 1900–2005 the average precipitation in a year increased by about 20%, as did

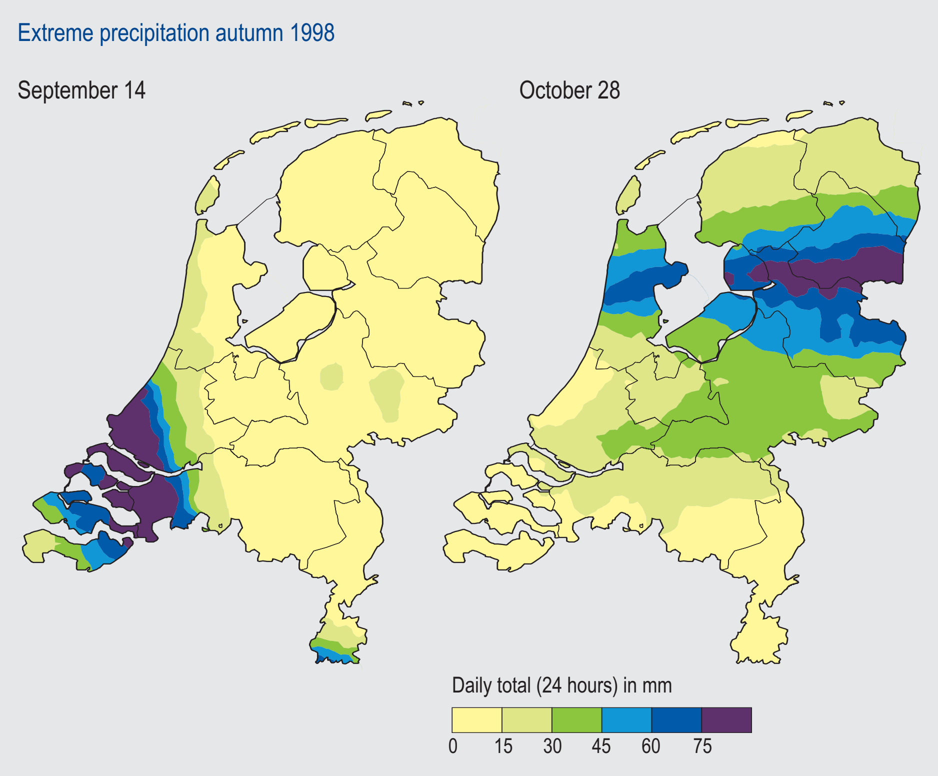

Figure 3.8: During extreme rainfall events, such as in the autumn of 1998, different regions were affected at different points in time (After: Rainfall figures KNMI)

the probability of showers with an intensity of 15–25 mm per day (Chapter 2). Although the number of extreme rainfall events (>50 mm/day) has increased, it still uncertain whether this is a long-year trend.

Based on the known relationships between temperature and rainfall, it is expected that a further increase in temperature will lead to an increase in the probability of extreme rainfall. At present a rainfall quantity of 73 mm in 24 hours occurs once every 100 years. The return period for such an event is expected to increase to once in every 78 years or even once in every 40 years by 2100 (Chapter 2).

Development in extreme droughts still uncertain

Summer drought is caused by both a lack of rain and deficits in the supply of river water. There is a considerable natural variation in the annual deficit of precipitation (Figure 3.9): the average deficit of rain in the Netherlands is about 150 mm; in years with the greatest deficits of precipitation, this is above 300 mm. These numbers shows that at present there is no clear trend in the annual deficit of precipitation.

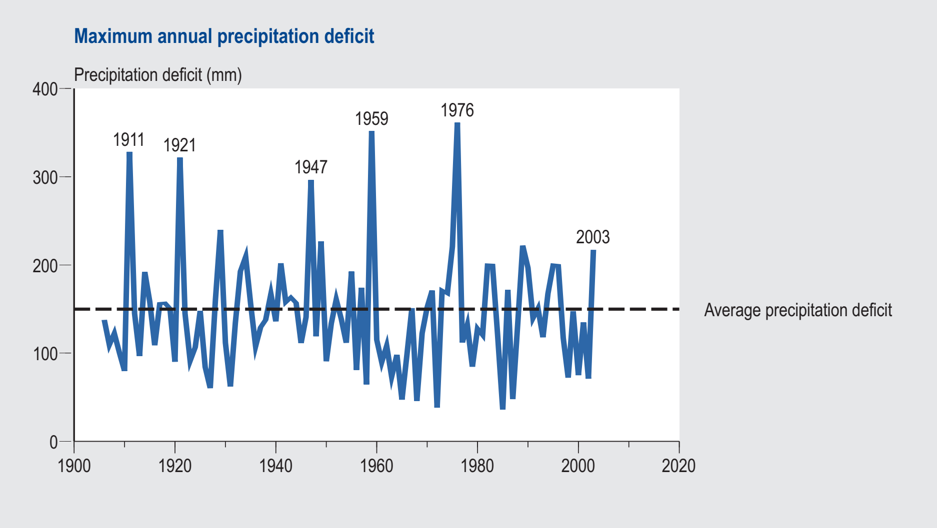

Figure 3.9: There is a considerable natural variation in the annual precipitation deficit (Source: RIZA, 2005)

Characteristic drought years of the previous 100 years are given in Table 3.1. For the whole of the Netherlands 1976 was the most extreme drought year to date. In drought years, the Rhine supplies only about 50% of its mean discharge whereas the discharge of the Meuse (rain river) is relatively low in all years. The combination of a low river discharge with the driest year generally has as a return period of 100 years. The dry summer of 2003 has a return period of 10–20 years.

In the climate scenarios (Chapter 2) it is anticipated that – dependent on the temperature rise – the average rain deficit during the summer in the period up to 2100 could increase by 3–12%. A slight increase in the average drought in the summer is less of a

Table 3.1: Characteristics of the most important years with a dry summer (Source: Beersma et al., 2004; RIZA, 2005)

Damage year	Precipitation deficit (mm)	River supply deficit Rhine[1] ($\times 10^9$ m^3)	Repeat time
1949	227	9.2	17
1959	352	5.1	55
1967	151	0.3	2
1976	361	10.7	110
1985	36	0.6	1
1995	200	0.6	4
1996	199	4.8	7
2003	217	7.3	12

[1]River supply deficit indicates the deficit in the summer discharge compared to the value of 1800 m^3/s (for the discharge of the river Rhine)

problem for nature, agriculture and the cooling water supply than a possible increase in the occurrence of extremely dry years. However, at present, the extent to which the return period of extremely dry summers will change is not known.

The supply of water through the Rhine during the summer months is expected to decrease by about 10% in the period up to 2050. In a dry climate scenario, however, this could be up to 60%.

Adaptation: the extent of flood prevention measures required still unknown

In the Dutch National Administrative Agreement on Water, the provinces, municipalities and water boards recognize the expected increase in precipitation and extremes and have jointly compiled working standards to indicate when the term 'light floods' can be used for various user functions (Table 3.2).

For the regional water systems, provinces, municipalities and water boards have made an analysis of the problems in the so-called sub catchment visions and have assessed the spatial measures necessary to prevent floods (Figure 3.10). The total amount of land claimed in the sub catchment visions for solving water problems is about 120,000 hectares for water storage and 430,000 hectares for water retention, based mainly on the assumption of an increasing rainfall intensity. However, there are still considerable uncertainties with respect to the measures that will eventually be needed. Most of the sub catchment visions have adopted the standard that 'light floods' is

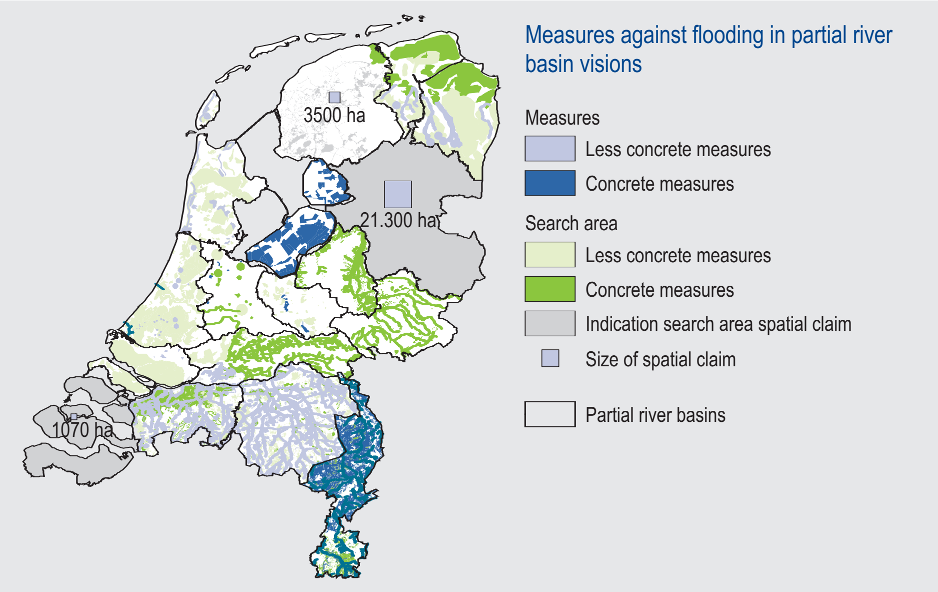

Figure 3.10: In their river basin outlooks, sub-national authorities in the Netherlands proposed different spatial measures in order to cope with increasing water problems due to climate change (MNP/RIVM, 2004)

Table 3.2: Working standards for water logging as agreed to in the Dutch National Administrative Agreement on Water (Source: Ministerie van Verkeer en Waterstaat, 2003). The standards are expressed as the probability that the level of surface water will exceed the ground level (´probability of inundation by surface water')

Standard class related to land use type	**Ground level height criterion[1] (%)**	**Baseline standard (expressed as 1/estimated number of years)**
Grassland	5	1/10
Arable land	1	1/25
High-value agricultural and horticultural land	1	1/50
Cultivation under glass	1	1/50
Built-up area	0	1/100

[1]The ground level criterion indicates which lowest part of an area is allowed to flood before the term 'water logging' can be used according to this standard class.

based on the present design standard for discharge capacity; i.e. rainfall which occurs once every 100 years. For rural areas the agreed-upon working standards are substantially lower (Table 3.2). Thus generally enough capacity exists within the current water systems to deal with even light floods.

3.3 Land subsidence in the peat areas

Land subsidence in the peat areas will probably increase

Independent of the changing climate and the isostatic land subsidence, the Netherlands is also confronted with a subsidence in peat areas. Since the Middle Ages as much as 2–3 m of land subsidence has occurred in some peat areas. This land subsidence is correlated with the drainage of the peat; as a result the peat shrinks and oxidizes, disappearing as carbon dioxide (CO_2) into the atmosphere. Depending on the water level, this land subsidence can be up to 1 cm per year. At this rate, a subsidence of 0.5 m will occur in some of the peat areas until 2050 (Figure 3.11). If land subsidence continues, areas with thick layers of peat – in particular in the western parts of the Netherlands, where there are local depositions of peat up to 12 m thick – could, over the long term, be subjected to increased flood effects, increased surface water salinity and a water system that is increasingly difficult to manage. In several areas (for example, around Slochteren in the north-eastern part of the country) land subsidence also occurs as a consequence of gas extraction. In these areas an extra subsidence of about 60 cm is expected by 2050.

The rising temperature, the longer summer season and a greater difference between wet and dry conditions (oxidation pump) will most likely result in a faster oxidation of peat. This in turn may lead to accelerated subsidence.

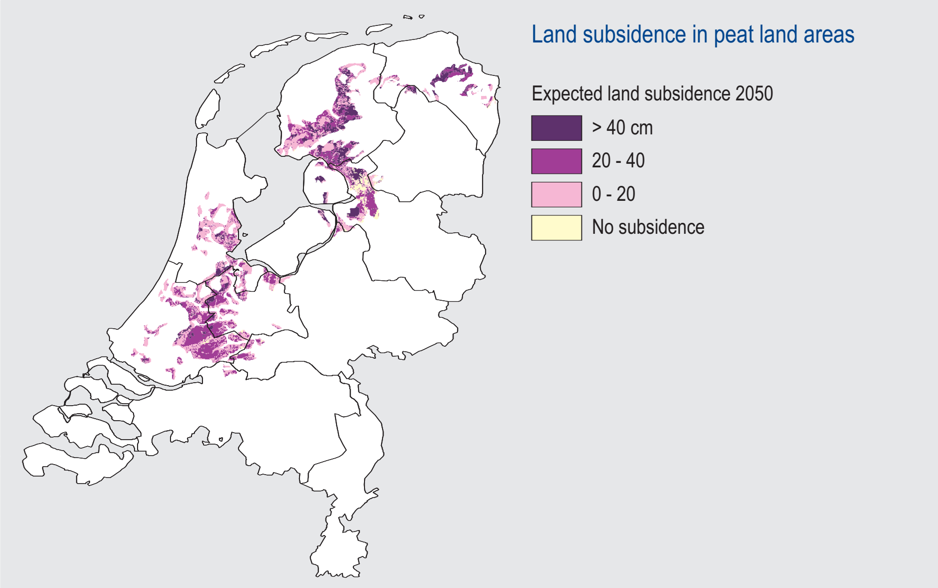

Figure 3.11: In some areas the land subsidence in the peat areas could be as much as 0.5 m in 2050. As a consequence of climate change, the land subsidence process will probably accelerate (TNO, 2003)

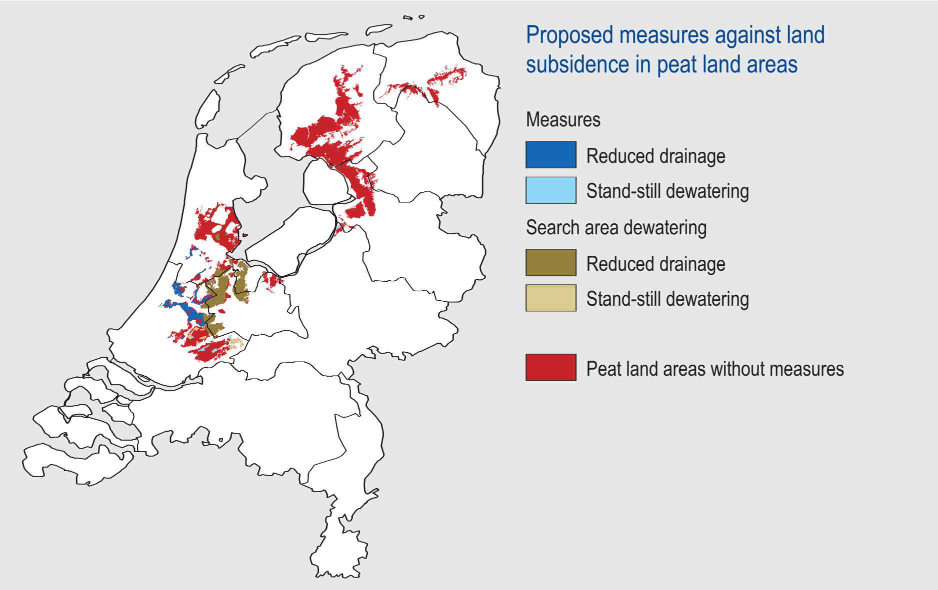

Figure 3.12: In the western parts of the Netherlands in particular, measures against land subsidence have been included in the sub-national river basin outlooks. Reduced drainage will affect agriculture in the peatland areas (Source: MNP, 2004)

The rates of land subsidence are the same everywhere due to variation in peat soils and differences in water management. For example, agriculture requires a relatively deep drainage level, whereas urban areas in peat areas require a relatively high water table in order to prevent wooden pile foundations from decaying. Land subsidence in the peat areas therefore leads to an increasingly fragmented water management system, to a stronger salt seepage (detrimental for agriculture) and to damage resulting from the subsidence of roads and buildings. Various provinces – especially in the western part of the Netherlands – have consequently included measures to counteract land subsidence (Figure 3.12). These measures, however, only affect 4% of the total peatland area.

3.4 Salt intrusion in surface water

The expected rise in salt intrusion will increasingly result in unusable inlet points for agriculture and drinking water

As a consequence of rises in the sea level and decreasing river discharges in the summer, seawater will penetrate further into the estuary area of the Rhine and Meuse rivers. Inlet points of river water for agriculture and drinking water will therefore be increasingly confronted with salt concentrations that are too high.

Ridderkerk is an example of an inlet point for drinking water. Table 3.3 presents the current annual chloride concentrations as averages over a number of years; these years are typical of salt intrusion. The expected annual average concentrations in 2050 are also presented; these show a considerable increase with respect to the concentration of chloride during the saline years. The frequency of the occurrence of a saline or an extremely saline year can also increase. As a result of this, the drinking water standard of 150 mg/l chlorine will increasingly be exceeded.

At Gouda, an important inlet point for agriculture, the increasing salt intrusion in 2050 will lead to a doubling of the duration of the period in which no water can be let in; in a dry year this period will increase from about 2 weeks to more than 1 month.

Table 3.3: The annual average chloride concentrations at the inlet point for drinking water in Ridderkerk will increase considerably in 2050 during extremely saline years (Source: Jacobs, 2004)

Annual Average Chloride Concentration (mg/l) at Ridderkerk	Present Climate	2050 Middle Climate Scenario
Moderately brackish year	82	82
Brackish year	122	122
Average saline year	167	178
Saline year	178	211
Extremely saline year	344	400

4 HOW WILL THE NATURAL ENVIRONMENT CHANGE?

Key points:

- Climate change will likely have worldwide consequences for the natural environment. About 80% of the observed changes in the behaviour and distribution of plants and animals in all regions of the world are consistent with the expected responses to climate change.
- Climate change places extra stress on the natural environment, which is already under pressure from fishing, manure pollution and lowering ground water tables the loss and fragmentation of habitats.
- The effects of the temperature rise can be seen everywhere in the natural environment of the Netherlands: plants and animals are migrating northwards, spring season is starting earlier and relationships within the food chains are becoming disrupted. Many plants and animals will be unable to adapt to the temperature rise or to migrate, due to the high rate at which it is occurring.
- The continuing climate change will highly likely have more effects on nature in the future than those currently visible. Widely-occurring plants and animals are extending their range, and more sensitive species will disappear.
- The quantity and composition of plankton populations forming the basis of the food chains in the North Sea and Wadden Sea are changing. The warming up of the seawater is likely one of the causes. Changes that have been observed further along the food chain may also be correlated to the warming up of the sea: low reproduction rate in fish, falling bird populations, shifting distribution of porpoises.

