11 Climate change and water systems

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OUTLINES

- All climate scenarios for Flanders clearly indicate an increase in the ambient temperature (e.g. by 1.5 °C to 4.4 °C in the winter and by 2.4 °C to 7.2 °C in the summer), a higher evaporation in the winter and summer and finally more precipitation during the winter by 2100. The sea level at the Flemish coast may rise by 20 to 200 cm this century.

- The majority of climate scenarios indicate a drop in the average summer precipitation for Flanders. Combined with higher evaporation this will decrease the lowest river flows during dry summers by over 50 % by the end of the 21st century. The chances of severe water shortages increase as a result.

- Despite a drop in summer precipitation, an increase in the number of extreme summer storms may be expected in Flanders. This increases the probability of flooding of sewers.

- The risk of financial damage due to flooding varies greatly, depending on the various climate scenarios for Flanders: from a drop by 56 % to a 33 % rise.

- Flanders is located between Northern France, where climate change strengthens the evolution towards more droughts and The Netherlands where an increase in the number of floods is expected to be more likely. In order to deal with the uncertain consequences of climate change, water managers in Flanders must therefore search for flexible adaptation strategies that are useful in any circumstances. This involves strategies that enable both flood risk limitation and the prevention of water shortages.

Introduction

The climate is the average weather condition over a period of a few decades or longer. It is described on the basis of parameters such as temperature, precipitation and wind. Apart from the annual seasonal fluctuations in weather patterns, the climate is subject to change. The current climate change is amongst other causes due to global warming and is becoming increasingly perceptible. This warming is considered one of the main problems confronting the Earth at this time. Climate change is a phenomenon that appears over a longer period. For that reason climate studies often work with a time horizon (e.g. to 2100) that is much further in the future than the target year 2030 that is considered in other chapters of this environmental outlook.

This chapter is the first to gather the results from eleven research projects recently completed or still underway which study the possible climate changes in Flanders and their consequences (see the list at the end). Achieving a more define view of the possible changes was a major focus of this chapter. New risk calculations for flood damage were carried out according to various scenarios. This information is crucial to allow the government and public authorities but also industry, agriculture, households, etc. in Flanders to adapt in time and purposefully to climate change and to be able to limit the damage due to flooding or water shortages.

This chapter will first consider the way in which climate scenarios were developed for Flanders starting from global climate scenarios. Temperature, evapotranspiration, precipitation and wind then illustrate the possible climate change for Flanders in the 21st century. The point of particular interest in this chapter will then be considered: the impact of climate change on water systems (rivers, urban drainage systems, coastal zone) in Flanders. Those consequences – for instance flooding, water shortages or exceeding water quality standards – in their turn have major socio-economic and environmental implications. Finally this chapter will conclude with recommendations to support water policy and management.

11.1 From global emission scenarios to three climate scenarios for Flanders

Climate change, which is expressed amongst other things in the global warming of the Earth, also became clearly perceptible in Flanders over recent decades. The Intergovernmental Panel for Climate Change (IPCC) is an organisation formed by the United Nations that brings together the scientific findings on climate change worldwide. According to the IPCC, humans very likely (>90 % probability) contribute to this climate change. This contribution is attributed to the increased emission of greenhouse gases[1] (carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3) and chlorofluorocarbons) due to human activities into the atmosphere. Other factors also play a role in the climate change observed: for instance the variation in solar radiation, the changing presence of particles in the atmosphere as a result of volcanic eruptions or natural phenomena such as fluctuations in atmospheric circulation patterns.

Researchers use climate models to calculate future changes in the emissions of greenhouse gases to their impact on the global climate system. This modelling required significant simplification due to:

- the, as yet, still incomplete knowledge of atmospheric processes and their interactions;
- the massive computation capacity required to calculate complex interactions;
- the large spatial dimensions of the global climate system.

This simplification means that the results are still uncertain. In the first place this applies for local processes. The results for temperature are significantly more accurate than those for precipitation and wind speed, particularly because they are much less variable spatially. The average values of climate variables are also considerably more accurate than those for exceptional or extreme values. Although the uncertainty remains great, the detail of climate models is continuously improving. Increasingly more processes and interactions are integrated (e.g. interactions with the land surface, sea ice, the carbon cycle, aerosols and changing vegetation). The resolution at which the models can work – currently for sections with a height and width of 10 to 25 km – is also increasingly being refined.

In order to gain a better picture of the variation of the possible impact and due to the simplifications and remaining uncertainties, impact analyses are carried out with multiple climate models and various emission scenarios.

Greenhouse gas emissions in Flanders contribute to climate change. However the speed with which the greenhouse gases emitted mix in the atmosphere and the length of time they remain there, makes climate change a pre-eminent global concern. In order to explore the possible climate changes in Flanders, the global greenhouse gas emission scenarios are consequently taken as a basis – rather than the scenario results for greenhouse gas emissions for the various sectors in this outlook report. The scenarios for the global greenhouse gas emissions are taken from the 4th Assessment Report of the IPCC (2007). They are constructed around various world views, starting from the increase or reduction of the globalisation of the economy, differing demographic changes, various technological growth paths and the extent to which the world economy is sustainable.

These different emission scenarios were used in twelve linked global and regional climate models. The results were tested against the historical progress

(1961-1990). This made it possible to explore the range within which the climate may change in Flanders by the end of this century (2071-2100). Researchers from the Catholic University of Leuven and the Royal Meteorological Institute (KMI) defined three climate scenarios from a wide range of simulation results obtained by climate models. These climate scenarios outline a range of climate change variation in Flanders by the end of this century. They include both the differences in the possible greenhouse gas emissions and the uncertainties linked to the climate models used:

- The *wet climate scenario* (a 'high' scenario) results in the greatest increase in the level of precipitation that leads to high runoff discharges, high water levels in the rivers, flooding, high soil water and groundwater levels in winter.
- The *dry climate scenario* (a 'low' scenario) results in the greatest problems with low river flows, low soil water and groundwater levels during dry summer periods. In the spring there may be somewhat higher groundwater levels.
- The *moderate climate scenario* (a 'middle' scenario) results in moderate results, both for high and low flows and wet and dry periods.

The natural variations in climate – the coincidence by which weather phenomena may occur over time – are also taken into account in this chapter. These variations are especially important in the analysis of extreme weather phenomena and their impact.