4.1 Signs of change

Changes in the natural environment can be observed everywhere

'Natural environment' is a complex term with many facets: flora and fauna, nature reserves and water bodies, nutrient cycles and relationships in the food chain, conversion of nutrients, carbon and energy in living material which dies and is broken down, life cycle and reproduction, the distribution of species, symbiosis and competition, succession and the development of ecosystems. Climate change intervenes in these complex processes and relationships. While this intervention has direct effects on the ecosystem, it also has indirect consequences that result from, for example, changes in the groundwater level, soil structure and availability of nutrients. These effects are becoming clearly visible because plants and animals change in their geographical distribution and behaviour.

Climate change will likely have worldwide consequences for the natural environment. This is apparent from an analysis of 143 studies into changes in the behaviour and distribution of plants and animals. These studies reveal that about 80% of these changes are consistent with the expected responses to climate change: the relationships between the numbers of plant and animal species are changing, vegetation zones and habitats of animals are shifting and the growing season is becoming longer. Such phenomena are also being observed in the Netherlands. Of all the climate factors, the temperature rise is the most important cause of the observed changes in the natural environment. Besides climate change as a causal factor, many other factors can be shown to cause changes in the natural environment, such as fragmentation and loss of habitats, lowering groundwater tables, manure pollution and fishing. It is not always clear which causal factor is the most important – climate change, other human interventions or natural processes – as these factors can have a synergistic effect on each other, which can lead to the effects of climate change being magnified.

Species that prefer warm conditions extend their habitat

Due to global warming the habitats of various plants and animals have shifted towards the poles and higher up mountains. For the Netherlands this means, for example, that more southern species are settling here.

In the case of insects, the habitats of about one-third of the species that have been investigated are shifting northwards. One example of an insect species showing a northwards shift is the Comma butterfly (Figure 4.1). These species that are able to shift northwards have characteristics in common: they can spread and reproduce quickly and they place few requirements on their living environment and type of

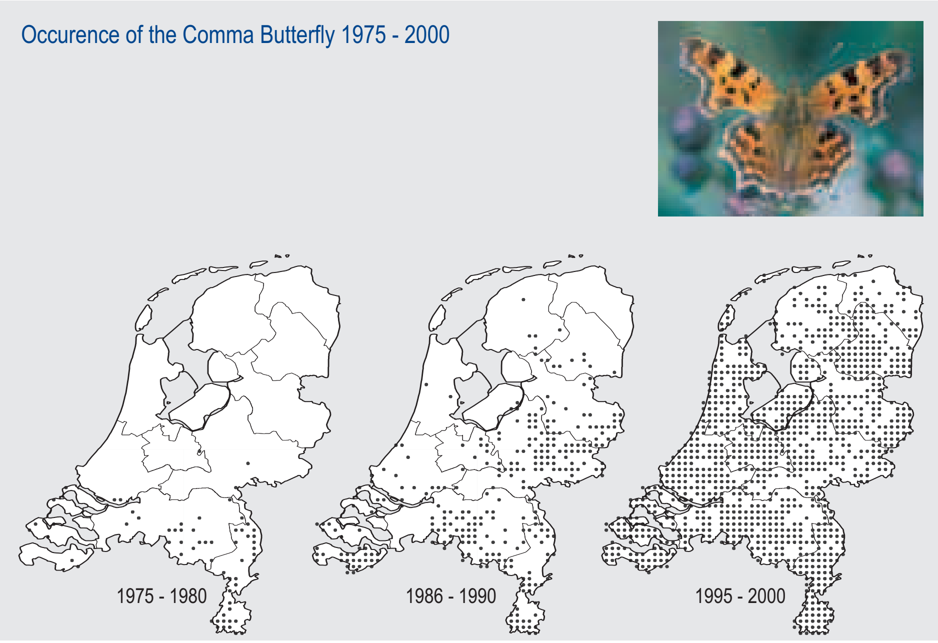

Figure 4.1: The Comma butterfly now feels at home throughout the Netherlands (Source: Dutch Butterfly Conservation, processed by Netherlands Environmental Assessment Agency for the Environmental Data Compendium)

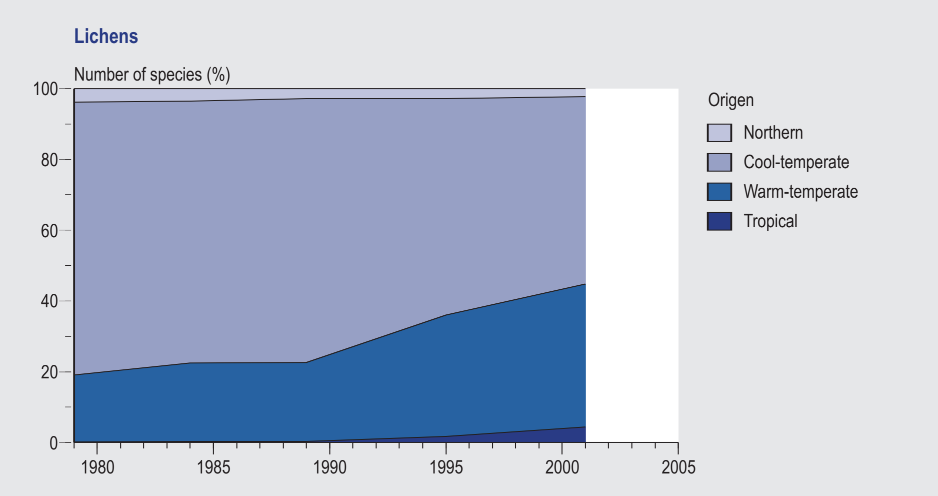

Figure 4.2: The proportion of lichen species that prefer warm conditions is increasing, whereas the number of species with a cold preference is decreasing (Source: Van Herk et al., 2002, Netherlands Lichenology Research Bureau, processed by Statistics Netherlands and the Netherlands Environmental Assessment Agency for the Environmental Data Compendium)

food. The traditionally southern insect species which have stricter preferences, are less mobile and reproduce more slowly are not extending their habitats. Other insect species are becoming rarer, a phenomenon that is also probably due to the effects of environmental pressure and the lack of a habitat. More northern species with stricter preferences are under pressure in the Netherlands; the Marsh Fritillary and Purple Edged Copper butterflies have, for example, disappeared.

Amphibians and reptiles seem to be less mobile and their changes appear to be influenced more by the restoration of the biotope and nature conservation than by global warming.

Of the lichens found in the Netherlands, the southern and even tropical species are starting to appear while the more northern species are starting to disappear (Figure 4.2). Lichens respond strongly to temperature changes because they can disperse well. At present the climate effect plays a secondary role to that of improved air quality on the development of lichens.

In the Netherlands the acreage of plant species that prefer warm conditions has increased while that of species that prefer cold conditions has decreased (Figure 4.3). Whereas up to about 1980 manure pollution had the greatest influence on changes in the composition of plant species in the Netherlands, since then increased temperature has been the main factor.

Breeding bird species with the centre of their geographical distribution in northern Europe have decreased in number in the Netherlands over the past 25 years. Species

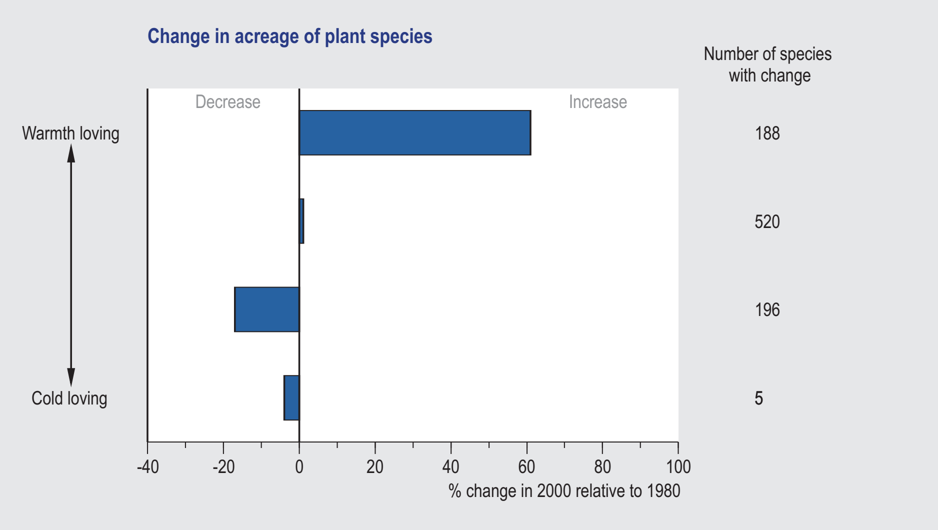

Figure 4.3: The acreage of plants that prefer warm conditions has increased and that of species with a cold preference has decreased (Source: Tamis et al., 2001; EEA 2004)

with the centre of distribution in southern or central Europe are doing much better in the Netherlands, considering the number. If we look at the area distribution, both southern and northern species of breeding birds are losing ground in the Netherlands, whereas central European and indifferent species are gaining ground.

Spring starts increasingly earlier and relationships become disrupted

Over the last 10 years, animals in all types of biotopes have been appearing earlier. Many species have been observed to respond quickly to the increased temperatures (Figure 4.4).

As plants and animals differ in their responses to warmer springs, relationships in the food chain are becoming disrupted. For example, breeding has to occur at the correct moment so that the rapidly growing young can benefit from peaks in the available food. Some birds, such as the Blue Tit, have adjusted to the early spring by laying their eggs earlier (Figure 4.5). Others, such as the Coal Tit, have not adjusted and, as a result, the young hatch too late to benefit from the spring peak in protein-rich caterpillars. Caterpillars, in turn, also emerge too early, namely before the common Oak, their host, comes into leaf and, consequently, many caterpillars starve.

Many migratory birds have an additional problem. The effect of climate change in one region is not necessarily the same as – and is most likely different from – its effect in another region. The Pied Flycatcher, for example, is faced with a surprise when it arrives in the Netherlands from Africa in the spring. With spring increasingly beginning earlier, they are still too late for some of their newly hatched young to benefit from the peak in caterpillars, even the parents start to breed as soon as they return-

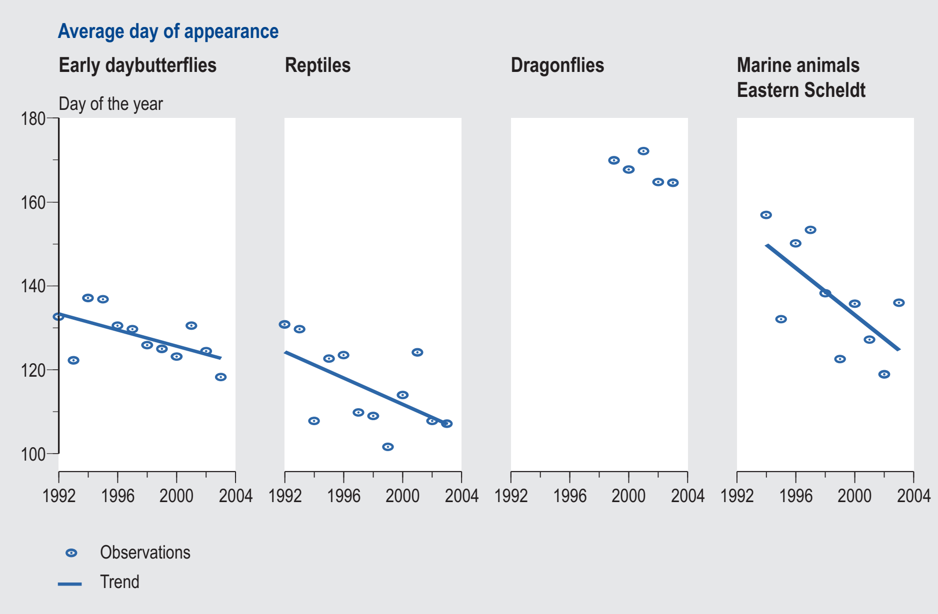

Figure 4.4: Butterflies, reptiles and marine animals in the Eastern Scheldt have been appearing increasingly earlier over the past 10 years. This is apparent from observations from the Ecological Monitoring Network (source: Dutch Butterfly Conservation, RAVON, Anemoon, Statistics Netherlands)

from Africa (days earlier than in the 1980s and without first of all regaining their strength). To date no effect on the total population of these birds has been demonstrated as a result of this mistiming in the food chain.

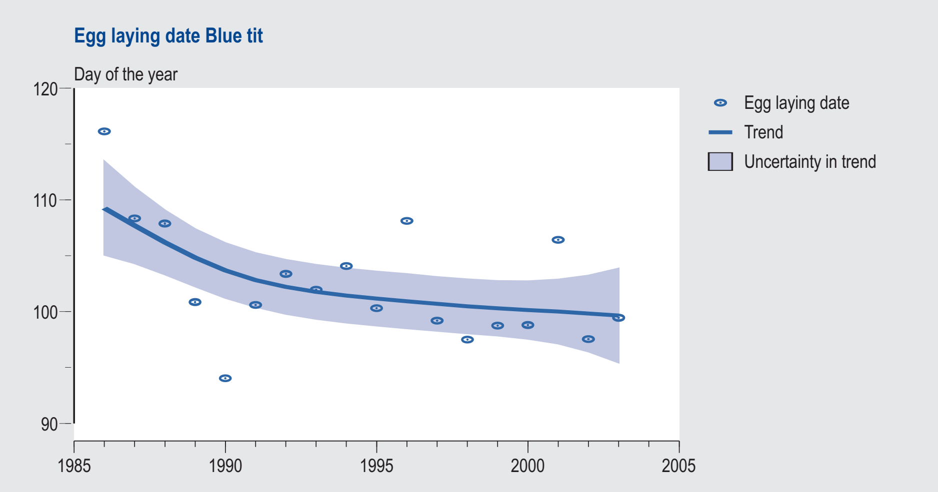

Figure 4.5: The Blue Tit lays her eggs increasingly earlier in the year (Source: SOVON, processed by Statistics Netherlands and Netherlands Environmental Assessment Agency for the Environmental Data Compendium)

4.2 North Sea and Wadden Sea

Ecosystems change

Changes in the plankton, the base of the food chain of the North Sea and Wadden Sea, can also lead to changes in the number of fish, birds and mammals (Figure 4.6).

The following factors have a particularly large effect on the ecosystems of the North Sea: fishing, the phosphorus and nitrogen burden and the North Atlantic Oscillation (NAO: see Section 2.4). In turn, the NAO affects the temperature, stratification and currents of the seawater. However, it is difficult to distinguish the effect of the North Sea becoming warmer due to climate change (Figure 4.7) from the other aforementioned factors.

Observations of, for example, plankton composition, the decreased number of seabirds in the northern North Sea and the habitat shift of porpoises would seem to indicate that the rise in the temperature of the North Sea is one of the possible causes of all of these phenomena. Some observed changes throughout the food chain in the North Sea are discussed below.

In a large part of the North Sea the quantity of phytoplankton is decreasing as the temperature of the seawater rises. In addition, the peak of the spring bloom is occurring increasingly earlier. However, the peak density of zooplankton feeding on phytoplankton occurs later in the season, when the availability of phytoplankton as a food source has already dropped. Some species of zooplankton are also directly sensitive to a temperature rise.

In the period 1980-2004 the larger species of zooplankton in the northern part of the North Sea were replaced by smaller species that also occurred in smaller numbers.

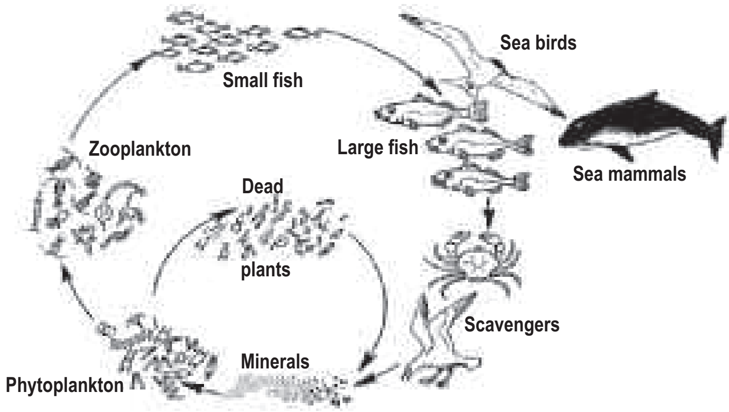

Figure 4.6: Changes in the composition and quantity of phytoplankton and zooplankton in the base of the food chain affect animals at all levels of the food chain, fish through to birds and mammals (Source figure: www.natuurinformatie.nl)

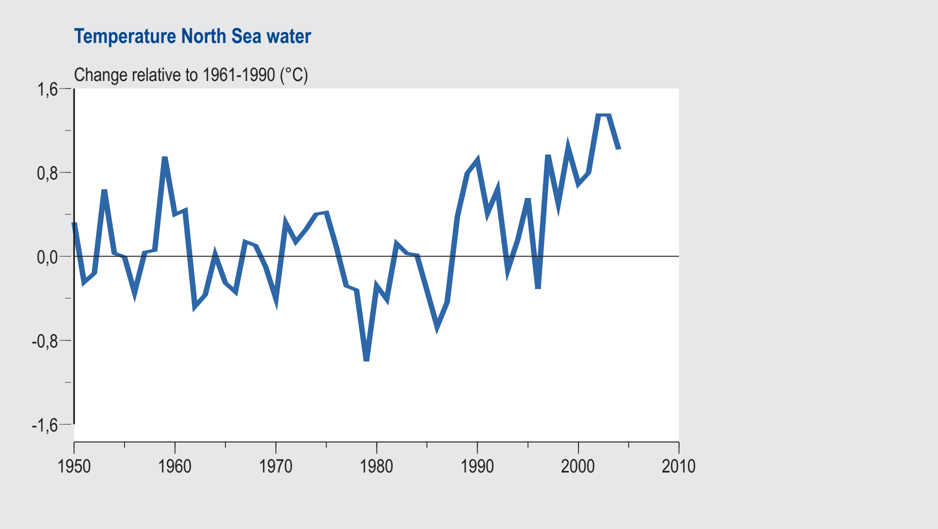

Figure 4.7: The temperature of the seawater in the northern North Sea has been higher since the end of the 1980s (Source: KNMI)

The distribution of plankton that prefers warm conditions in the North Sea has extended northwards, whereas the diversity of plankton with a cold preference has decreased (Figure 4.8).

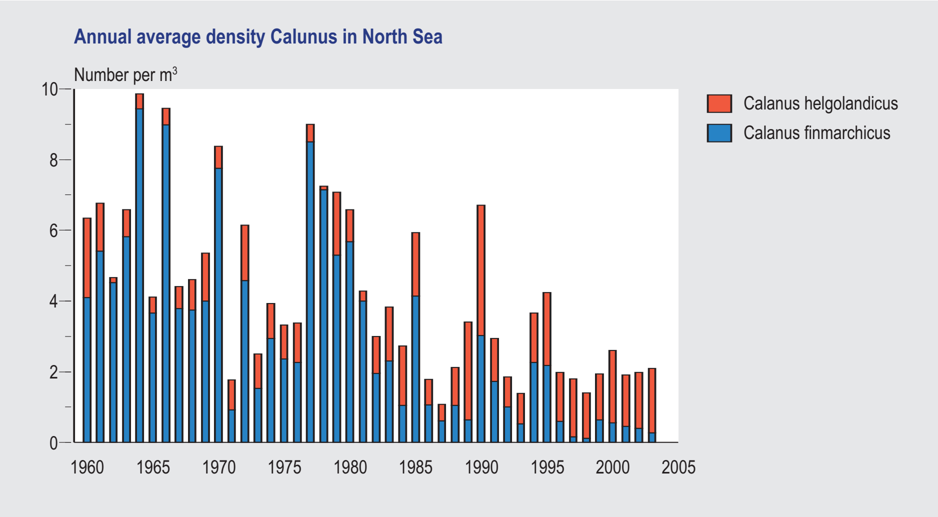

Figure 4.8: Calanus finmarchius, a plankton species that prefers cold conditions, has become less prevalent in the northern North Sea. The helgolandicus population (preferring warm conditions) tends to stabilize or increase. The combined total population of the two species has decreased (Source: Edwards et al., 2005)

The peak in the plankton bloom is also no longer synchronized with the larval stage of fish and, therefore, fewer fish reach maturity. This means that a limited amount of food is available for the higher levels in the food chain, such as fish (in particular the lesser sand eel, an important food source in the ecosystem of the North Sea), birds and certain mammals (for example, porpoises).

While overfishing in the North Sea is directly affecting fish populations in general, the rising temperature is probably at least in part responsible for the poor state of the cod population. Fewer larvae are surviving than in the past. This decrease in cod numbers has been attributed to both changes in the plankton and the direct effect of the water temperature on the physiology of the cod. However, there are indications that at the end of the 19th century equally large shifts in the fish populations of the North Sea have occurred, in the absence of anthropogenic climate change effects. Therefore, natural variations and other human influences probably play a considerable role as well.

In the 1960s porpoises were rare along the Dutch coast. Since the 1980s they have been increasingly sighted, and in the past 15 years their numbers have increased by more than 40% per year (Figure 4.9). It is highly likely that this is due to a geographical shift in their distribution and not to an increase in the local population. This habitat shift of the porpoise is possibly correlated (fifty-fifty probability) with a local decrease or geographical shift in its prey in the northern North Sea, as a result of which the porpoise has moved further south looking for food. In turn, this change in prey abundance is probably an indirect consequence of the warming up of the seawater and the effects of this on the basis of the food chain.

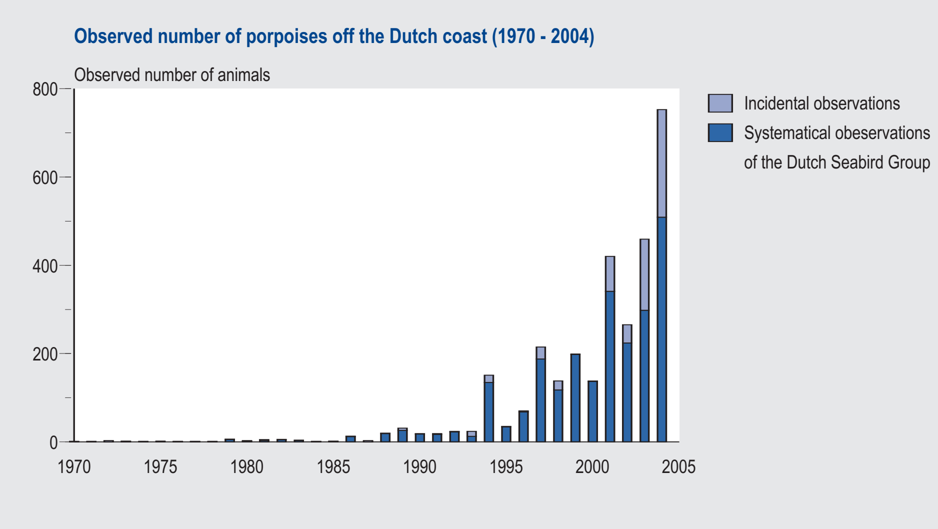

Figure 4.9: Since the 1990s the number of porpoises observed in Dutch coastal waters has strongly increased (Source: Marine Mammal Database; Camphuysen, 2004)

Occasionally the changes are not gradual but sudden. The ecosystems of the North Sea and Wadden Sea have changed enormously in 1979 and 1988 – and possibly in 1998 as well – in physiochemical and biological properties. The biological changes (plankton, fish, birds, mammals) were the most apparent. It seems that these were set in motion by earlier, more gradual changes in a number of environmental factors, which in turn were influenced by the interaction between the sea and the climate system. Salinity and weather conditions were the more important causal factors of the changes that occurred in the ecosystem in 1979, whereas temperature and weather conditions were the more dominant causal factors of the changes observed in 1988. These results are in line with observations in the northern Pacific Ocean and possibly with observations of weather phenomena in the Netherlands as well.

Fewer shellfish in the Wadden Sea

The winter temperature is an important factor in the reproductive success of shellfish: the next generation of shellfish are heavier and more numerous after a severe winter than after a mild winter. Mild winters have a negative effect on the reproduction of the most important species of bivalves (cockles, winkles and mussels), especially if these occur for several years in a row. In addition to this direct effect, an indirect effect also plays a role: the most important predators of shellfish, shrimps and shore crabs, occur earlier and in greater numbers after a mild winter than after a cold winter. As a direct result of these two factors, the consecutive mild winters in the period 1988-1990 led to a strong decrease in the number of shellfish, and in 1991 the fishing industry came to a standstill. Shellfish are also an important source of food for some birds. Therefore the decrease in shellfish numbers led to a massive mortality of species such as eider ducks and oyster catchers in the winter of 1990/1991. The climate effect puts extra stress on the shellfish numbers, which are already under pressure from other human interventions, such as the cockle fishing industry and its disruption of the sea floor.

4.3 Future effects of climate change

Species adapt, migrate or disappear

Climate change has several aspects that affect the natural environment: the rise of the average temperature, changes in the average precipitation and the increase in the frequency of extremes, more frequent discharge peaks and periods of drought, changes in the wind direction. In view of the size of the expected climate change, future effects on the natural environment will probably be greater than those currently observed. Some habitats and species will disappear, new habitats will arise and new species will arrive in the Netherlands. At the end of the 21st century ‘Dutch nature’ will probably look quite different from now. Strongly competitive species from the south will settle in the Netherlands and might suppress presently indigenous species. Instead of being gradual, such changes may occur quite suddenly if thresholds are exceeded. While changes in the rest of Europe, particularly in the Mediterranean area and Scandinavia, will probably be larger than those in the Netherlands, these will exert an important indirect influence on the Dutch natural environment. For example, migratory birds may lose their resting grounds.

Some plants and animals are more sensitive to climate change than others; for some species the changes are favourable, and for others they are not. Plants and animals can acclimate to climate changes by adjusting their physiology or behaviour. Species can also adapt genetically by means of natural selection, which takes place far more quickly in rapidly-reproducing species than in species which reproduce slowly. Entire ecosystems can also adapt to changes. If one species is not able to adapt or adapt quickly enough, then it has to migrate or it will disappear. A species will disappear if it fails to migrate to a suitable ecological niche elsewhere, either as a result of not being mobile enough or due to a lack of suitable habitats within its range.

Warmer at an increasing rate

The combined effects of more rapid temperature rises and higher temperatures are expected to have large consequences for the natural environment, such as a loss in biodiversity. For example, if the temperature rises by 2°C compare to the temperature around 1900, millions of geese in the Northern Hemisphere will lose 50% of their breeding ground and more than 30% of plants from more than 40% of Europe will disappear. Indigenous and specialized species may become extinct. It is estimated that the Benelux countries will remain a suitable habitat for about 90% of the current plant species (Figure 4.10) and will become suitable for about 5-15% new species. Newly arrived species will only be able to settle in the Netherlands if there are suitable locations of the necessary size and quality, and if barriers do not hinder their migration.

Few ecosystems can adjust to a rise of 3°C or more. More than 20% of the ecosystems worldwide will then completely change, and more than 20% of all marsh areas will be lost.

It is not just the absolute temperature rise, the rate of this rise is also of particular importance. A rate of 0.1°C per 10 years is considered by many experts to be a threshold value. In such a situation, 50% of the current ecosystems are still capable of coping with the changes. Above this threshold level, ecosystems will become damaged. With a rise of 0.3°C per 10 years, about 30% of the current ecosystems worldwide may be able to cope; the others will probably become unbalanced and extra sensitive to pests, diseases and fire. With a rise of 0.4°C per 10 years, present ecosystems will degenerate (fifty-fifty probability), and likely more obtrusive and opportunistic species will predominate. Biodiversity will probably be reduced, and it is expected that more CO_2 will be released than is assimilated.

In the Netherlands, the temperature has risen by almost 1°C over the past 30 years – in other words, close to 0.3°C per 10 years. This rate is so high that non-mobile plants and animals cannot keep pace with it. Moreover, as the Netherlands is densely populated and urbanized, plants and animals continually face man-made barriers and therefore cannot always shift their habitat.

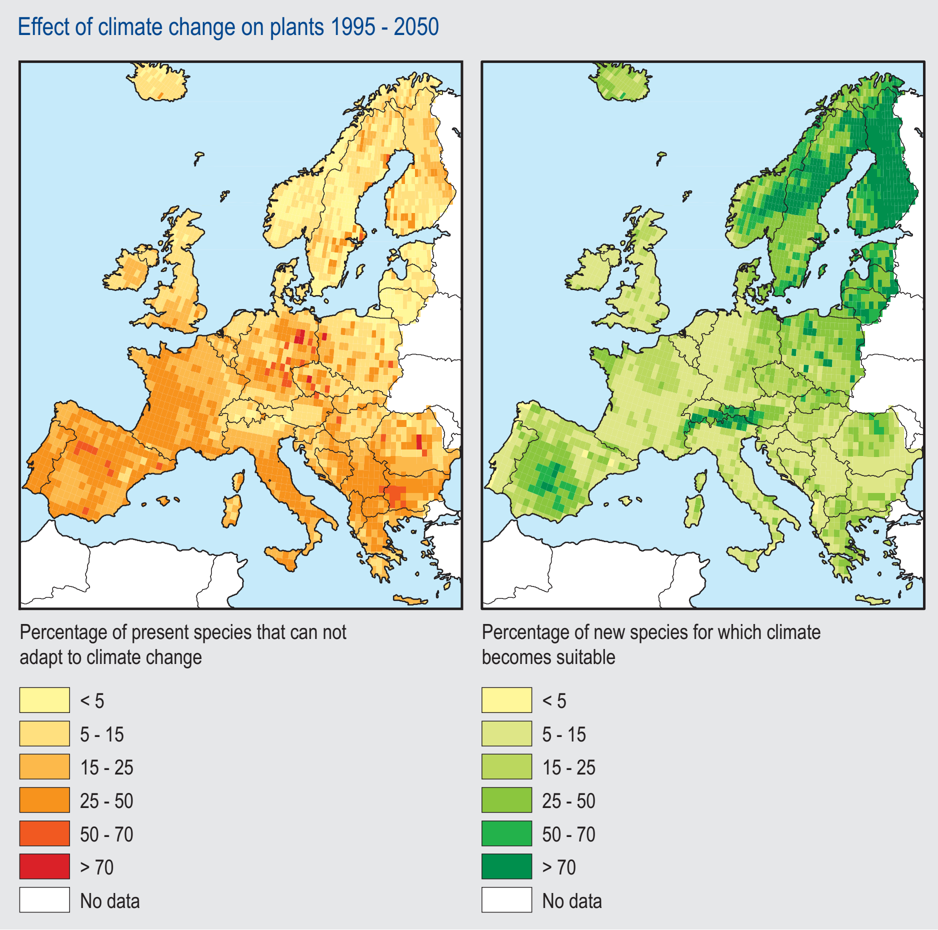

Figure 4.10: In 2050, the climate in the Benelux countries will be unsuitable for 5-10% of the current plant species (from 1995) and suitable for about 5-15% of all newcomers (Source: Bakkenes et al., 2002)

Species need to shift by 4 km per year to keep pace with the current temperature rise. This is equivalent to about 10 m per day over the entire year irrespective of the season. Animals and plants that are on the northern boundary of their distribution area in the Netherlands can extend their natural habitat further northwards if they are sufficiently mobile. Warmth-loving plants and animals in particular can extend their natural habitat in the case of a rising temperature, as long as suitable habitats are available. More northerly species will experience difficulties. Table 4.1 indicates how some species are responding to the temperature rise.

Climate change imposes an extra stress on the natural environment, which is already under pressure in many areas in the Netherlands. The migration rates that are required under current conditions are possibly (fifty-fifty probability) much greater than those in the period following the last ice age. Some experts claim that this stress

Table 4.1: Expected response of several animal and lichen species to temperature rises in the Netherlands

Species	Consequences of the temperature rise
Amphibians and reptiles	Like warmth, benefit if suitable habitat present
Moor frog	Risk of extinction in fragmented habitats because heathland ponds warm up too quickly
Northern waterfowl Wild swan, Common Merganser	Overwinter in severe winters. Northwards shift of frost limit makes the Netherlands less attractive
Teal, Common Pochard, Tufted Duck, Greater Scaup	No longer come to the Netherlands, but remain in the Baltic states
Various migratory and resident birds	Increased survival in the winter
Southern butterflies, mobile and general	Spread further in the Netherlands
Butterflies of peat moors: common ringlet, Cranberry Fritillary, Cranberry Blue. Small Pearl-bordered Fritillary, Grizzled Skipper	Risk of disappearing from the Netherlands, risk of extinction in the case of insufficient migration possibilities
Northern dragonflies: Irish Damselfly, Subarctic Darner, *Leucorrhinia dubia*	Disappear from the Netherlands, because they are at the southern boundary of their distribution area
Southern dragonflies	Extend into the Netherlands
Northern ground-growing lichens, lichens in fragments of ancient woods	Risk of extinction because the natural habitat (shifting sands, dunes, ancient woods) is fragmented

is causing ecosystems to become unbalanced so that they are extra sensitive to pests, diseases, drought and fire.

Plants and animals that adjust to the temperature rise at different rates can cause even greater problems in the food chain and have consequences for the survival of the species involved, with species that are dependent on a limited number of relationships in their food web running the greatest risk. Long-distance migrants are possibly more vulnerable, as they depend on various habitats that will probably change in different ways due to the changes in the climate. Changes in the wind patterns might also form extra problems for these migrants.

Precipitation, evaporation and water management exert a large influence on the natural environment

Wet natural environments such as wet hay meadows and floodplain woodlands can benefit from the increasing precipitation in the spring and winter, the shallow spring groundwater levels and the increase in groundwater seepage. The extent of the benefit will depend on how the water management responds to these changing weather conditions: if the water is retained and is not immediately discharged again as excess water, the natural environment is given an extra chance to recover. Due to the higher evaporation rate, however, the summers will become drier and the water deficits greater. The result will be that the surface level will drop even further in summer or, in areas with a controlled water level, more water will have to be let in. This water not necessarily meet the quality requirements of aquatic ecosystems. Drought has negative consequences for such valuable natural habitats as bog woods, peat bog reed areas, quaking bogs, bluegrass areas, wet dune slacks, wet heathland and moor. These areas experience difficulties in recovering from droughts and require a specific water quality. Nutrient-poor natural environments seem to be more sensitive to the effects of water stress than nutrient-rich ones. Nature areas that already suffer from lowered groundwater tables -because of surrounding agricultural practices and resulting lack of buffer capacity- are vulnerable to droughts. These affected nature areas are common in the Netherlands.

A warmer climate and drier summers lead to desiccation and eutrofication of marshlands. They also become more brackish. The projected more frequent occurrence of extreme weather conditions can also be disadvantageous for less dynamic natural species, especially if their habitats are strongly fragmented. Marshland birds such as the Bittern, Great Reed Warbler and Savi's Warbler can be confronted with both drought and floods during the breeding season, as a result of which the brood fails.