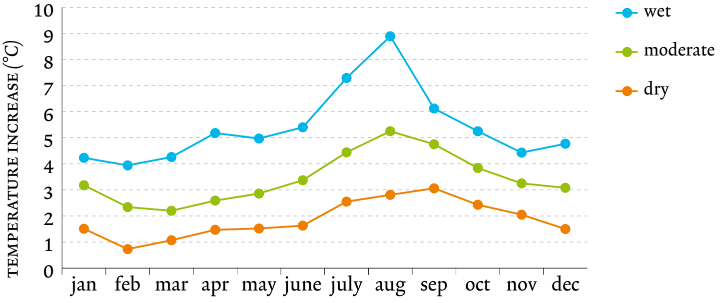
11.2 Climate scenarios for Flanders

Temperature

The three climate scenarios indicate that by the end of the 21st century Flanders will be significantly warmer over all the months of the year (FIGURE 11.1). How large the increase will be remains uncertain. For instance in January the ambient temperature rises, depending on the scenario, by 1.5 to 4.2 °C. In August the temperature may increase by 2.8 to 8.9 °C. For seasonal averages this would give an increase in the winter (December, January, February) by 1.5 to 4.4 °C and for the summer (June, July, August) an increase of as much as 2.4 to 7.2 °C.

Not only the average monthly temperature but also the temperature on the hottest and coldest days will clearly increase. The expected increase in the average day temperature for the 10 % coldest days is 1.5 to 6 °C in winter, and 2 to 5 °C in autumn (winter and autumn are the seasons in which this increase is the sharpest). For the 10 % hottest days this increase is sharpest in summer and ranges from 3.2 to 9.5 °C. This means that by the end of the 21st century there will be a lot more very hot days in the summer than during the summer in the 1961-1990 period. So far since the 1990s, the annual and seasonal temperatures

FIG. 11.1 *Increase of average monthly ambient temperature according to the three climate scenarios (Uccle, scenario period 2071-2100 compared to the reference period 1961-1990)*



and the frequency of heatwaves have also already significantly increased. The average annual temperature increased during the 20th century by about 2 °C (KMI, 2009).

Evaporation and precipitation

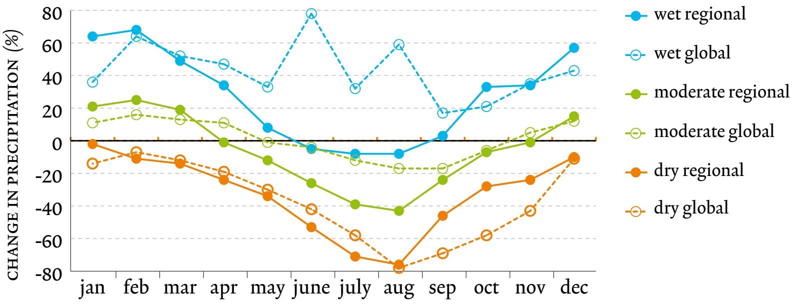
The level of evaporation increases as a result of the increase in temperature, both in the winter and the summer. For instance in February the increase of the potential evapotranspiration – an indicator of evaporation – is between -3 % and +37 % depending on the scenario and the calculation method. In August this evapotranspiration may increase by 73 %. In the spring some scenarios indicate an increase in evaporation while other scenarios indicate a decrease.

The precipitation will also increase in the winter. The changes to precipitation in the summer are more complex:

- The total amount of precipitation will probably decrease.
- There should be fewer showers.
- The heavy summer storms could be more extreme and more frequent.

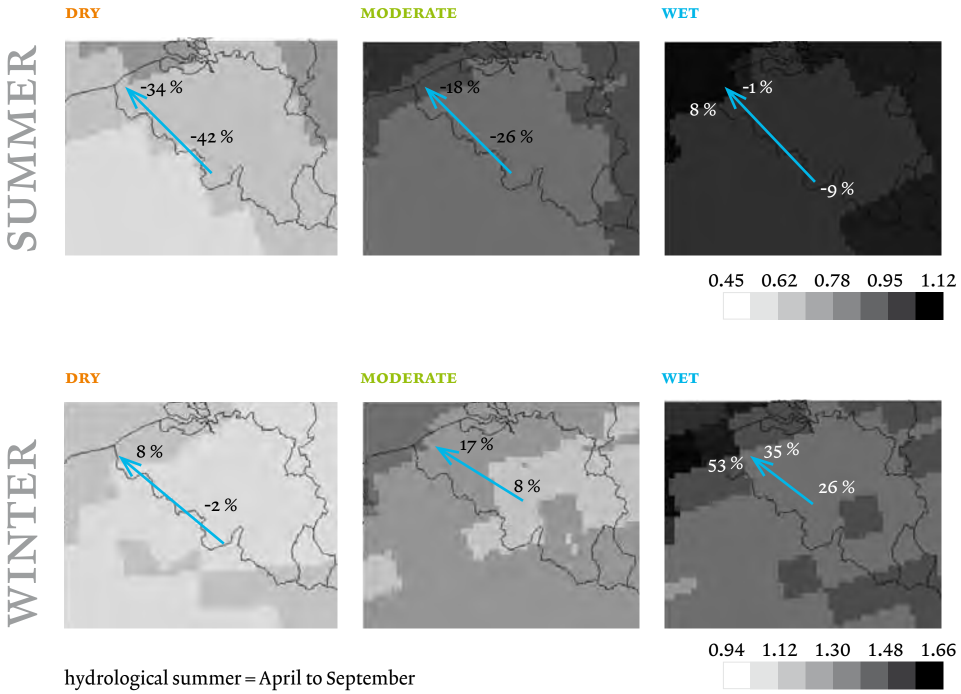
FIGURE 11.2 gives an overview of the changes to average monthly precipitation. Belgium belongs to the area where the global climate models indicate a larger spread in changes to precipitation than the regional climate models. This is the result of the larger set of emission scenarios available for global models. However, the calculations on the basis of regional climate models are geographically more precise. Simulation results from both global and regional climate models were therefore analysed. They indicate an evolution for Belgium to drier summers, although this picture is less clear in the global model results. These sometimes indicate a small increase in precipitation in the summer. The sharpest drop in summer precipitation is found in the dry climate scenario and for August. The average monthly precipita-

FIG. 11.2 *Change in the average monthly precipitation according to the three climate scenarios (Uccle, scenario period 2071-2100 compared to the 1961-1990 reference period)*



'Regional' relates to the results with regional climate models, 'global' relates to results with global climate models.