More algal blooms in lakes, other fish species in small water bodies

The rising temperature will probably facilitate blooms of blue algae and botulism in Dutch lakes, thereby leading to a higher chance of mortality among waterfowl. A higher temperature will maintain turbid systems, which will counteract the effect of restoration measures. Increasing peaks in rainfall will increase the leaching of phosphorus from the soil into surface water and, consequently, loading of lakes. More phosphorus means a higher chance of algal blooms, as a result of which lakes may become even more turbid. Turbid lakes have a lower biodiversity than those with clear water.

Higher temperatures result in a shift in the fish population in water bodies. Warmer water does not contain as much oxygen as cold water. As a result, fish with a high oxygen requirements, such as pike, rock bass, perch and pike perch, may become less abundant. Fish from shallow polder waters, such as carp, the clay spined loach and tench, can tolerate low oxygen levels well. The European catfish also feels quite at home in oxygen-poor and warm water.

A temperature rise of 2–5°C may lead to an increase in the species diversity in streams. However, when bodies of water will dry up, the number of species would drastically decrease to those that have adjusted to such conditions (several species of mosquito, flies and beetles).

Possible double effects on shellfish-eating birds in the Wadden Sea

With rising temperatures in the Wadden Sea, the expectation is that the reproductive capacity of shellfish will further decrease in the near future, with the result that shellfish-eating birds, such as Red Knots, oystercatchers and eider ducks, will find less food. Moreover, if a sea level rise of more than 60 cm occurs in the second half of this century, the shellfish eaters might be doubly affected. The rate at which the sea level rises is more important than the absolute rise in sea level. If this rate rises above a critical value, the sedimentation might no longer keep pace, and sandbanks and salt marshes will become submerged. It is estimated that this critical boundary is between 3 and 6 mm per year. If sandbanks and salt marshes disappear, then many of the plants and animals that are dependent on these (such as shellfish-eating birds) will also disappear. Other factors such as eutrophication and fishing also play a role. The temperature might also influence the availability of nutrients.

4.4 Anticipating climate change

Robust corridors are important

The majority of breeding birds and mammals on the Red List (rare and threatened species) can cover reasonable distances. If their habitats are not too fragmented, then these animals may be able to move along with the shifting habitat. It is mainly plants, butterflies, grasshoppers and crickets that run the risk of not keeping up with the pace (Figure 4.11). Plants and animals for which the Netherlands forms the southern boundary will find themselves in the danger zone and, consequently, run the risk of disappearing from the Netherlands and become extinct if there is no suitable habitat elsewhere. Non-mobile species with fragmented habitats are also vulnerable, such as species from woods, marshes and heathlands.

In practice it will not always be feasible to protect certain habitats, plants and animals in a designated area, which is the objective of current nature management policy. However, the nature management policy can ensure that nature areas remain well-connected and of good quality to provide a suitable space and living conditions for many species: those that remain, the newcomers and those passing through. A robust Dutch Ecological Network with key areas and corridors between these areas will make it easier for species to follow climate change by shifting their habitat. However, this will only work if the coherence is also present at a European level ('Natura 2000' network).

'Room for the river' provides opportunities for wildlife

Since the two peaks of high water in the 1990s, safety has become the main priority for water management in the Rhine and Meuse river basins, and 'Room for the River' an important theme. Partly as a consequence of climate change, large discharge peaks can also be expected in the future, and further adjustments to the river system will be necessary. Wildlife can benefit from nature areas that are developed as part of these

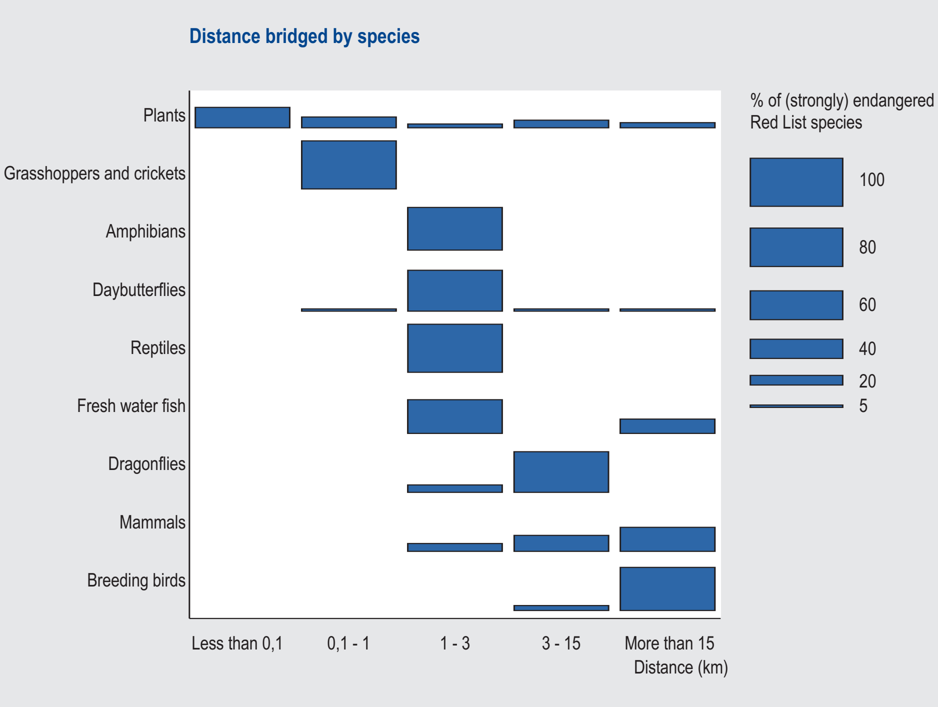

Figure 4.11: The distance which protected plants and animals can bridge in one generation varies from less than 10 cm to more than 15 km (Source: Alterra, processed by the Netherlands Environmental Assessment Agency, 2003)

adjustments. The river forelands have a spatial coherence that can be turned into large connected nature areas. The requirements of water management will necessitate these being robust wet nature which can cope with high variability, such as softwood riparian woods, reed marshes and reed salt marshes (if the tidal effect in Haringvliet and Biesbosch increase again). Initially, this natural environment will mainly be colonized by species that spread easily. As a concession to water management, the lowland riparian woodland will occupy a smaller surface area than can be viewed as desirable from a wildlife viewpoint because lowland riparian woods obstruct flow and may cause undesired water level increases.

Natural environments can store carbon

The Netherlands is undertaking efforts to increase the acreage of woodland to 410,000 hectares in 2018. This increase acreage can work to the benefit of wildlife and climate objectives, because a more natural woodland management can result in extra carbon that will be stored (Figure 4.12) and as such will enable several percentage points of the Kyoto target to be realized. In peat meadow areas, the conversion of meadow into woodland or marshland can also contribute to a decrease in the emission of carbon dioxide. A possible extra emission of methane from the marshland will

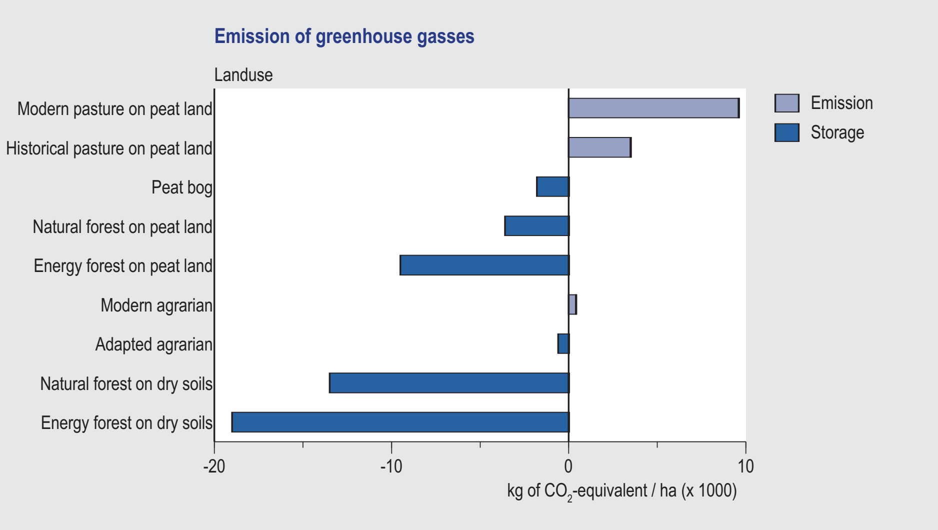

Figure 4.12: Greenhouse gases are stored in marshland and woods (Source: Kuikman et al., 2002; Van den Born et al., 2002; Nabuurs et al., 1996 and 2000; Van den Bos, 2003)

be more than compensated. By making areas wet and stimulating the growth of the peat, the rate of land subsidence in the lower parts of the Netherlands will be slowed down; the land there is currently subsiding at the rate of 0.5–1 cm per year (see Chapter 3).

5 HOW WILL CLIMATE CHANGE AFFECT AGRICULTURE?

Key points:

- Climate change will have both positive and negative effects on agricultural production and the economics of the various agricultural sectors.
- The negative effects are greater if extreme climate conditions occur more frequently or persist for longer periods.
- Agricultural sectors capitalize on the changes with respect to natural and economic circumstances. Anticipating a changing climate can limit the risks and increase the opportunities.

5.1 Climate change is one of the factors that influences agriculture

Agriculture is an umbrella term which covers very diverse sectors: livestock farming, arable farming, horticulture in open air and horticulture under glass. The effects of climate change or, expressed differently, the direct and indirect consequences of the changes in precipitation and temperature – in space and time – and of the increasing CO_2 concentration differ per sector. Some sectors will benefit, whereas others will experience considerable disadvantages. The economic effects of changes in physical yields partly depend on developments in the market price. These in turn are influenced by the consequences of climate change outside of the Dutch borders and by the world market.

It is important to note that agriculture not only depends on natural circumstances (in particular, climate, soil condition, pests) but also strongly on the choices that the farmer makes (e.g. choice of crop and variety, management decisions) and the economics of the specific agricultural sector (costs, subsidies, price, world trade). The European Common Agricultural Policy and national developments (spatial planning, water, nature and environmental policy) also determine the eventual size of the economic effects for the sector. No known studies describe the relative importance of each of these interrelated factors, but it is estimated that the influences of the European Common Agricultural Policy and the world market dominate all other factors with respect to having an economic effect on a specific agricultural sector. A coherent investigation of agricultural economic scenarios is needed to shed light on the economic weight of the various factors.

Possible effects of climate change for agriculture in the Netherlands are:

- higher – but sometimes also lower – yields; possibly different choices of crop;
- sowing and harvesting problems, and glass and crop damage due to extreme rainfall (also with hail);
- harvest losses due to insect and fungal pests;

- night frost damage, particularly in the fruit-growing sector;
- crop development difficulties due to pollination by insects no longer being synchronous;
- consequences of land becoming brackish;
- a lower energy bill in the horticulture (under glass) sector and a higher energy bill in the livestock sector due to the need to maintain cool animal housing;
- less favourable production conditions in southern Europe and possibly more favourable conditions in Northern Europe.

All of these effects could occur to a greater or lesser extent, scarcely or very frequently, locally or over large areas, in dry or indeed wetter parts of the country, affect one or more agricultural sectors and may or may not result in economic damage that is too heavy to bear.

In particular, the frequency and size of the climate-related events and the economic buffer capacity of the agricultural sectors determine the impact. Agriculture in general has a strongly innovative character and is no stranger to adjusting to changing circumstances. Yet being aware of the consequences and perhaps even anticipating them is necessary, not only because of the possible strong effects of climate change but also because of the opportunities these provide.

5.2 Rise in CO_2 concentration leads to higher production

Over the past two centuries the CO_2 concentration has risen by 100 ppm to 380 ppmv (particles per million on basis of volume; see Chapter 2). The scenarios used for predicting the climate expectation in the Netherlands reveal a further increase that lies within the range of 500–900 ppm in 2100. An increase in the CO_2 concentration in the air can lead to an increase in agricultural production. Such an increase in yield is crop-type-dependent, as it will only happen under optimal cultivation conditions. A doubling of the CO_2 concentration can lead to a 15–20% increase in yield. A positive side effect of the higher CO_2 concentration is the higher water efficiency. However, this effect is counteracted by the increased evaporation due to the higher temperature. Therefore, on balance, the total crop evaporation scarcely changes. Not all institutes subscribe to this analysis, and further field trials and laboratory research are needed to resolve the differences of opinion.

Research that has been carried out in 1998 into the effects of climate change on agricultural yields in the Netherlands has revealed that grass(land), sugar beet and winter wheat would benefit from the changing conditions but that the yield for silage maize would be lower. The results are the effects of a change in temperature and CO_2 concentration, and a slightly higher precipitation (see Table 5.1).

Table 5.1: Relative change in physical production per hectare in the Netherlands (expressed in percentages) in 2020 and 2050 (Source: Schapendonk et al., 1998)

		Climate characteristics			Results			
Year	Description*	CO_2 concentration	Precipitation	Temperature	Winter wheat	Silage maize	Sugar beet	Grass (land)
1990	Reference year	354	794	9.3	100.0	100.0	100.0	100.0
2020	Low scenario	425	794	10.8	103.7	93.1	116.2	118.2
2020	High scenario	438	794	10.9	104.3	92.2	118.1	120.6
2050	Low scenario	512	794	12.3	105.1	84.0	129.0	139.6
2050	High scenario	566	794	12.8	107.6	83.8	135.1	149.1

* Concerns results of a study from 1998; the calculations made in this table utilize different scenarios than those presented in Chapter 2 of this report.

5.3 Higher temperature, diverse effects

The current average temperature in the Netherlands is about 1°C higher than it was at the start of the 20th century. This has led to a longer growing season: compared to the period 1961–1990, the growing season during the past 15 years has increased by an average of more than 3 weeks (Figure 5.1).

Many weather stations in north-western Europe have measured a similar gradual increase in the length of the growing season as that in the Netherlands. In the period 1995–2050, the growing season is expected to lengthen still further in large parts of Europe. Global warming occurred homogenously over the months of the year during the period 1901–2004. However, the growing season is not only determined by the

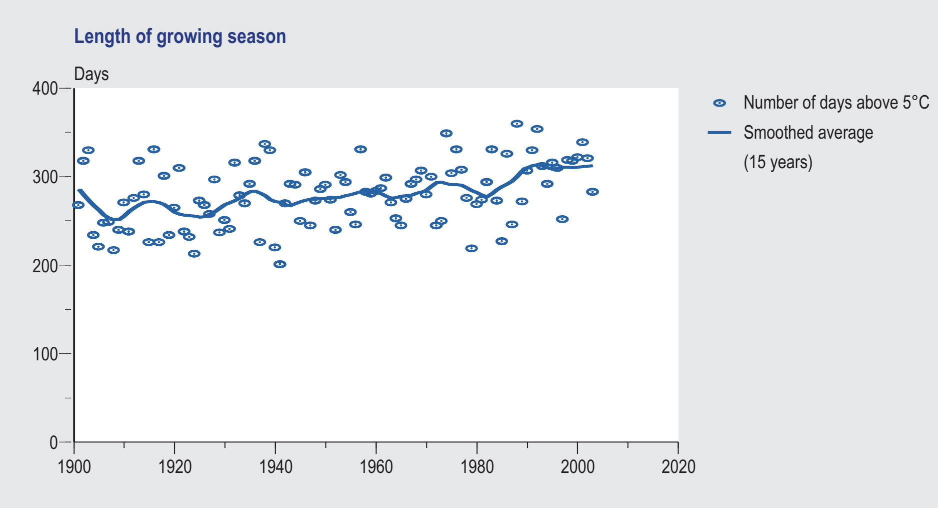

Figure 5.1: Trend in length of growing season (Source: Rooijers et al., 2004)

temperature; Plants can only grow if they receive sufficient moisture (precipitation plus possible irrigation minus evaporation). The growing season in southern Europe is becoming shorter for non-irrigated agriculture due to decreasing precipitation and increasing evaporation. Accordingly, the cultivation conditions for outdoor crops in north-western Europe are becoming more favourable, and over the long term the situation in southern Europe will become less favourable. The agricultural economic consequences of this are expected to be mainly negative in southern Europe and possibly positive for the more temperate regions.

Due to the rise in temperature, plants will bud/germinate earlier in the spring and fruit trees will blossom earlier. If we look at just the effects of a higher temperature (therefore without the increase of CO_2 and changes in precipitation), some crops, including root crops and maize, will benefit more than others from the higher temperature and longer growing season (higher yields and higher sugar level in sugar beets). Grain crops do not benefit from the higher temperature and longer growing season because grain ripens earlier and therefore the plants have less time to grow. With a rise of more than 2^{o}C or 3^{o}C the negative effect will be greater and the yield for agriculture as a whole will be less.

Little is known about how climate change might influence the chance of night frost. However, one disadvantage of early germination/budding is the greater risk of night frost damage in early spring. This risk is particularly high for fruit growers. Such was the case in the spring of 2005 in Flevoland. The damage was quite considerable because the night frost occurred fairly suddenly following a relatively warm period that had seen the initiation of blossoming, fruit formation and sap flow.

For dairy farmers, a higher temperature could lead to a decrease in the requirement for roughage because the cows can be left out longer to graze. Conversely, more energy will be needed in the summer to keep the cowsheds cool. In the horticultural sector, energy use will mainly decrease with higher average winter temperatures. Opportunities to grow other crops will also arise.

A rise in temperature will increase the developmental rate of insects, which in turn will result in fertility being reached more quickly. This could lead to larger populations that might (fifty-fifty probability) eat more and could also result in pollination and crop development no longer being synchronous.

Pathogenic organisms from southern Europe and the Mediterranean areas are expected to invade the Netherlands and subsequently survive. This could give rise to a loss of yield. Whether or not such an invasion will be a temporary phenomenon and the scale on which this will occur cannot be predicted. In general, the survival chances for insects and pathogenic organisms are increasing because there is less frost in the winter. Even potatoes, which at harvest remain in the soil (for example, because the harvesting was difficult due to water logging), will be able to pass on diseases more easily if there is less frost.