FIG. 11.3 *Regional differences for the average seasonal precipitation according to the three climate scenarios (Belgium, scenario period 2071-2100 compared to the 1961-1990 reference period)*



hydrological summer = April to September
hydrological winter = October to March
Results expressed as perturbation factors:
factor = 1 indicates no change;
factor = 1.2 indicates a 20 % increase;
factor = 0.8 indicates a 20 % decrease

tion would decrease by 76 to 78 % in relation to the current situation. Taking account of the major uncertainties this reduction may also be 17 to 43 % (moderate climate scenario), barely 8 % (wet climate scenario with regional models) or even result in an increase (wet climate scenario calculated with global climate models). The sharpest increase in precipitation is expected for January (from hardly any change to an increase by 64 %).

In addition to the average monthly precipitation the probability of occurrence of extreme precipitation events was also studied. More exceptional events may be subject to greater changes than small or average events. For instance for precipitation events that only occur once every ten years, the level of precipitation might be up to a factor of 2.5 higher than in the reference period. However, exceptional events are subject to greater uncertainty than the scenario results for the average monthly precipitation.

As mentioned above a significant increase is already noticeable in the average annual and seasonal ambient temperature and in the number of heat waves. An analysis of the measurements of the precipitation over a one hundred year period in Uccle shows that an increase is also already apparent in the number and intensity of extreme rain storms in winter (Ntegeka & Willems, 2008). Extreme rain storms are here defined as rain events that occur less frequently on average than ten times in a year. The result of the climate models is also in line with the trend already observed: the extreme daily precipitation in winter increases a few percent every ten years.

The historical data series does not yet show an increase in the number and extent of summer storms. The numerous, heavy summer storms over the last 15 years may consequently also be the result of natural fluctuations in climate over the North Atlantic and North Western Europe. Indeed, the same occurred in the decades 1910-1920 and in the 1960s (Ntegeka *et al.*, 2008).

The possible change in precipitation also shows minor regional differences within Belgium (FIGURE 11.3). In the coastal region the change is 10 % higher than inland both for the summer period and the winter period. For the summer this means that the decrease in precipitation is less strong in the coastal region (the future climate is closer to the current climate). In the winter an additional increase in precipitation of 10 % results in greater moisture in the coastal region.

Wind

The precipitation results have already shown that climate change will have an impact on the incidence of storms. However precipitation alone does not significantly define the damage that storms may cause, wind speed also plays a role. Calculations for the wet, moderate and dry climate scenarios show an increase in the average wind speed during the winter months. The wind speed would systematically be 10 to 20 % higher by the end of the 21st century compared to the 1961-1990 reference period. The results for the summer months do not give a clear picture.

11.3 Impact on high and low water in rivers in the Flemish inland: flooding and ... water shortages

Rainfall run-off from river catchments

The simulation[2] of the wet, the moderate and the dry climate scenario until 2100 makes it possible to study the impact on high and low rainfall run-off discharges to rivers in Flanders. The wet scenario results in the most extreme impact for high flows and floods, the dry scenario in the most extreme impact for low flows and droughts. The conclusions for all rivers are along the same line:

- *Low flows in summer:* due to the significant decrease in summer precipitation and the increase in evaporation the flow will fall considerably. During dry summers the lowest river flows may drop by over 50 % (20 % on average in the least unfavourable scenario, 70 % on average in the most unfavourable scenario). As a result the frequency of water shortages may increase considerably, with possible detrimental consequences to industrial and household water consumption, shipping, agriculture, environmental conditions, river water quality, etc. Groundwater levels will also drop, resulting in similar problems.
- *High flows in winter:* the sharp increase in evaporation (both during the winter and the summer) compensates for the increase in winter precipitation to a great extent. As a result, the increase in the number and extent of floods (particularly along rivers in the winter) is relatively limited. Peak flows in the rivers will increase by a maximum of 35 % in the most unfavourable scenario. This increase could locally result in more frequent and more extensive flooding.
- *High flows in summer:* extreme summer showers could result in flooding of sewers and smaller watercourses. The majority of climate models predict an increase in the number (the frequency) and extent of heavy summer thunderstorms, so that an increase in the number of such floods is also to be expected. For the largest events

which currently occur once a decade, the average daily precipitation in the most unfavourable scenario increases by approximately 30 %.

The impact of climate change is not only highly seasonal but also extremely variable regionally. Climate models show a north-south variation in the precipitation and temperature change (Baguis *et al.*, 2009). In northern France, climate change will further strengthen the development towards desiccation, with a decrease in both summer and winter runoff volumes and consequently also a decrease in the number of floods. The probability of water shortage also increases in Flanders. The trend towards more floods is, however, still unclear. The increase in the number of floods is clearer to the North of Belgium, e.g. in The Netherlands.

Adaptation of sewer systems and urban retention basins[3]

In Flanders, sewers often do not only remove wastewater. Together with ditches and streams they are also often responsible for the removal of rainwater (precipitation). The peak drainage into the sewage systems, ditches and streams increases due to heavy precipitation. A precipitation intensity that in the current climate only occurs once every month and a half might occur monthly by 2100 under the wet climate scenario. A period of heavy precipitation that now only occurs once every two years would occur annually according to that wet climate scenario. The heaviest, short precipitation episodes (1 hour or less) that previously only occurred once a century might occur once a decade (Willems, 2009).

In the next decades climate change might result in a gradual increase in the number of sewer floods and overflows, resulting in a negative impact on the quality of the surface waters. To combat this, the (re)dimensioning of the sewers and ancillary structures such as urban retention basins, rainwater tanks, infiltration beds, green roofs, etc. have to take more intense periods of precipitation into account. Design values that have a return period for the overflow of the storage tank of two years according to the current approach would have a shortened return period of six months by the end of this century according to the wet climate scenario. The current design values with a five year return period will have a shortened return period of between one and one and a half years. The retention basins or storage tanks must consequently be given bigger dimensions due to climate change or additional provisions will be necessary for storing the rainwater and/or allowing it to infiltrate in the subsoil. In order to retain the same overflow return period, the storage volume must increase by 15 to 35 % according to the wet climate scenario compared to current practice. Another option is to use the existing storage capacity in a more optimal way by real-time control mechanisms.

It is still highly uncertain how future climate change will be felt. The wet climate scenario differs indeed strongly from the dry climate scenario and the actual uncertainties could be even greater. For that reason it is not advisable to design future sewer and storage systems and water management measures already now and at large scale according to the most pessimistic climate scenarios. However, new designs should best take account of the potential future climate change. This is possible through adaptive designs that allow the realisation of additional storage and pumping capacity with the lowest possible cost if it should become clear that the climate is moving in the direction of the wet climate scenario.

Moreover, the changing climate and its impact on the sewer systems must be seen in the broader context of the impact on the entire water system. If the variation in precipitation increases (more precipitation in a shorter time span, lower total precipitation volumes in summer) it is best to look for changes that combat the impact on the water balance. Additional storage and infiltration provisions for rainwater make it possible to limit both the risk of flooding during heavy showers and to decrease the expected increase in water shortages. An example of an effective and cheap measure is the careful installation of local depressions in public land (e.g. in parks), that can hold a lot of water temporarily and without much damage. This measure moreover ensures that the water stored infiltrates into the ground after the rainy period and thereby directly contributes to combating the dry-out of soils and groundwater resources. These types of measures require good coordination between urban planning and water management.

A revision of the Flemish guidelines for the design of sewer systems (current guidelines date from 1996) is necessary. Not only the precipitation statistics used to draw up the designs require updating, but the management choices for the drainage of rainwater from public roads, the separation of rainwater and wastewater and the issue of the quality of the rainwater draining away must be revised.

Flooding translated into economic risk

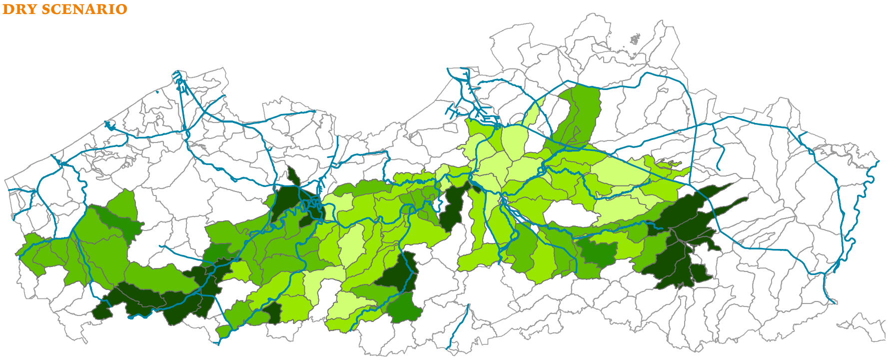
The impact of climate change on high and low river flows are further converted[4] into the possible economic risk as a result of flooding. This risk of flooding is described as the average expected damage per surface and time unit, expressed in euro per m^2 and per year. The damage at a specific location is thereby primarily defined by the land use and the local socio-economic context (housing prices in a specific municipality, yield from arable land, price of agricultural produce, vehicle prices, etc.). Densely built-up areas will suffer greater damage than pasture in the same flood; nature areas would not even suffer any financial damage from the same flood.

FIGURE 11.4 shows the ratio of the risk under a climate scenario with the current risk per zone from the Flemish Hydrographical Atlas (VHA-zone). Green indicates a drop in the risk of flooding, red indicates an increase in the risk.

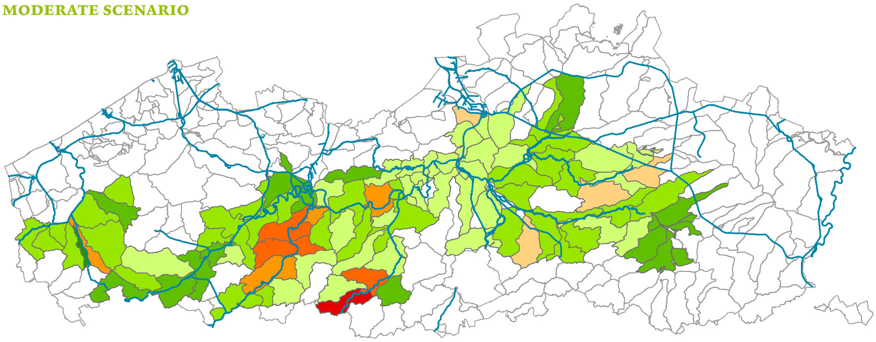
In the dry climate scenario the risk decreases strongly for all basins in Flanders. The total risk for the modelled part of Flanders has consequently also fallen

FIG. 11.4 *Evolution of the risk of flooding with the current land use as a result of the three climate change scenarios by 2100*

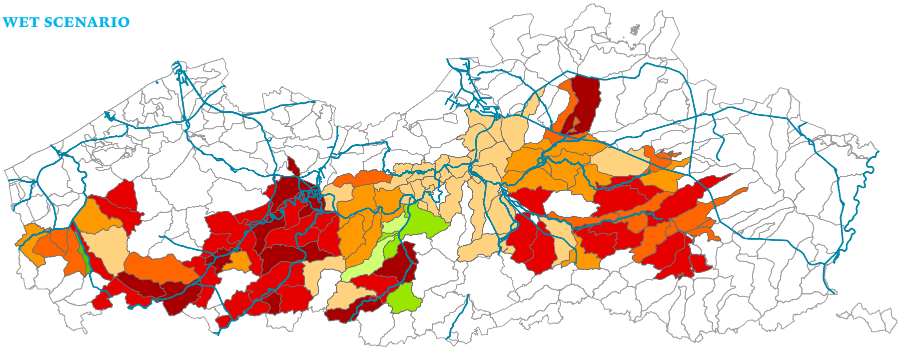
DRY SCENARIO



MODERATE SCENARIO



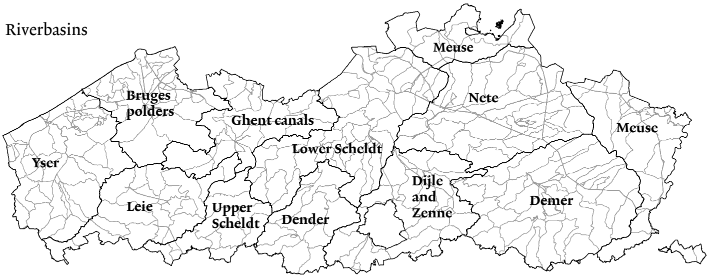
WET SCENARIO



Ratio of the climate scenario compared to the current climate *(%)*

- 🟩 < 5
- 🟩 5 - 10
- 🟩 10 - 50
- 🟩 50 - 90
- 🟨 90 - 100
- 🟨 100 - 110
- 🟧 110 - 150
- 🟧 150 - 200
- 🟥 200 - 500
- 🟥 > 500
- ⬜ no data

Riverbasins



Values expressed as a comparison of the risk in 2100 following a climate scenario with the current risk. 100 % indicates no change between 2005 and 2100.