5.4 The greater dynamics in precipitation, the more risks for agriculture

The scenarios used for the climate expectation in the Netherlands (see Chapter 2) reveal an increase in both the winter and summer rainfall and a higher level of evaporation in the summer. In view of the uncertainty with respect to the development of the summer rainfall pattern and the problems during dry summers (e.g., 2003), the KNMI has also modelled a dry scenario. These effects have yet to be quantified in terms of agricultural damage.

Water logging

Elevated precipitation dynamics and intensity (see Chapter 2) will have a direct effect on agricultural business practices. The land will be less easy to work and less accessible to machinery. This situation applies in spring for sowing and planting and in autumn for the harvesting of late crops, such as seed potatoes, potatoes and beets. Tillage and the application of manure and fertilizer in spring and autumn will also be more difficult. All of these factors will lead to a loss of yield and damage to the harvest. In 1998, two regions in the Netherlands were affected by extreme rainfall that eventually resulted in a total damage of about 600 million euros (see Figure 5.2). Farmers were compensated for 70% of the damage through the Harvest Damage Regulation and the Disasters and Serious Accidents (Compensation) Act (WTS). Compensation is only paid under this regulation if a proportion of the damage is partly caused by the decisions of policymakers.

Changes in the precipitation dynamics and rainfall intensity has also lead to a higher frequency of peak discharges in streams and rivers (see Chapter 3). The need to realize

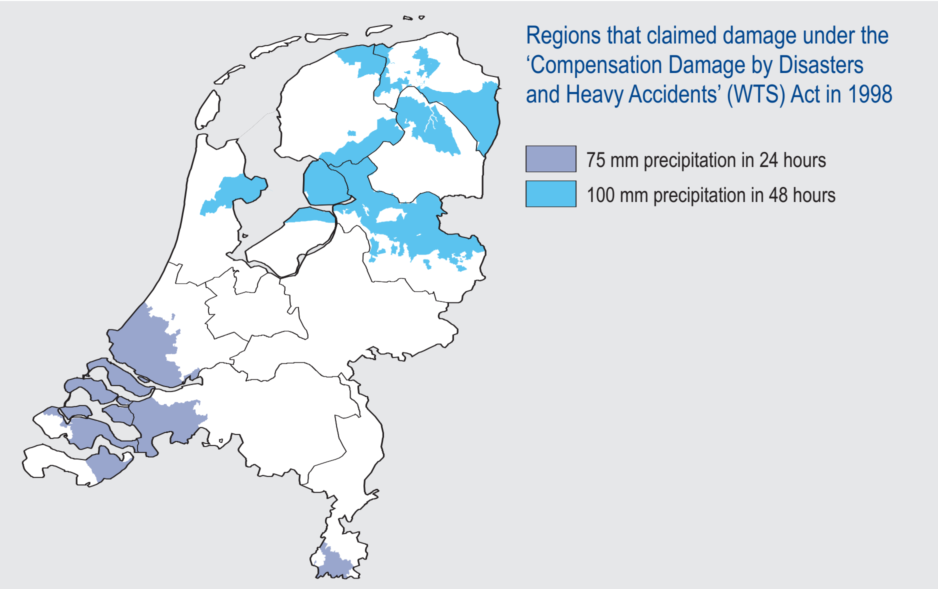

Figure 5.2: Extreme rainfall and agriculture (Source: van Duinen et al., 1999)

water storage is increasing. Wet damage or limiting measures for agricultural activities and agricultural areas along the larger rivers could arise as a result of this. Peak discharges in combination with the sea level rise increase the need for water buffering and water storage functions. Polders with a limited retention capacity will be more frequently affected by water logging in the winter and spring if the water discharging capacity is too limited. Water logging limits the accessibility of the land for the application of fertilizer/manure, tillage and grazing by cattle. To what extent economic and physical yields will be lower as a result of this cannot be indicated at present. The economic losses in the agriculture sectors can partially be guarded against by the agreements between water managers and agricultural enterprises (so-called 'Blue functions').

Drought

The Netherlands has a rain deficit (cumulative sum of precipitation and evaporation) in the summer. This deficit is not experienced as a problem because it occurs every year and agricultural practices take it into account (by means of irrigation). The surface water system is mostly capable of satisfying the water demand (for the current capacity of irrigation), even in years of extreme drought. Damage to crops arises because the plants are unable to evaporate the quantity of water necessary for optimal growth. This is often a consequence of an insufficient irrigation system capacity or an irrigation ban. A ban on irrigation is a measure which is often taken to prevent groundwater levels becoming too low in those areas where groundwater is used for irrigation. In the western areas of the Netherlands, the salt concentration of both the surface water and groundwater also imposes a limitation on irrigation (see also Section 5.5).

In the case of a changing climate, the Netherlands will be increasingly confronted with water deficits. In rainfall-dependent areas, especially the more highly situated and drought-sensitive sandy soils, an increased precipitation dynamics will also have a negative effect on the production and the quality of the product due to drought damage. The level of damage will partly depend on the irrigation capacity and on possible irrigation bans (if other functions necessitating the ground and surface water have priority). The effects of water deficits are even greater in the dry scenario (see Chapter 2). In lower parts of the Netherlands, more water will have to be supplied to maintain the water level and to counteract the effects of the land becoming more brackish.

Other weather effects

In erosion-sensitive areas such as the loess landscape in South Limburg, erosion will increase due to the increased precipitation intensity. In the lower-lying parts of the Netherlands, arable farming in particular will experience more hindrance from a periodically higher groundwater level.

Changes in the frequency and dynamics of the climate parameters will have a direct effect on the risk of harvest loss and the quality of the product. The frequency and extent of the damage to crops and glasshouses as a consequence of extreme weather (storms, hail, extreme frost) could increase, but no quantitative total picture can be given for this. In the Netherlands damage to crops or glasshouses through hail or storms can be covered by private insurers.

5.5 Brackishness will increase due to a rising sea level and subsiding land: increased agricultural damage

In the coastal zones, saline seepage will increase as a consequence of the rising sea level, and this in turn will increase the brackishness of the groundwater and surface water. If increasingly more saline water enters the upper groundwater and ditches due to increased saline seepage, existing agricultural and horticultural crops/plants with a low salt tolerance will be detrimentally affected. Various agricultural/horticultural crops/plants impose different requirements on the salinity of the irrigation water, the quantity of irrigation water and the groundwater level.

The sensitivity of crops to salt concentrations has been determined by the Dutch research institute Alterra with damage functions. Above a threshold value, the crop damage increases in a linear fashion with increasing salt concentration (see Figure 5.3). In particular, tree nurseries, the horticultural sector (under glass) and the fruit-growing sector are highly sensitive to increasing salt concentration, and even at low concentrations considerable damage can occur. In the dry summer of 2003, tree nurseries located in the middle of the Netherlands were confronted with damage due to brackishness. Grass, grains and sugar beet are relatively tolerant to the concentration of salt in the soil.

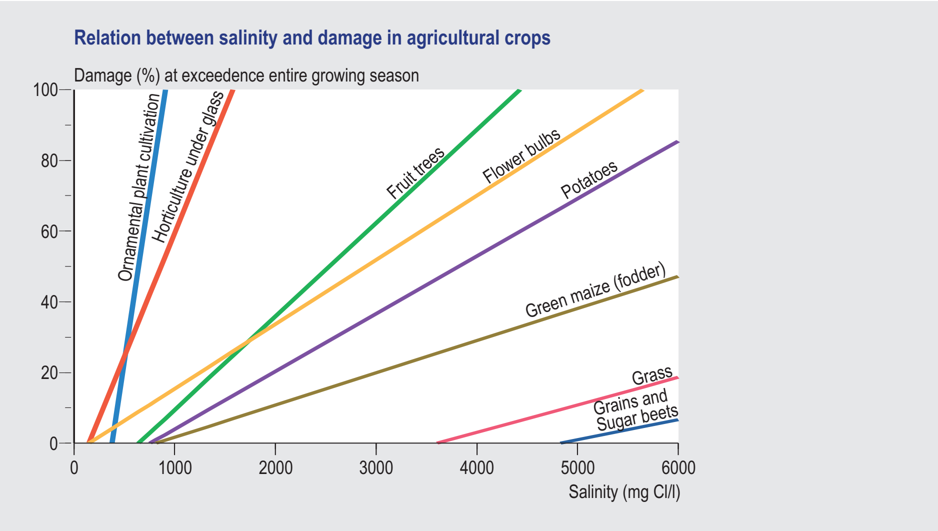

Figure 5.3: Salt damage functions for agricultural crops (Source: RIZA, 2005)

The areas that will increasingly suffer from saline seepage are the deep polders in the western part of the Netherlands in particular as well as the peat meadow areas. The need for fresh water for rinsing will then increase, although in dry years this is not always available (see Chapter 3).

The outcomes of the modelling of brackishness under different climates scenarios and sea level rises are associated with many uncertainties. Both the Dutch Research Institute for Inland Water Management and Waste Water Treatment (RIZA) and the research institute for the water sector KIWA state that the differences in intensity of the seepage flow (salt load) between an average and extremely dry year in the current situation are small. The highest salt burden currently occurs in the coastal area of Friesland and Groningen, the IJsselmeerpolders, Zeeland and the Haarlemmermeerpolder. A climate study from RIZA reveals that particularly for these areas, the salt concentrations in the surface water will strongly increase in an extremely dry year. In the future scenarios, the salt load mainly increases due to the combination of the increased seepage pressure, decrease in the effective precipitation (= precipitation minus evaporation) and land subsidence and sea level rise. The effects will be greatest in extremely dry years and less drastic in average years. The agricultural areas in Groningen, Friesland, North Holland and South Holland are the most dependent on water supply from the surface water and would therefore seem to be the most prone to damage due to brackishness. Sensitive crops are frequently grown in these areas.

5.6 Pests and diseases increase

The chances of new types of pests and strains of diseases settling in the Netherlands is increasing due to climate change. In a recent publication of the Plant Protection Service of The Netherlands on the negative aspects related to pest, disease and weed development in the period 1998–2004, sector experts highlighted the fact that pests which normally occur to the south of the Netherlands are increasingly being sighted in the Netherlands. This occurrence is mainly related to the change in climate; for example, for the past 5 years the winters have been wet and relatively warm.

One possible future threat is the Corn rootworm, which is currently spreading throughout Europe. This beetle, which originates from the United States and Mexico, arrived in Southern Europe by means of the transport sector and has subsequently spread (through natural spreading and the transport sector) to other parts of Europe. It was first observed in the Netherlands in 2004. At the present time, the Netherlands is at the northernmost edge of its possible distribution area; however, in the event of a further temperature rise, this boundary will shift further north. Climate studies from, for example, the Plant Protection Service of The Netherlands, have demonstrated that the Corn rootworm can now establish itself and complete its life cycle in the Netherlands. Based on the experiences of other countries, it is apparent that if the beetle is not well controlled, harvest losses on plots with continuous cultivation can rise to between 6.5 and 13%. For silage maize, which with more than 200,000 hectares under

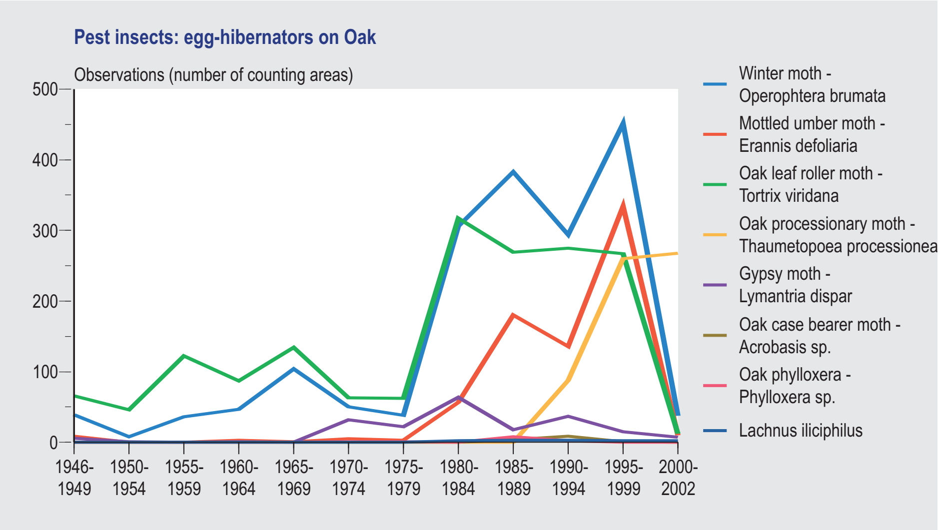

Figure 5.4: Trends in pest insects since 1946 (Source: Moraal et. al., 2004)

cultivation is by far the most important maize crop in the Netherlands, this means an economic loss of € 15–30 million per year (for a market value of € 1550 per hectare).

Research into the interactions between pests and diseases and climate in Dutch forests has revealed indicators of the effects of climate change in this environment as well.

The survival chances of insects living on deciduous trees are determined by the weather conditions in the winter. It can be generalized that the Netherlands has predominantly a sea climate with mild winters and variable summers – and a lot of rain. Cold winters and hot dry summers only occur when there is an easterly wind. Insects find it difficult to adjust to the unpredictability of a sea climate. In milder and damper winters, which have occurred with increasing frequency since 1976, insect species that overwinter as vulnerable adult insects and larvae suffer more from fungal infections than those that overwinter as eggs. Other climate effects also play a role. For example, many insects require a cold shock to become active in the spring and, if they do not get this cold shock, a mismatch can occur between the time the insect becomes active and the time the leaves (its food) bud in the spring.

Researchers have observed groups of insects with certain basic survival strategies and found that species which overwinter as eggs have been more successful in recent decades than species which overwinter as larvae, pupae or adults. This has been taken to be a strong indication for an effect of climate change. Figure 5.4 presents the number of sightings of pest insects which overwinter as eggs on oak trees.

The annual monitoring of pest insects on trees reveals that since 1946 there have been relatively more invasions of non-indigenous insect species. However, shifts have also occurred in the incidence of plagues of indigenous insect species. One line of thought is that changing environmental factors, such as the desiccation, nitrogen deposition and climate change, have had a causal effect on this shift. However, it is often impossible to filter out the effect of one of these factors from this combined effect.

6 CONSEQUENCES OF CLIMATE CHANGE FOR RECREATION AND TOURISM

Key points:

- The temperature is likely to rise further in the Netherlands, thereby extending the summer season and, consequently, increasing the possibilities for tourism and recreation.
- The Netherlands will likely become a more attractive destination for foreign tourists. The Dutch will probably be more inclined to spend their holidays in their own country.
- Climate change will likely enhance the growing demand for recreation and wildlife areas.
- The higher temperature of shallow (swimming) water poses potential health risks due to a possible increase in the occurrence of pathogenic micro organisms.

6.1 Introduction

The worldwide diverse and growing tourist sector is sensitive to the effects of climate change. Sea level rises linked to a greater probability of weather extremes form a threat for tourist destinations in coastal areas. Changes in temperature and precipitation patterns will have major consequences on the attractiveness (or non-attractiveness) of tourist destinations: areas that are too hot or too cold will become less attractive destinations as will regions which are too wet. The ideal climate for tourism in the summer is expected to shift northwards in Europe: Mediterranean countries will become too hot and dry and countries in the north of Europe – for example, along the Baltic Sea – will no longer be too cold. The Netherlands can therefore look forward to becoming an increasingly interesting place, not only to foreign tourists but also to the Dutch people themselves, who might spend their holidays more often in their own country.

The fear of being exposed to excessively high doses of harmful UV radiation may result in a gradual shift from coastal tourism to other forms of recreation. This development could also be favourable for the Netherlands in view of the broad range of recreational possibilities in our country: culture, large cities, water sports and woodland and heathland areas.

It should be realized that tourism and recreation are subject to many influences including, for example, technological, social and economic influences. These may be stronger than the influence of climate change.

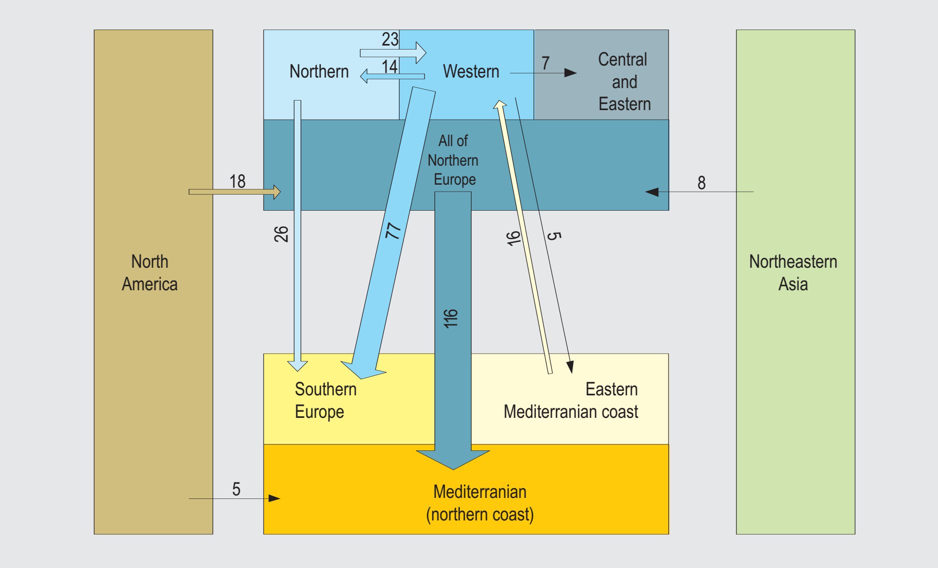

Figure 6.1: If climate changes continue, large distribution shifts are likely to occur in the present flow of tourists; these will have major consequences for the recreation and tourism sectors. (Source: Mather, Viner and Todd, 2005)

6.2 Coastal tourism in general

Coastal tourism is by far the most important segment of the international tourism market. The climate plays an important role in the choice of a holiday destination on the coast. For example, it is estimated 116 million tourists (one-sixth of the world's total) from northern Europe visit the Mediterranean Sea region each year and then in particular, the coastal zones. Many Dutch tourists also spend their holiday in the Mediterranean Sea area (Figure 6.1).