New: flood risk management plans

The European Floods Directive of 2007 obliges member states amongst other things to draw up flood risk management plans (FRMP) by the end of 2015. Those FRMPS include measures for the reduction of potential adverse consequences of flooding for human health, the environment, cultural heritage and economic activities.

The FRMPS contain a lot of new elements in relation to the traditional approach to flood risks. For instance what flood risks the water manager must still protect will be defined. At places where flooding occurs too frequently, the risks must be managed with instruments from urban planning (e.g. by moving buildings). In the case of too extreme flooding the private insurance system and the Disaster fund must cover the risk. In the future the probability analysis of floods in the FRMPS will only be based on climate and land use scenarios for the coming decades and consequently no longer on the precipitation statistics of the previous decades.

The eleven Flemish basins will each be given a FRMP. This planning process started in the spring of 2009 and will run for four years. By September 2011 all risk analyses will have been completed and a broad range of possible sets of measures will be presented. The optimal sets will be selected from these via a broad social consultation, which will run together with the consultation on the drafting of the new basin management plans. This selection will be realised on the basis of a costs and benefits analysis. Spreading the costs and the benefits over the stakeholders involved (water managers, urban planners and insurers) will also play a role.

sharply (56 % lower than the risk in the current situation). The drop is particularly pronounced primarily in the Demer (-84 %) and Yser basins (-72 %). This is a direct result of the fact that the peak drainage into the watercourses in the dry climate scenario and consequently also the flooding areas are much smaller than in the current situation. Naturally this drop is not homogeneous everywhere in a river basin.

In the moderate climate scenario there is still a drop at the Flemish level (-8 %) when compared to the current situation, albeit of a different order of magnitude than in the dry scenario. However the risk increases both in the Upper Scheldt basin and within individual VHA-zones in other basins.

There is an increase in the risk for all basins in the wet climate scenario. At the Flemish level the increase in risk is 33 %. The Leie, Upper Scheldt and Demer basins particularly experience a very sharp increase in the risk by a factor of 2 to 3. For the Lower Scheldt and tributaries the increase is minimal: the risk would only increase strongly along the Nete and the Dijle.

Climate change clearly impacts the risk of flooding. However the frequency of flooding and furthermore the probability of damage, depends to a great extent, in densely built-up Flanders, on urban planning. To verify the extent by which the urban development within Flanders influences the possible effects of climate change, in addition to the risks of flooding with the current land use, the risk of flooding with two land use scenarios was calculated as described in Chapter 10, Land use. The built-up area increases in both scenarios, but is greatest in the reference scenario

(REF). In the European scenario (EUR) the additional built-up area is assumed to be smaller and the population density for each built-up area increases. Urbanisation primarily develops at the expense of pasture and arable land, which has lower flood damage per unit area. The nature and woodland area, for which the financial damage in the case of flooding is negligible, then progresses in both scenarios. In the land use scenarios changes in the land use were only calculated until 2030. Between 2030 and 2100 the land use is assumed to be unchanged for the calculation of the risk of flooding.

TABLE 11.1 shows the extent by which changes in the land use and climate result in a deterioration (red background) or improvement (green background) in relation to the current risk of flooding in Flanders. The following is clearly apparent from this:

- In the moderate and particularly in the dry climate scenario the risk of flooding decreases by 2100 both in the current land use and the land use under the REF scenario and the EUR scenario.
- There is hardly any difference for Flanders in the risk of flooding between the EUR scenario and the current land use. Unlike the REF land use scenario, the population increase and the corresponding housing needs in the EUR scenario are consequently absorbed without any additional increase in the risk of flooding.
- The most unfavourable combination for the risk of flooding consists of the REF land use scenario combined with the wet climate scenario.

TAB. 11.1 Risk of flooding* with a dry, moderate and wet climate scenario compared to the current risk of flooding with different land use scenarios** (Flanders, 2100)

(Ratio*** in %)	RISK IN 2100 WITH A LAND USE IDENTICAL TO THAT OF 2005			RISK IN 2100 WITH A LAND USE ACCORDING TO REF			RISK IN 2100 WITH A LAND USE ACCORDING TO EUR		
	Dry	Moderate	Wet	Dry	Moderate	Wet	Dry	Moderate	Wet
Demer	16	61	213	14	63	234	12	53	204
Dender	61	86	123	61	86	128	60	85	129
Upper Scheldt	50	134	266	50	138	279	50	136	274
Lower Scheldt and tributaries	40	93	104	41	93	104	40	92	103
Yser	28	64	134	34	81	221	30	67	140
Leie	44	79	283	88	143	377	52	95	322
Flanders	44	92	133	46	96	143	44	92	136

* solely as a result of the changing precipitation and evaporation. The changing sea level is not taken into consideration here.
** The effect of the changing land use is only taken into account in the definition of the possible economic risk. The effect of the changing land use on infiltration and drainage of rainwater could not be calculated.
*** Ratio: current situation with the land use of 2005 and 2005 climate is equal to 100 %.

With the REF land use scenario, the level of risk rises slightly under the three climate scenarios at the Flemish level compared to the scenarios with the current land use: from 44 to 46 with the dry climate scenario, from 92 to 96 with the moderate scenario and from 133 to 143 with the wet scenario. This is a direct result of the fact that there will be a larger built-up area under the REF land use scenario (both housing and industrial sites) in the flood plains. There is a high increase in the risk for all climate scenarios by 2100 especially in the Yser and Leie basins. The cause of this is an increase in urban development and industry in the flood plains to the detriment of the agricultural sector (pasture and arable land). In the Demer basin there is still a fall in the risk under the dry climate scenario. This is due to the decrease in arable land in the flood plain to the benefit of a nature area. In the moderate and especially the wet climate scenario the risk of flooding does increase here caused by the conversion of arable land into built-up land. In the other basins there is always a status quo in the three scenarios or a slight increase in the risk. The increase in the built-up area in the flood plains to the detriment of agricultural land is less strong than in the basins previously mentioned. Furthermore part of the agricultural land is then transformed into nature, which decreases the economic risk.

If the land use evolves according to the EUR scenario, it is apparent that the risk of flooding in the three climate scenarios hardly changes in relation to the current land use. The increase in built-up areas in the flood plains is limited in this land use scenario. And where there is a small increase in urban development, this is compensated by an increase in nature to the detriment of agricultural land in the flood plains. Regional differences again show higher increases in the risk for the Demer, Yser and Leie basins here. In the Demer basin a sharp fall in the risk can be noted by 2100 both in the dry and moderate scenario. The reason for this is a decrease in the arable land and the urban development in the flood plains to the benefit of nature. In the Yser basin there is again an increase in the risk in relation to the risk with the current land use in all climate scenarios but the increase is considerably less than in the REF scenario. Where a lot of grassland was transformed for urban development and industry in the REF scenario, this is not the case here. The level of industry remains constant and the level of urban development even drops slightly. A lot of grassland is transformed into arable land however which consequently means that there is still a slight increase in risk. The risk also increases in all scenarios in the Leie basin due to the conversion of the agricultural land into urban development.

Damage due to water shortages

In addition to damage due to flooding it is also important to consider damage due to water shortages. In every climate scenario for Flanders the frequency of low flow or drought periods increases and these periods become more extreme. The development towards drier and hotter summers combined with changes in the intensity of the precipitation will have a particularly negative impact on the quality and availability of the ground and surface waters and consequently also on the supply of drinking water. Climate change not only impacts the supply but also the demand for drinking water: in periods of great drought the peak consumption will increase. An analysis in Flanders shows indeed that peaks in the maximum temperature measured coincide with peaks in the daily consumption of drinking water (Peeters & Tops, 2009).

The damage in periods of drought will – as with flooding – depend on the ability of individual businesses and agriculturists to adapt. The priority the social interest places on water capture by the various parties involved (shipping, agriculture, nature, power supply, drinking water, etc.) is also important. Unlike with flooding, the spatial definition of the damage due to drought is much more difficult to assess. That damage strongly depends on the duration of the water shortage period. Furthermore systematic figures on interruptions to the water supply are currently not kept in Flanders.

11.4 Impact of climate change on the sea and the impact on the coastal region

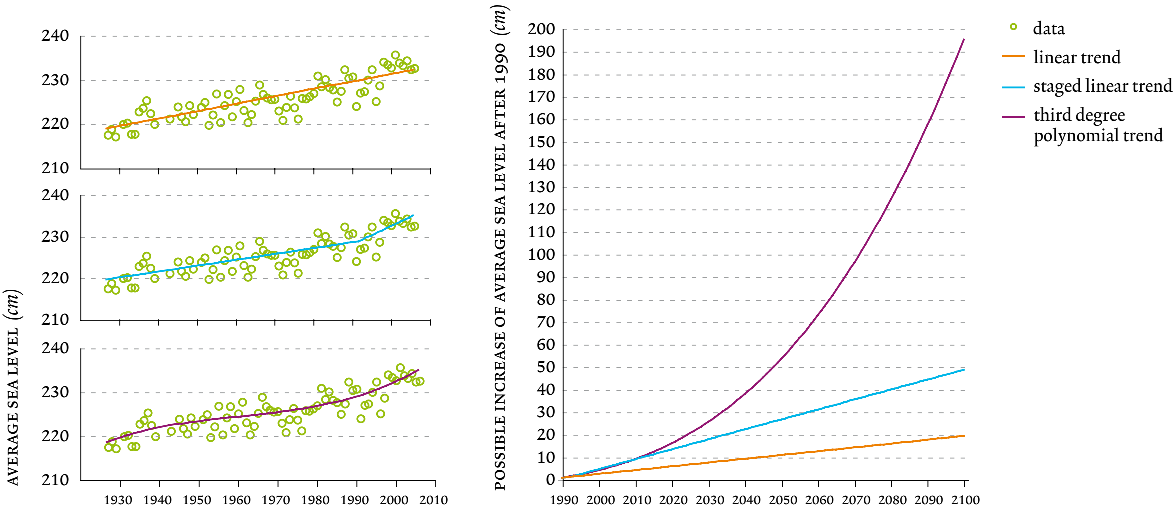
Sea level

The sea level in Ostend has risen on average by 1.69 mm/year since 1927. This rise fits closely to the global average which the IPCC derived for the 20th century (1.7 mm/year). Measurement series which started later at the Flemish coast, show even higher values. This indicates an acceleration of the rise in sea level. This is confirmed by regression analysis of the Ostend series of measurements: for instance a staged linear profile results in a kink in 1992. The increase was 1.41 mm/year on average between 1927 and 1992, but already 4.41 mm/year between 1992 and 2006. Extrapolation of the historical trend shows a further rise in the sea level for the Flemish coast, depending on the relations applied, of 20 cm to 200 cm for the period from 1990 to 2100 (FIGURE 11.5).

Temperature of the seawater

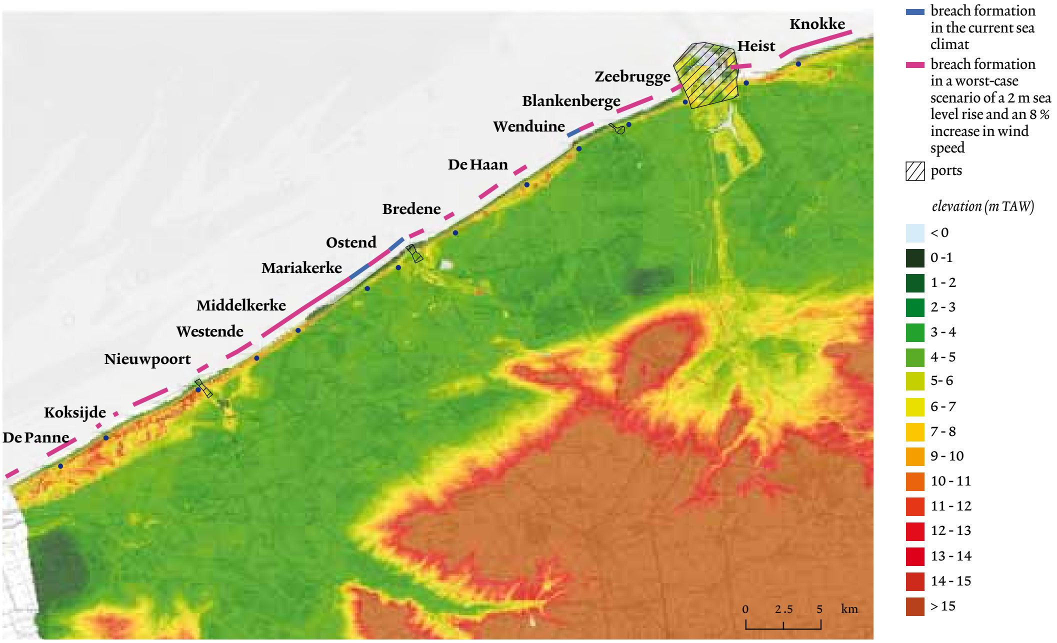
Together with the drainage of melting land ice to the sea, the thermal expansion of seawater is the main cause of the sea level rise already observed. The temperature affects the density of the water and consequently also the currents and sea level. In addition the temperature also affects the solubility of CO_2 in seawater and is thereby connected to the composition of the atmosphere. The temperature of the seawater is rising in all sub-regions of the North Sea (not only the Belgian part of it). Fur-