6.3 Shifts in the warm and hot season

The current Mediterranean climate is famous for its attractiveness to tourists; this despite the fact that even in the summer heat waves can strike, water shortages can occur, forest fires can break out and/or extremely large quantities of rain can fall in short periods of time. When making predictions for this area, climate models take into account an increase in heat and drought in the summer. In addition, these effects are greater and will occur more quickly in the Mediterranean area than in other parts of Europe. It is also highly likely that these effects will make the Mediterranean Sea area less attractive as a holiday destination, in part because (almost certainly) the competition for water between the tourism sector, agriculture and other water users will become increasingly more serious.

Summer traditionally provides the best conditions for tourism in Europe, but this may change in the future. By as early as 2020, the traditional summer peak tourist period in the interior and on the eastern coasts of Spain and in parts of Greece and western Turkey will be less attractive (too hot) than the autumn and spring. By 2050, the zone with good tourist conditions in the spring and autumn and the loss of these conditions in the summer will probably have spread to almost the entire northern Mediterranean coastal area. As a consequence of this, the Mediterranean Sea area will be confronted with a shift in the peak tourist season from the summer to the spring and autumn.

A measure of the attractiveness of an area for tourism is the 'Tourism Climatic Index' (TCI). This TCI takes a variety of different factors into account, such as temperature, humidity, sun, rain and wind. A score above 70 is very good, and one above 90 is ideal. Figure 6.2 (left picture) shows the possible effect of climate on the TCI over several years for the Balearics (Mallorca, Menorca and Ibiza). In northern regions such as the Netherlands (Figure 6.2 – right picture), the summer will continue to be the most important tourist season, but this season will last much longer and will not only include July and August but the entire period from May to September.

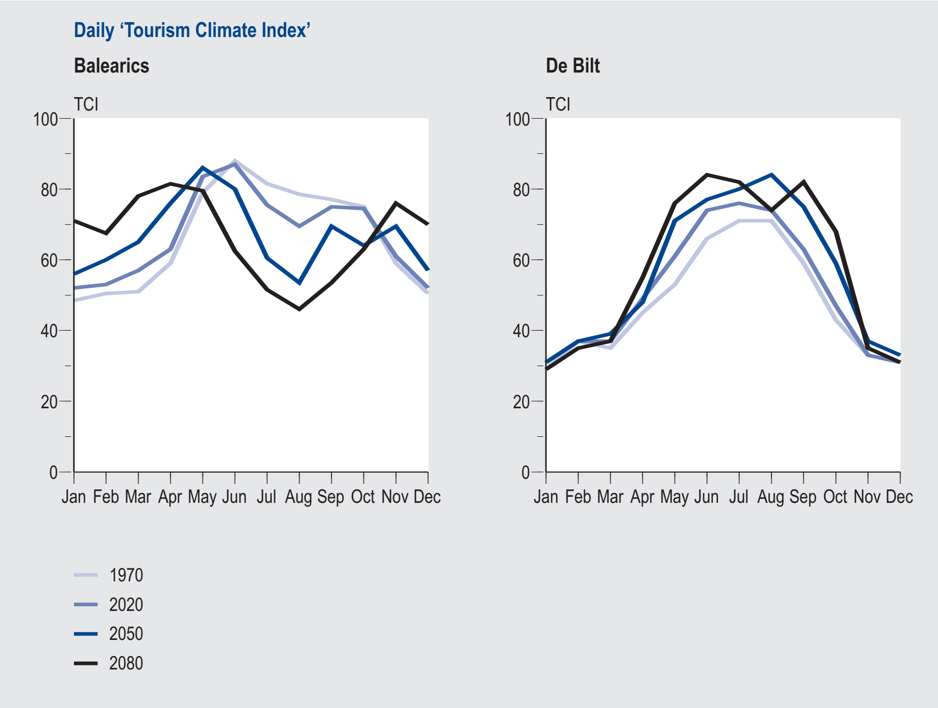

Figure 6.2: Climate change is expected to influence the summer tourist season. More southern areas such as that Balearics (left picture) will be confronted with a worsening of the factors that determine tourism in the summer season. In more northern regions such as the Netherlands (right picture), the summer season could last longer with the result that the scope of the tourism and recreation sectors along the coast will expand. (Source: Amelung, 2002)

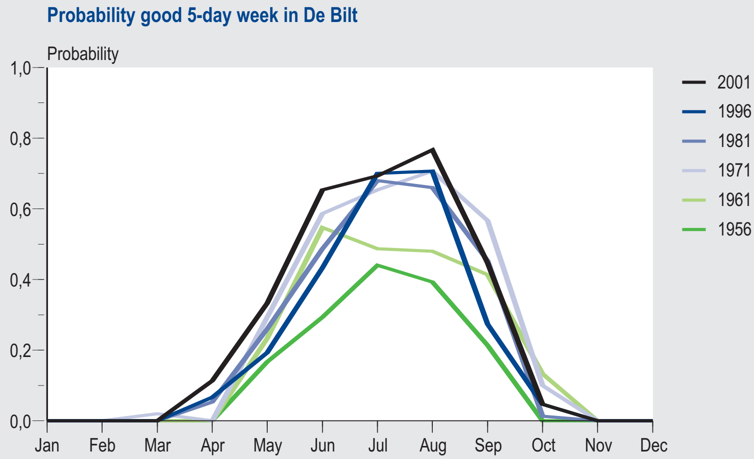

Figure 6.3: Due to the effect of already observable climate change, the number of periods with very good (warm) weather conditions has increased significantly (Source: Brabson, Amelung and Viner, 2004)

Such a climate change – on average, warmer and longer summers – is already observable in the Netherlands: since the 1960s, weeks with at least 5 'good' days (TCI>70) have become a far more common occurrence (Figure 6.3). This trend is not only occurring at the height of the summer but also over a large part of the year. This historical tendency – that of a gradual improvement of the best conditions and the extension of the season – fits in well with the projections from Figure 6.2. The year 2003 is probably a good indication of the warm and dry years that will occur more frequently in the future (Box F).

Box F: The heat wave of 2003

The summer of 2003 was an extremely warm summer in Europe, and in many countries thousands of people succumbed to the heat [some of this total can be attributed to air pollution (see Chapter 8 – health)]. For Switzerland, it has been demonstrated that the probability of a hot summer such as that of 2003 is negligible, based on the climate records kept there since 1864. The summer of 2003 can therefore be seen as a strong indication of climate change. In a changing climate, a summer like 2003 could become normal, and at the end of this century it could occur every other year (see also Chapter 2). Data for the year 2003 can therefore – when applied with care – be used as a window into future climate conditions. In Figure F.1, the TCI pattern for the year 2003 at De Bilt is compared to the trend for the years 1930–2003. This figure suggests that the Dutch summer climate might well become reliable enough to make the Netherlands an attractive destination for foreign tourists, similar to how it is now for the Mediterranean Sea area. Such an extension of the tourist season and an increase in the number of pleasant, warm days will cause an increase in the number of beach visitors, resulting in extra pressure on the beaches and the transport infrastructure towards the coast.

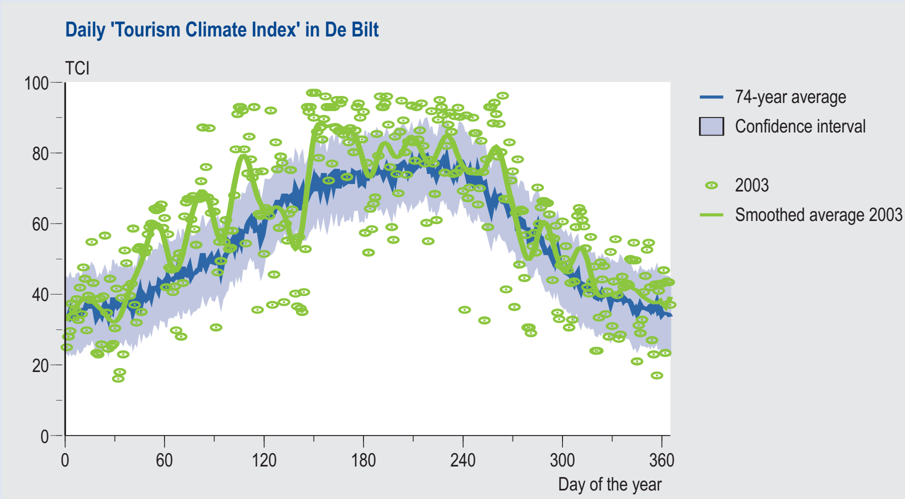

Figure F.1: The historical series of summer temperatures shows that the Dutch summer is becoming warmer (Source: Brabson, Amelung and Viner, 2004)

6.4 Tourism, recreation and water in the Netherlands

While the changing climate will make the Netherlands a more attractive tourist destination, at the same time it will ensure a rise in sea level and lead to increased erosion of the beaches and dunes. Considerable efforts will be needed to raise the sand level of beaches so as to maintain their breadth – if this indeed proves to be possible. Tourism in the coastal areas could therefore either benefit or lose out as a result of climate change.

Winters will become warmer

The winters in the Netherlands are becoming warmer, with the result that there will be fewer opportunities to skate on natural ice. For a culturally and recreationally important event such as the '*Elfstedentocht*' skating tour, the temperature must be well below freezing for several weeks. The chance of this happening is already relatively small, and the effects of climate change will decrease the chance still more, even though this decrease will not be as strong as would be expected from the general temperature rise (see also Chapter 2).

As a result of climate change, rivers will need to carry more water on an incidental basis;. Furthermore, due to the rise in sea level it will be more difficult for this water to be discharged into the sea (see also Chapter 3). Therefore, areas throughout the Netherlands are being set up to store the extra water. Water storage, also as a means to bridge the larger periods of drought, is one of the adaptation measures being explored. A number of these storage areas will probably turn out to be suitable for recreation and water sport. Taken alongside the general improvement in the weather conditions during the summer season, this is an extra stimulus for the water sport sector.

Table 6.1: Due to climate change and the rise in temperature, the snow line in the Alps will shift upwards, the certainty of snow will decrease and the skiing season will become shorter. (*Source: Abegg, 1996)*

Region	Number of skiing areas	Certainty of snow					
		1200 m + sea level		1500 m + sea level		1800 m + sea level	
		Number	%	Number	%	Number	%
Jura	15	4	27	1	7	0	0
Alps	19	16	84	7	37	4	21
Valais	54	54	100	52	96	40	74
Bern (exclusive of the Jura)	35	30	86	20	57	12	34
Central Switzerland	35	26	74	13	37	7	20
Ticino	8	8	100	3	38	2	25
East Switzerland	18	11	61	6	33	3	17
Grisons	46	46	100	42	91	33	72
Total Switzerland	230	195	85	144	63	101	44

The Dutch and snow tourism

For the Dutch, the Alps are an important holiday destination in the summer, but an even more important one in the winter. The Swiss skiing resorts are situated relatively high compared to those in the other Alpine countries and, consequently, there is a greater chance of snow. However, since the start of the 1980s the certainty of snow has shown a marked decrease. It is suspected that this is related to climate change. Research has indicated that the snow line shifts 100–200 m upwards with every degree in temperature rise. The higher temperature will not only lead to a reduced certainty of snow but also to a shorter skiing season, and this will typically apply to ski resorts at lower altitudes. At present there is a sufficient certainty of snow at about 85% of the Swiss skiing areas. However, if in the period 2030–2050 the snow limit shifts to 1500 m above sea level, then only about 63% of the current ski resorts will still be certain of snow (Table 6.1). The consequences of this shift are even more dramatic for Alpine countries with ski resorts at lower altitudes, such as Germany and Austria, and will have a detrimental effect on the number of Dutch winter sport tourists going to these areas.

Swimming water quality

The RIZA drought study revealed that in an extreme situation the number of tourists, the annual spending and the number of people employed in the water tourism sector will decrease by a few percentage points at the most due to changes in the quality of the water, navigability, the quality of the fish stock and the hold-up at by bridges and locks. Of these factors, deterioration of the (swimming) water quality had the greatest effect on recreation. The positive effect of the good weather in a dry year on the number of day trippers was found to be much greater than the possible negative effect of a deterioration in the water quality: in an extremely dry year the number of day trippers increases by 40% relative to an average year, whereas the number of day trippers decreases by about 4% for all of the years calculated due to a lower water quality. The employment opportunities in the recreation sector exhibit the same patterns as the number of day trippers: employment opportunities are more sensitive to the weather situation than to the water quality.

Box G: The possible increase in the prevalence of blue algae (cyanobacteria) in lakes as a consequence of climate change

The water temperature in the shallow lakes of the Netherlands is gradually increasing (data from RIZA). This is in line with the climate expectation, in view of the strong correlation between the outdoor air temperature and water temperature (see Figure G.1 for the Lake Veluwe). These data clearly show that the water temperature in the period since 1990 is significantly higher than that prior to 1985. A sudden rise seems to have taken place between 1987 and 1990; this rise is parallel to the outdoor air temperature and probably associated with a rise in the NAO index. At present, nothing else can be said about a possible further increasing trend after 1990.

Climate change and the rise in the (swimming) water temperature associated with this in shallow lakes can pose potential health risks due to the possibly higher prevalence of pathogenic micro- organisms such as blue algae. The influence of water temperature and other climate effects on (swimming) water quality is on balance much smaller than the influence of nutrients and the composition of the fish stock. For example, lakes with a high phosphorus load are always turbid and mostly experience problems from blue algae, whereas those with low phosphorus loads are always clear and do not, or scarcely ever, experience problems from blue algae. The net result is that climate effects are often difficult to distinguish from other effects. The effects that are strongly dependent on the type of ecosystem and other conditions can be conflicting and are still only partly quantified.
In the case of moderate phosphorous load – a condition that can be applied to most Dutch lakes – warming up leads to an increased chance of a blue algae bloom. In the moderately loaded Border Lakes, severe winters lead to about a 50% probability of a blue algae bloom in the summer; for mild winters there is a 75% probability. In clear, vegetation-dominated lakes, the effect of temperature on the blooming of blue algae is slight (determined by means of mesocosmos experiments). However, an increase in the water temperature does increase the risk that clear, vegetation-dominated lakes, with a phosphorous load close to the critical value, regress to turbid condition. In mesocosmos experiments carried out in various European lakes over 2 consecutive years, the quantity of blue algae observed was mostly higher in the year with the warmest summer. Other than a temperature rise, climate change will probably also lead to an increase in the phosphorus load in a number of lakes.

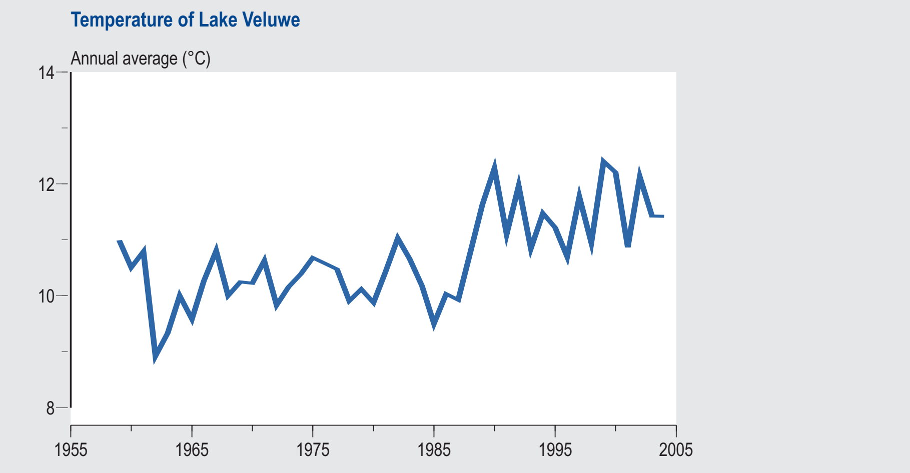

Figure G.1: Trend in the water temperature of the Lake Veluwe (Source: RIZA)

Drought and recreation/tourism

In addition to modelling the current situation, an analysis has also been made of the effects of future climate change on recreation and tourism. To this end, the expected temperature and durations of sunshine and precipitation in 2050 were used. Two scenarios were simulated: one scenario with a temperature rise of 1°C in 2050 and the so-called 'dry' scenario. Based on these calculations it is apparent that climate changes will have a positive effect on the expenditure in water recreation. The climate scenario with a 1°C temperature rise leads to an increase of 1% in the expenditure, and the dryer scenario to an increase of 6%. Deterioration in the water quality has less of an effect on the expenditure than the positive effect of climate change and the associated rise in temperature. It should be noted that the calculations for the future scenarios can at most be seen as indicative because the behaviour of vacationists in the future may strongly change; the present models have not taken this factor into account.

In conclusion, it can be stated that climate change and the rise in temperature will give a positive impulse to tourism and recreation in the Netherlands, mainly as a result of the longer and warmer summer season. The temperature of the (swimming) water will, however, have a negative effect on the quality of this water (Box G).

7 SOME CONSEQUENCES FOR COMMERCIAL SECTORS

Key points:

- The consequences of climate change for the transport sector are highly uncertain.
- Inland navigation will likely be confronted with more limitations due to lower minimum discharges of the Rhine and Meuse.
- It is highly likely that electricity companies will experience greater problems with their cooling water systems due to the rise in temperature and more frequent low discharges.
- Peak water use during dry periods is likely to be higher and more frequent.
- Damage due to light floods can be insured against; damage due to severe flooding cannot.

7.1 Transport sector

The consequences of climate change on the transport sector have received little attention in this report thus far, but it is possible that climate change may lead to problems in various areas of this sector. The transport system as a whole performs worse under extreme weather conditions, and it does appear that warm extremes will occur more frequently in the future (see Chapter 2). These warm extremes can, for example, lead to longer traffic jams (for example, when going to the beach; see Chapter 6), greater disruptions on the railways and for air traffic and to a more limited navigability of rivers for goods transport. On the other hand, cold extremes will decrease to a limited extent. Whether this will lead to less iciness is unclear as iciness is not so dependent on extremely low temperatures. The possible economic and spatial consequences on the transport sector still need to be investigated.