FIG. 11.5 *Trend analysis of the sea level measured (Ostend, 1927-2006) and extrapolation to a possible sea level rise in the period 1990-2100*



Source: Ozer *et al.* (2008), Van den Eynde *et al.* (2008)

FIG. 11.6 *Location of breaches due to erosion of beach and dunes in the event of a super-storm that occurs once every 17 000 years, both in the current sea climate and in a worst-case scenario by 2100*



Source: Van den Eynde *et al.* (2008)

thermore there appears to be a natural variability with a period of 7 to 8 years. The increase in the temperature of the seawater is between 0.023 °C/year (in the northern North Sea) and 0.053 °C/year in the central and southern North Sea. In the area closest to the Flemish coast the increase is about 0.034 °C per year or 3.4 °C per century.

Wave height and wind speed at sea

As regards wave height, the historical data series in and near the Belgian part of the North Sea shows a natural variation with a period of around seven years. There is also a seasonal cycle: there are higher waves on average in the winter and lower waves in the summer months. A clear climate trend could not yet be shown in the historical series of measurements of wave heights and wind speeds. However due to the expectations of a changing wind climate in the 21st century (see above), the frequency and size of the wind waves could change on the North Sea – and consequently also the likelihood of high water along the Flemish coast and in the Scheldt. Those wind waves may thereby result in an additional increase of coastal level maxima.

Impact on the coastal region

The flood risks are influenced along the coast by the sea level rise and the change in wind with the corresponding wave climate. The most unfavourable scenario for the Flemish coast assumes a sea level rise by two metres and 8 % increase in wind speed by 2100. This sea level rise is comparable to the upper limit scenario given by the Delta commission in the Netherlands: two to four metres sea level rise by 2200.

The wave load on the coast and sea defences increases significantly in any scenario. This relates to the increased water depth as a result of the sea level rise. Because high water rises faster and low water rises slower than the mean sea level, the semidiurnal tidal range (i.e. the difference between high and low tide) would also increase. The increase in the wave load and the semidiurnal tidal range would cause more erosion of the beaches and dunes. It would also increase the corresponding frequency of breach formation (the breaking through of a dike or natural dune belt). In the event of a super-storm that occurs on average once every 17 000 years, a breach formation is only expected in the current climate in Wenduine, Ostend and Mariakerke (excluding the coastal harbours). In the future climate, in the most unfavourable scenario and without measures, breach formations may develop over almost the entire coastline by 2100 (FIGURE 11.6).

The current coastal management designs sea defences in such a way that a storm that only occurs once every 1 000 years would not cause significant damage and has very limited likelihood that breach formation would occur. The return periods, used for a flood protection along the coast, are generally many times greater than those for watercourses not bound by tides. The coastal defence must indeed be resistant to more extreme conditions. If it goes wrong, the consequences are after all many times greater than if a river would burst its banks. Currently the Agency for Maritime Services and the Coast of the Flemish Government is developing a master plan for the coastal zone: the Integrated Coastal Safety plan 2010 (Geïntegreerd Kustveiligheidsplan 2010). Based on risk assessments of different water levels and storms, measures are being developed based on an economic analysis of costs and benefits. This plan is intended to protect the coastal region in an acceptable way until 2050. Measures will be chosen to allow them to be effective in any potential climate scenario and adapted to maintain an acceptable level of safety even after 2050.

High water levels along the coast result in a higher risk of flooding along the tidal influenced part of the Scheldt. In the current climate, flooding between Vlissingen and Ghent occurs on average every seventy years, which corresponds to a high water level in Antwerp of 7.83 m TAW. After the realisation of the controlled flood plain of Kruibeke-Bazel-Rupelmonde[5] this probability drops to once every 350 years, which corresponds to a high water level in Antwerp of 8.24 m TAW. With a middle scenario of a 60 cm rise in the sea level by 2100 and if no further measures would be taken the risk of flooding would again rise to the current probability of once every 70 years by 2050 and even once every 25 years by 2100. Furthermore there is still the combined impact of the rise in the sea level and the increased flows upstream caused by the changing precipitation, which could play a major role in the Sea Scheldt region between Ghent and Antwerp. This emphasises the importance of realising the fully updated Sigmaplan to control the risk of flooding and achieving the nature objectives in the Sea Scheldt basin. In addition to the installation of controlled flood plains that plan also includes raising the dikes in cities and industrial regions.

11.5 Conclusions for policy

General

The uncertainty concerning future changes in temperature and precipitation means that the impact of climate change on the water system cannot be established conclusively. However that is no reason to delay adaptation measures: these are initiatives by which Flanders can adapt to climate change.

Under the assumption that few measures are taken solely and exclusively to overcome the consequences of climate change, it is clear that the measures proposed must be efficient and effective, regardless of the primary reason for them being carried out and independently of the climate scenario chosen. The effects of climate change on flooding could evolve in different ways for Flanders. Even if the future would evolve more in the direction of the dry climate scenario, measures must be useful and justified. On the other hand if the climate should develop according to the wet climate scenario in the future, it must be possible to adapt, adjust, accelerate and intensify the measures en route. It is also important to stress that such focus on adaptation planning should not diminish our efforts to limit our emissions of greenhouse gases (mitigation measures).