In the period up to 2050, the transport costs of inland navigation will mainly change as a result of changes in the supply of freight. According to the 'Drought study', the expected increase in transport costs as a consequence of climate change will remain limited to between 2 and 4%. In the event of extremely low water levels, such as in 2003, inland ships can only use a fraction of their normal loading capacity, which increases the transport costs considerably. The probability of such low river discharges (<1250 m^3/s) and low water levels mainly increases in the dry climate scenario (Figure 7.1). The negative effects of floating ice on the large rivers will hardly ever re-appear in the future. Partly as a result of climate change, the temperature of the river water is now already much higher than it was several decades ago (see Chapter 3). It is highly likely that this trend will continue at an increased rate.

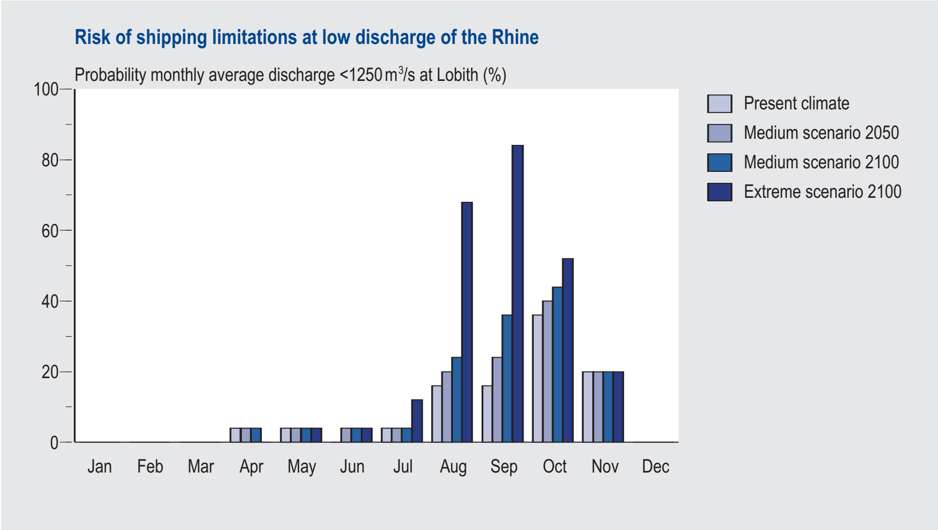

Figure 7.1: The probability of an extremely low river discharge and limited navigational depth mainly increases compared to the current situation in an extremely dry year ('extreme 2100'). (Source: Buiteveld, 2005).

7.2 Energy

Energy consumption

Energy consumption depends on, among other factors, the outdoor temperature. The Energy Research Centre of the Netherlands (ECN) and Netherlands Environmental Assessment Agency (MNP) have estimated the influence of the temperature increase that has already occurred on the energy consumption to be about 3 million tonnes CO_2 emission saving (a collective measure of various types of energy consumption incorporated into a single denominator). This is about 1.5% of the total Dutch CO_2 emission in 2000 and is mainly the consequence of less heating in households, industry and the glasshouse sector. The various scenarios show that an additional emissions-saving of 0.5–0.8 million tonnes CO_2 is likely over the next 20 years. It would seem that any future saving is to a large extent offset by the extra requirement for cooling.

Electricity production

Surface water is used on a large-scale in the Netherlands as a coolant in the production of electricity. Two limitations apply to the discharge of cooling water:

- the maximum discharge temperature must be below 30°C;
- the temperature difference between intake and discharge may not be more than 7°C in the summer and 15°C in the winter.

Consequently, a water temperature of 23°C applies as the critical limit for the use of cooling water.

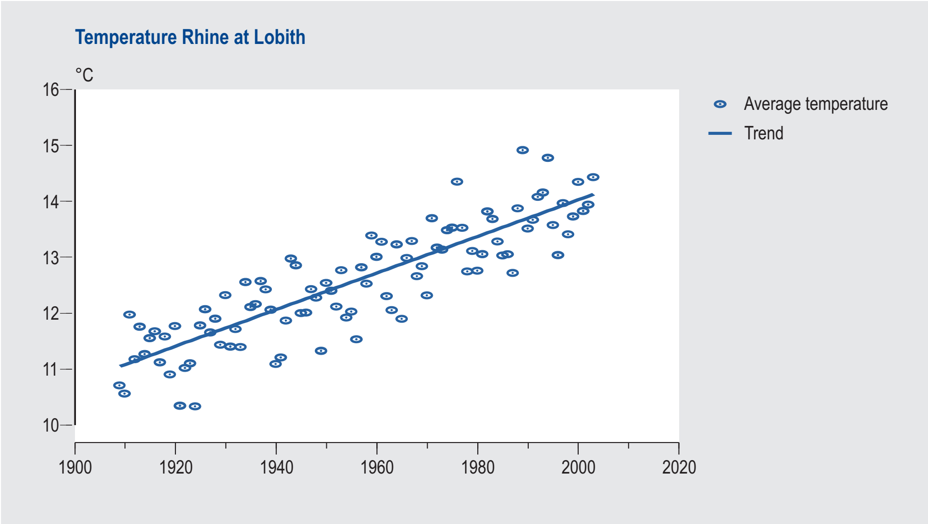

Figure 7.2: Average annual temperature of the water in the Rhine River at Lobith during the period 1909–2003 (Source: RIZA, 2005)

Research has revealed that the temperature of the river water is more of a determinant of cooling water restrictions than the discharge of the river (KEMA 2004). Over the past century the average annual temperature of the water in the Rhine has increased from 11°C in 1910 to above 14°C in 2003 (Figure 7.2). Two-thirds of this temperature rise is estimated to be due to the increased use of cooling water in Germany and one-third to the increase in temperature as a result of climate change.

Due to the temperature rise that has already occurred in recent decennia, the number of days in the year that the water temperature is above 23°C has also increased (Figure 7.3). During the very warm summers of 1994 and 2003, energy production temporarily decreased as a consequence of a shortage of cooling water; in 2003, a tight situation even arose (code 'red' in terms of the certainty of delivery) for a period of almost 40 days when the water temperature was above 24°C.

How the temperature in the Rhine and Meuse will continue to rise in the future is uncertain and depends on both the rise in the air temperature as well as developments in the utilization of cooling water upstream in Germany and Belgium. With a further increase in the air temperature, it can be expected that the water temperature in the Rhine and Meuse will rise and – if the use of cooling water upstream remains the same – the chance of temperatures for which a cooling water restriction applies will also increase. A previous study into the cooling water problem of the Meuse emphasizes that the probability of these problems will increase still further (Figure 7.4), assuming the current discharge characteristics and use of cooling water. However, the energy sector has various options available for reducing the sensitivity of the system to the temperature of the river water.

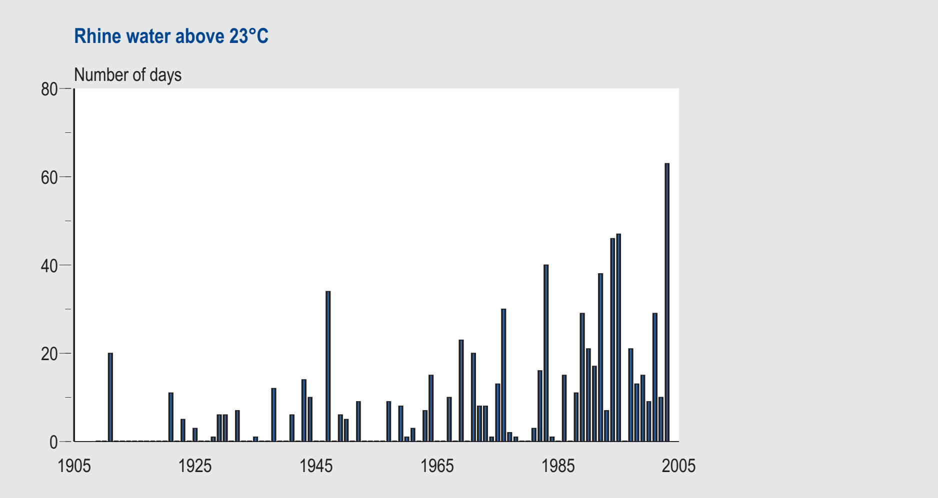

Figure 7.3: Trend in the number of days per year when the temperature of the water in the Rhine was higher than 23°C during the period 1909–2003 (Source: RIZA, 2005)

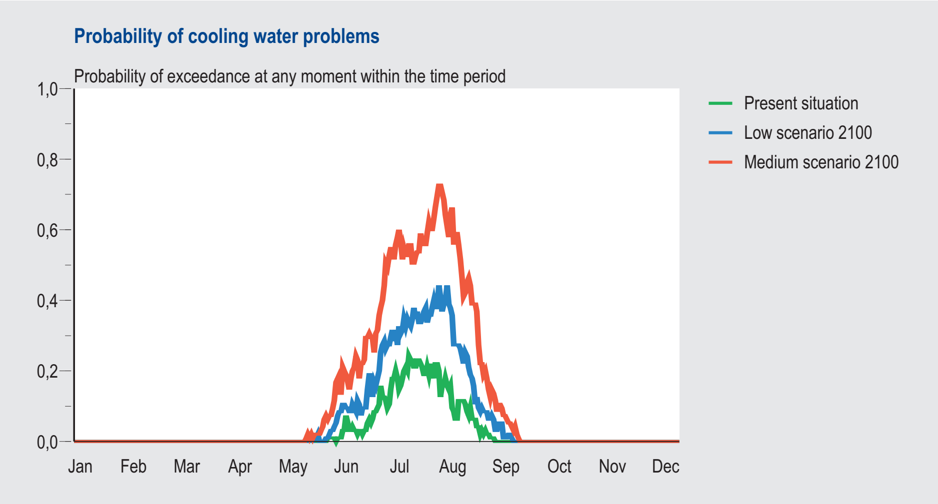

Figure 7.4: The probability of cooling water problems occurring during the course of the year (Source: RIZA, 2005)

7.3 Water use

The summer of 2003 was dry and extremely warm. The consumption of drinking water in this year was 2% higher than in 2002. This in itself is particularly striking because drinking water consumption has shown a decreasing trend since 1995. This rise was entirely due to consumers, who used 25 million cubic metres more water (3.5% of the annual consumption by households) than normal, mainly for watering gardens and lawns.

The heat wave in June 2005 also led to a record quantity of drinking water being used according to a press release from the Netherlands Water Companies Association (VEWIN). In the week of the heat wave 8 million cubic metres more water was used than the weekly average over the entire year. On the warmest day the use was at times 50% higher than average.

The expectation is that the average demand for drinking water will rise by several percentage points due to the rise in temperature. More peaks in the demand for drinking water are expected in the future as a result of climate change. Drinking water reservoirs are being constructed to bridge periods of water shortage due to low river discharges or a poor water quality. These are large enough to ensure that a national shortage of water for drinking water preparation is highly unlikely.

7.4 Insurance

Damage due to severe and lights flooding is distributed differently across citizens, companies and government. Households and, since recently, the agricultural sector as well, can frequently be insured on a commercial basis against the damage which arises from heavy rainfall. Damage which arises from the failure of dykes can no longer be insured against in the Netherlands since the storm flood disaster of 1953. Damage due to heavy rainfall elsewhere or due to the rise or fall of the groundwater is also not insurable. Damage which cannot be prevented, which cannot be reasonably insured against or cannot be compensated for in another manner, can be covered by the government via the Disasters and Serious Accidents (Compensation) Act (WTS; see also Chapter 5).

In the Netherlands, consideration is being given to an improved coverage against the risks of damage; see, for example, the recommendations of the Advisory Commission Water and the ‘Commission for Compensation in the Event of Disasters and Serious Accidents’ (Borghouts Commission). Solutions are also being sought within the European Union for catastrophic damage; for example, the so-called EU solidarity fund.

The risks in the Netherlands associated with severe flooding are distributed differently over the country. This can, for example, be seen in the spatial differentiation of safety levels, such as those established in the Flood Defences Act. At the present time, the damage is covered uniformly by both commercial insurance policies as well as through the government by means of the Disasters and Serious Accidents (Compensation) Act. It is plausible that the coverage of commercial insurance policies and compensation from the government will become spatially differentiated, as a result of which the risks of the participating parties will be better manageable. This will also provide a stimulus for the more sustainable use of land. In addition to this, damage that is not yet covered might be covered by public-private insurance constructions.

8 ARE THERE HEALTH RISKS DUE TO CLIMATE CHANGE?

Key points:

- Climate change could have a negative effect on health in the Netherlands.
- Health effects are difficult to quantify; for a number of effects – for example, a malaria epidemic – the risks are probably slight.
- Possible important health effects are related to temperature rises like an increase in Lyme disease, effects of air quality and allergies.
- Risk groups will probably experience stronger effects and a greater burden of disease.

Climate changes can threaten human health in many ways (Figure 8.1). The nature and severity of the health effects depend on the sensitivity of people to climate change, the degree of exposure and the ability to adapt.

How will climate change affect the health of the Dutch population? Which effects are already observed and which can be assumed with a reasonable degree of certainty? What is the disease burden associated with these effects and what are the risk groups? This chapter provides an overview.

8.1 Temperature-related effects

The relationship between temperature and mortality

Many studies have shown the relationship between temperature and death. A Dutch study carried out by Huynen *et al.* revealed that, in the Netherlands, this relationship has a 'U shape' (Figure 8.2), with an optimum temperature (the average temperature with the lowest mortality) of 16.5°C. Above and below this optimum mortality increases. The results also showed that temperature primarily increases mortality from cardiovascular and respiratory diseases, and mortality among the elderly (65+).

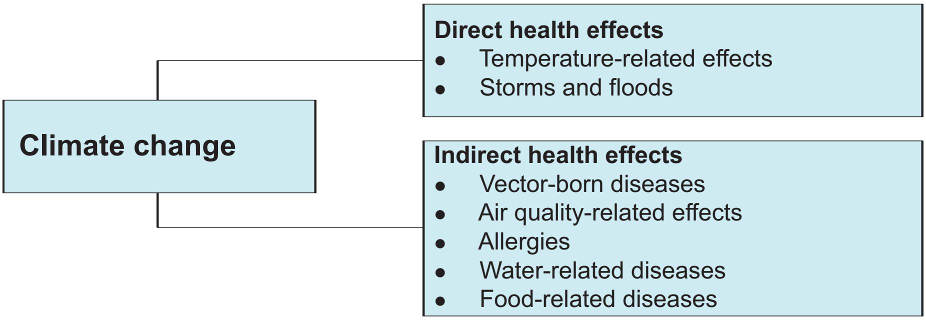

Figure 8.1: Climate change can affect health in many ways

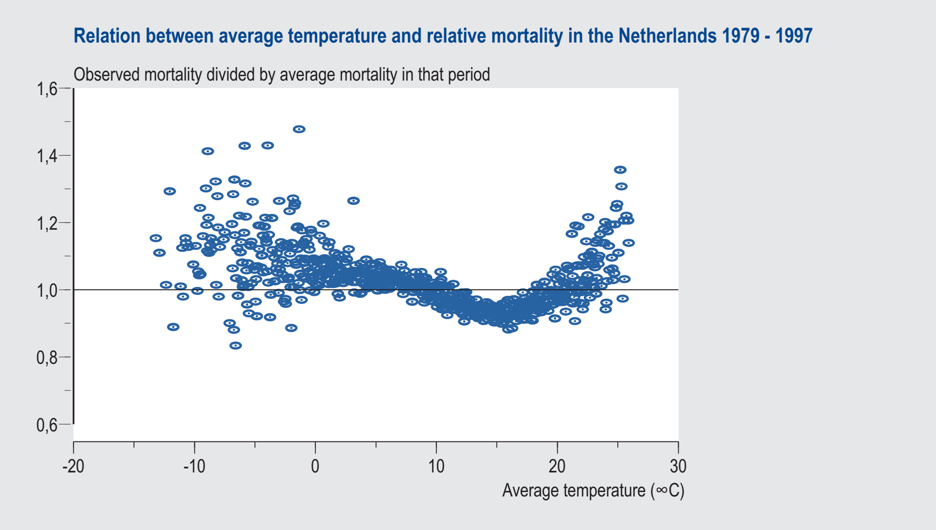

Figure 8.2: The U-shaped relationship between the average temperature and mortality in the Netherlands, as measured between 1979 and 1997 (expressed as relative mortality = observed mortality/average mortality in that period). (Source: Huynen et al., 2001)

This increased mortality also implies an increase in morbidity, the size of which is at least proportional to that of the increased mortality and probably greater.

Climate change in temperate or cold areas such as the Netherlands will lead to warmer summers and milder winters, independent of the extreme circumstances that will occasionally occur. Based on the temperature-mortality relationship, it is supposed that the increasing mortality in the summer will possibly be compensated for by a decreasing mortality during the winter.

Effects of temperature extremes

However, climate change will also result in more frequent and severe extreme temperatures.

Effects of cold periods

The probability of extremely cold periods will decrease, even though this will not be as strong as the shift in average temperatures (see Chapter 2). The probability of excess mortality during periods of extreme cold (13% or an average of 47 people per day, mainly elderly) will therefore also slightly decrease.

Effects of heat waves

Climate change will result in an increase in heat stress due to an increase in the number of heat waves (see Chapter 2). Daily mortality rate increases during heat waves (Table 8.1), probably accompanied by an increase in heat wave-related illnesses. During the heat waves of 1982, 1983, 1990, 1994, 1995 and 1997, the extremely high

Table 8.1: Excess mortality during past heat waves. (After: Huynen et al., 2001; McMichael et al., 1998; Rooney et al., 1998; Sartor et al., 1994)

Heat wave	Relative increase in mortality
London, 1995	15%
London, 1976	15%
Belgium 1994	13% (mainly elderly)
The Netherlands 1982, 1983, 1990, 1994, 1995, 1997	13% (equivalent to about 40 extra deaths per day)

temperatures resulted in an average of 40 additional deaths per day in the Netherlands. The heat wave of August 2003 lasted about 2 weeks. Compared with the mortality rate during a normal August (with a mean temperature of about 22ºC), Statistics Netherlands concluded that about 400–500 extra deaths occurred due to the extreme heat in that period. Recent calculations for the Netherlands demonstrate that the increased air pollution (ozone, particulate matter) during heat waves is responsible for about 25–40% of the registered 'heat wave mortalities' (see also Section 8.3).

The elderly (65+) and people with respiratory or cardiovascular diseases are particularly sensitive to extreme heat. In many countries the population is ageing, resulting in an increase in the population vulnerable to heat stress and in climate change having an added detrimental effect. However, the figures need to be put into perspective as not all heat-related deaths are of the same category. Research has revealed that part of the excess mortality during heat waves must be viewed as 'only a slight forward displacement of death'. As a result of this forward displacement, a temporary fall in mortality is often observed in the weeks following a heat wave. The other part could be viewed as excess mortality with substantial loss in life years. Unfortunately, little is known about the ratio between these two categories.

Babies and young children possibly form a risk group as well because their temperature regulation still needs to develop and dehydration may also occur; signs of this are, however, difficult to observe. Little information is available about the precise effects of heat waves on babies and young children.

8.2 Vector-born diseases

An important potential effect of climate change and temperature rise is the increase in – and transmission of – vector-born pathogens. Several examples are given in the following sections.

Malaria

Malaria is an infectious disease caused by the bite of a mosquito infected with malaria parasites. Will the effects of climate change result in an increased occurrence of malaria in the Netherlands? There may be an increase in the risk of an occasional

Meer malaria door het broeikaseffect

Kans op terugkeer malaria in Europa

Broeikaseffect opsteker voor malariamug

Figure 8.3: Even though malaria is often mentioned in newspapers as a possible health effect of climate change, the risks of a malaria epidemic will be extremely small (Photo: newspaper headings).

local epidemic in the summer due to the transmission of the less dangerous malaria parasite *Plasmodium vivax*. In addition, it is possible that the Mediterranean mosquito will expand into Central and Western Europe, presenting a potential for infections with a more dangerous malaria parasite (*P. falciparum*). Although reports in the media sometimes indicate otherwise (Figure 8.3), experts argue that the chance of a large-scale malaria epidemic in the Netherlands as a partial result of climate change is extremely small, mainly due to the excellent health care facilities in the Netherlands and preventative measures that can be taken. There could be a possible increase however in imported malaria from less developed regions where the disease occurs more frequently.

Lyme disease

A number of infectious diseases can be transmitted through tick bites, like for example Lyme disease. This bacterial infectious disease occurs frequently in Europe and is mostly caused by sheep ticks. Lyme disease is a complex infectious disease with an unpredictable clinical course that presents many symptoms. If treated insufficiently, or too late, it can lead to severe disability and illness. Risk groups are people who spend a lot of time in gardens, parks and woods, thereby increasing their chances of coming into contact with an infected tick and being bitten by it. Between 1994 and 2001, the estimated number of tick bites in the Netherlands doubled from 30,000 to 61,000. The number of patients with a bull's-eye shaped rash on the skin as an early symptom of Lyme disease also increased by about a factor of two (Figure 8.4), which indicates that the risk of infection is rapidly increasing. The increasing popularity of outdoor recreation is believed to be one of the most important causes.

The transmission of the causal bacteria mainly takes place in periods that ticks are active, namely during the spring, summer and autumn (April–October). The distribution and population density of ticks in the Netherlands is climatologically determined and is dependent on warm and humid weather. Lyme disease is therefore sensitive to changes in the climate. It is possible that as a result of climate change in the Nether-

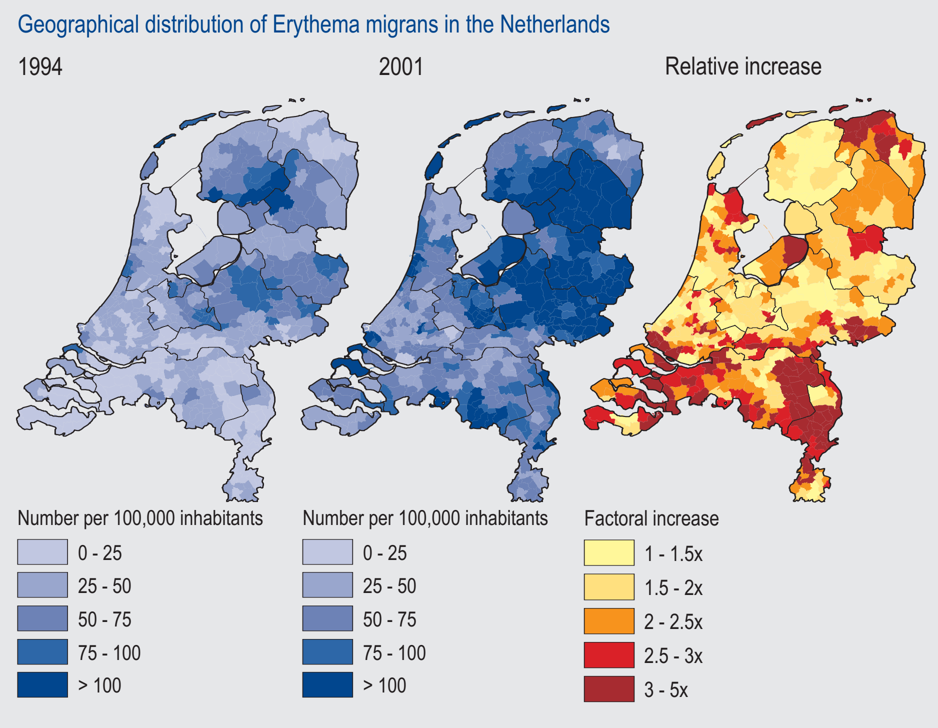

Figure 8.4: The geographic distribution of Erythema migrans (a bull's-eye shaped rash on the skin as an early symptom of Lyme disease) in the Netherlands in 1994 and 2001 and the relative increase between 1994 and 2001. (Source: Den Boon and Van Pelt, 2003)

lands, Lyme disease could occur more frequently because warmer and wetter winters and earlier springs ensure an extension of the transmission period. In addition, climate change could lead to more outdoor recreation in the Netherlands and, hence, a greater risk of infection. The possible increase in Lyme disease cannot yet be estimated in quantitative terms.

8.3 Air quality and effects

There is an enhancing interaction between extreme temperatures and the degree of air pollution. Weather conditions in part determine the air quality due to their influence on the formation and spread of air pollutants. This often leads to air quality limit value or standard being exceeded (episodes of summer and winter smog). Two components in particular are important with respect to the health effects of air pollution: ozone (in the troposphere) and particulate matter. Ozone is only important as an air pollutant during the summer. Particulate matter, on the other hand, is a problem throughout the year, although levels are higher in the winter. Research shows that both short- and long-term exposure to these substances are associated with a large number of health effects (including premature death and increased illness). There are also indications that health effects arising from simultaneous exposure to stressful weather conditions and air pollution are greater than the sum of the separate effects. It is expected that climate change will influence the frequency and concentration of both summer and winter smog. In addition to the effect in rural regions, increased air pollution as a result of climate change poses a particular problem in highly polluted urban areas.

Summer smog and ozone

Figure 8.5 shows that the concentration of ozone at ground level is higher in periods with higher temperatures. As a result of a photochemical process on sunny and warm days, ozone is formed from nitrous oxides and volatile organic substances. Although still uncertain there seems to be no threshold value for the occurrence of ozone-related health effects. The higher the ozone levels, the greater the increase in, and severity of, the effects.

Risk groups are people who exercise outdoors, people with cardiovascular diseases and respiratory problems and people who are extra sensitive to ozone exposure. Climate change in the Netherlands results in an increase in the number of summer days, with the result that the probability of smog formation will increase. Another phenomenon that is in part associated with climate change, is the increase in the background concentration of ozone in the entire Northern Hemisphere. This significant increase has also been observed in the Netherlands. In the absence of a threshold value for effects, an increase in this background concentration will have a direct negative influence on the health. This impact is difficult to estimate quantitatively.

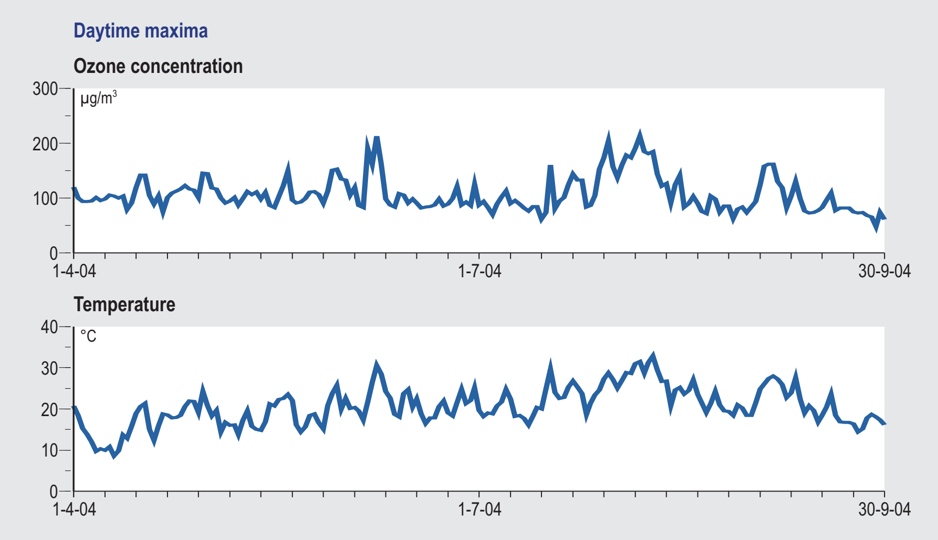

Figure 8.5: National maximum ozone concentrations and the maximum temperature are strongly related to each other; the summer of 2004 is given as an example. (Source: RIVM, 2004)

Winter smog and particulate matter

Particulate matter (fine particles in the air) is a general air pollution problem with considerable negative consequences on human health with illness and premature mortality. People with respiratory problems or cardiovascular diseases, the elderly and people who exercise outdoors are the first to run the risk of health effects. In the winter, during stable cold weather with frost, periods can occur in which there is a strong increase in the levels of fine particles for prolonged periods (winter smog) and during which the negative health effects of this form of air pollution increase. If Dutch winters become on average less cold due to climate change, then the chance of winter smog could decrease. However, in the future, extremely cold periods can still occur, and it is during such periods in particular that the chances of winter smog are much greater.

8.4 Allergies

Allergic conditions seem to be increasing in Europe for reasons that are still unknown (although recent reports indicate that the peak now seems to have passed). These conditions include allergic hay fever (with a running nose and sneezing), allergic eczema and asthma. Climate change could have a further detrimental effect; for example, due to an increased exposure to pollen and house dust mites. From a health point of view, these can be important effects because such conditions are already major causes of morbidity, loss of productivity and increasing healthcare costs in some European countries.

Pollen and hay fever

Pollen-related allergic diseases may well account for 10–20% of allergic diseases in Europe. Climate changes and weather conditions affect the timing and perhaps also the duration of the pollen season, the quantity of pollen produced, and the geographic distribution of flowering plants. The prevalence of hay fever is therefore often correlated with the pollen season. Climate change in the Netherlands and its possible effect on pollen production can therefore have a direct negative effect on allergic conditions such as hay fever and asthma and on the number of patients affected by these diseases. Although an effect of climate on pollen seems likely, there are no quantitative data to predict the size of this.

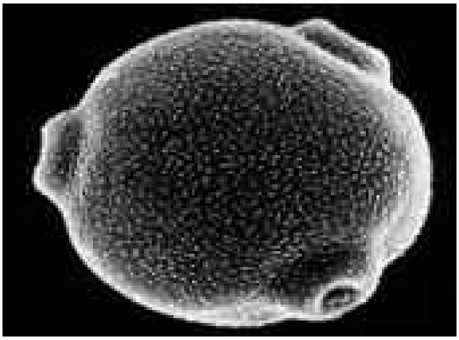

Figure 8.6: If climate changes extend the pollen season, this could lead to more allergic reactions under a relatively large proportion of the European population. (Photo pollen grain: H. Behrent)

Figure 8.7: The house dust mite needs a high relative humidity; climate change can affect the occurrence of the house dust mite and subsequently the allergies that they can cause (Source photo: unknown)

House dust mite

The house dust mite (Figure 8.7) is one of the most important indoor sources of allergies. Dust mite-related allergies are associated with eye irritations, hay fever, asthma and skin problems (eczema). Changes in temperature and relative humidity can lead to an increase in the level of house dust mites. Mites need moisture to survive, which is why mites thrive best in a stable humid environment with a relative humidity between 65 and 85%. Their numbers increase considerably during the autumn in particular due to the higher indoor humidity. Although a climate effect on the house dust mite is likely, no quantitative data are available to predict the size of the effect.

8.5 Other developments

Water-related diseases

It is not very likely that climate change and temperature rise in the Netherlands will contribute to any great extent to diseases related to water quality. However, the following health effects might occur:

- effects caused by the increasing growth of – and exposure to – microbiological pollutants in the coastal, surface, and recreational and drinking water in the Netherlands; for example, blue algae or botulism;
- effects of pathogenic micro-organisms which up until now have caused little or no problems, such as amoebae, particularly during warm summers;
- effects of pathogenic micro-organisms from less developed areas (such as the cholera bacteria).

In order to provide an indication of the possible consequences of temperature changes on the increased occurrence of pathogenic micro-organisms, a trend analysis of the water temperature in one of the largest rural recreational lakes has been made (see Chapter 6).

Food-related illnesses

Climate change can also affect the prevalence of diseases such as salmonella poisoning following the consumption of infected food because the transmission and formation of this type of infection is directly temperature-dependent and, therefore, also climate-dependent. In the Netherlands, but also in other countries, significant effects of this have already been demonstrated. However, it is unlikely that these effects will be very large in the Netherlands due to the high standards of hygiene.

Exposure to UV radiation

Although the climate problem and the ozone problem (stratospheric ozone depletion: the so-called 'ozone hole') must not be confused with each other, there are number of interactions between the two. For example, due to the enhanced greenhouse effect, the recovery of the ozone layer might well be delayed at the two poles (by several decennia), while at temperate latitudes it might be enhanced (recent IPCC report). In this way, health will be indirectly affected as a result of increased or decreased exposure to ultraviolet (UV) radiation. Furthermore, if there is an increase in warmer and drier summers, the chances of a greater exposure to sunlight and UV radiation (staying outside and in the sun more often: see Chapter 6) will increase the health risk. Exposure to UV radiation can lead to cataracts, skin cancer, and a weakening of the immune system.

EPILOGUE

The very long term

The effects of climate change for the Netherlands covered in this report have been approached assuming a time horizon of a few decades, except for a few cases where a longer time horizon – the end of the century– has been used. In general, it can be concluded that the effects of climate change for the Netherlands would appear to be manageable over the next few decades. However, this is subject to a few qualifications. Fundamental problems that threaten to make their appearance in the long term can best be included well in advance when deciding on possible measures. Such an approach could lead to solutions that are more robust than what would come to mind in the 'gradual changes approach'.

The projections for the climate at the end of this century and beyond encompass a number of changes that occur worldwide (for an overview of these, see the MNP report, 'Limits to warming; in search of targets for global climate change'). Greenhouse gas emissions have a delayed effect throughout the entire climate system. The effects of the current elevated concentrations of greenhouse gases will have unavoidable consequences for several more decades or even centuries. The temperature rise will result in thermal expansion of thick ocean layers, an expansion that can only be restored by long periods of much colder weather. Views on the melting of land ice differ considerably (see also Box B in Chapter 2). Along with the continuing subsidence of the Dutch coastal land area, melting of land ice could lead to a relative rise in the sea level of up to several metres over the next few hundred years. This may bring with it even greater rises should the land ice melt substantially.

It is uncertain whether the techniques currently used in water management and coastal protection – beach nourishment by raising sand levels in coastal areas, increasing the height of dykes and maintaining dune areas – will be sufficient to keep pace with this change while still maintaining the current safety standards.

The consequences of continuing climate change on the natural environment, agriculture, recreation, health and other sectors in the Netherlands are difficult to project in concrete terms so far into the future. The manner in which water management is responding to the forthcoming climate changes will be of considerable consequence for all sectors. Coherent analyses will be needed to achieve a coherent policy. However, it is clear that the species composition and biodiversity in the Netherlands will change to a certain extent in the longer term. Agriculture will most likely adjust to the changes in terms of, for example, chosen crops, timing of planting and harvesting and pest control. However, for agriculture and other economic sectors, climate change is probably less important than other, more economic, and social developments.

Scenario studies and adaptation

The currently available knowledge on the effects of climate change in the Netherlands has been presented in this report. This knowledge is still far from complete, and often still based on analyses having different starting points. Thus a broad, coherent analysis is needed to provide a clearer basis for adaptation policies. The Royal Netherlands Meteorological Institute KNMI is currently working on new climate scenarios that are expected to become available early in 2006. A good place to begin would be agreement on common starting points for the analyses of climate change effects on the basis of new scenarios from KNMI. In that case it becomes possible to examine the uncertainties in a more coherent manner. Many of the current analyses still fail to provide a picture of the expected costs and benefits of climate change for the different stakeholders. This is important information when considering potential measures.

The analyses also reveal how difficult it is to make a good quantitative estimate of climate change effects, especially in economic terms. Yet this is often necessary for a careful weighing of public interests and deciding between short-term and long-term objectives. Scenario analyses should preferably be detailed enough to include these economic estimates.

The effects of climate change could be far more serious in many regions outside the Netherlands. Such changes will have an increasing effect on Dutch society through such factors as migration, changing trade patterns and changes in the behaviour of tourists. Consequently, scenario analyses into the effects of climate change for the Netherlands will always need to be supplemented with European and global analyses.

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