Instead of avoiding flooding insofar as possible the management will have to increasingly focus on limiting the risk of flooding. Areas where the potential damage is great (residential areas, industrial areas) will thereby be protected to the prejudice of areas where the potential damage is small or non-existent (pasture, nature areas) or where it can even be turned into a win-win situation for functions like nature conservation and recreation. Additional efficient measures are conceivable, e.g. a warning system that tells residents how they can get themselves and their valuables to safety in time in the event of a threatening flood. In addition a policy is required that works against new homes and infrastructure being built in flood plains or makes them adapted to flooding. Water survey linked to spatial planning is a useful instrument to support that policy.

Inland adaptation

Currently adaptation measures for water management generally come down to a limitation of the likelihood of flooding by means of structural interventions. In addition the Flemish government is also developing flood predictors to allow the timely anticipation to potential floods. Considering the diverse effects of the various climate scenarios for Flanders, measures will mainly count in the future if they can offer a response both to flooding and water shortages. Whether a measure is adaptable and useful in different circumstances will determine whether that measure makes a substantial contribution in the adaptation to climate change. An example of this kind of measure is the creation of controlled flood plains along rivers. These plains can reduce the risk of flooding upstream or downstream and could possibly allow the temporary storage of water for use in agriculture in the event of a drought. Other examples include provisions for the storage and infiltration of rainwater in urban areas. These limit the rainwater draining into the sewer system and simultaneously supplement the groundwater. The stimulation of the reuse of purified wastewater is also a possible measure.

Coastal adaptation

The main adaptive measures for the coastal area are raising and broadening the beach through the supply of sand or the reinforcement of the dune bases through planting. These measures could be adjusted at the five-yearly maintenance according to the expected sea level rise. Other possible measures could include constructions to combat erosion for example (such as groynes or breakwaters) or to damp waves.

Recommendations

Public authorities have an important role to play in raising awareness amongst the population and in the adequate adaptation of the infrastructure which it manages in order to overcome the consequences of climate change, regardless of the future scenario which will ultimately prove to be the closest to reality. The communication on interventions that might limit the probability of damage due to climate change and the involvement of all relevant stakeholders in drawing up the plans are necessary in this. The public authorities can also direct policies on urban planning to reduce the consequences of flooding and water shortages. The development of a long-term vision and permit policy (such as building and environmental permits) that does not mortgage the future situation desired is crucial for this. One of the supporting instruments for this would be drawing up a climate adaptation plan by 2012. The European Water Framework Directive and the directive on the assessment and management of flood risks (Floods Directive) oblige member states to draw up management plans that must show that account is taken of the possible consequences of climate change.

Other groups also play an important role in the adaptation to climate change: (re)insurers (e.g. through targeted financial incentives), drinking water companies (e.g. by encouraging rational water consumption and guaranteeing the availability of drinking water), power producers (e.g. by safeguarding energy production) ... It should not only be emphasised here that limited adaptive measures now could avoid excessive costs in the future. It should also clearly be stated what measures would be relevant in concrete cases. This includes short-term actions (e.g. knowing where current information is available on flooding or water shortage in a specific region) and long-term actions (e.g. for rebuilding/renovations).

The impact studies for Flanders clearly show that in addition to flood management, sufficient attention must also be paid to the threat of water shortages. There is currently insufficient attention to these shortages amongst others because they develop gradually and are consequently less visible and more indirect. Low water problems might become more important in this century than the problem of flooding. The government can also give direction in the limitation of the consequences of droughts. Examples include the development of regulations on water capture, standardisation and economic instruments such as water price management in relation to rational water consumption.

END NOTES

1 Water vapour (H_2O) is the main greenhouse gas but its presence in the atmosphere is mainly the result of natural phenomena. It is of little importance when considering the human role in the warming of the Earth.

2 Solely the impact of the potential future climate change was verified. Future changes in land use were not taken into consideration here – unlike in the translation to economic damage.

3 Climate change may influence the quality of the surface water in various ways (e.g. via increased sewer overflows but also due to lower flows in the rivers, higher water temperatures, etc.). The effect on water quality due to an increase in the water temperature is modelled in the 'Surface water quality' chapter.

4 This was only possible for the 67 sub-basins (VHA-zones) and corresponding watercourses in the Flemish inland for which models were available from the Hydraulics Laboratory of the Flemish Government. This primarily relates to navigable watercourses (i.e. large and more downstream watercourses) but also upstream sub-basins as these supply the navigable watercourses.

5 Tentative forecasts state that the area will be ready for commissioning in 2011 (www.gogkbr.be).

LIKE TO KNOW MORE?

If you would like to know more, please consult the scientific report on which this chapter is based:

Willems P., Deckers P., De Maeyer Ph., De Sutter R., Vanneuville W., Brouwers J. & Peeters B. (2009) Climate change and water management. Scientific report, MIRA 2009 & NARA 2009, VMM, INBO, www.milieurapport.be and www.nara.be. (in Dutch)

This chapter is based on the following research projects amongst others:

Research project ADAPT 'Towards an integrated decision tool for adaptation measures - Case study: floods', for Belgian Federal Science Policy Office, Research programme Science for a Sustainable Development, executed by ULB-CEESE, Arcadis Ecolas & UGent , UA-ECOBE, K.U.Leuven-HIVA and ULG-HACH; http://dev.ulb.ac.be/ceese/ADAPT/home.php .

Research project CCI-HYDR 'Climate change impact on hydrological extremes along rivers and urban drainage systems', for Belgian Federal Science Policy Office, Research programme Science for a Sustainable Development, executed by K.U.Leuven – Hydraulics Division and Royal Meteorological Institute of Belgium; http://www.kuleuven.be/hydr/CCI-HYDR.

Research project CLIMAR 'Evaluation of climate change impacts and adaptation responses for marine activities', for Belgian Federal Science Policy Office, Research programme Science for a Sustainable Development, executed by the Management unit of the Mathematical Model of the North Sea, Arcadis Ecolas, UGent, Flanders Hydraulics Research, the Institute for Agricultural and Fishery research and the Maritime Institute of UGent; http://www.arcadisbelgium.be/climar/.

Research project 'Actualisation and extrapolation of the design guidelines for sewer systems (in Dutch: Actualisatie en extrapolatie Code van Goede Praktijk voor ontwerp van rioleringsstelsels)', for Flemish Environment Agency, executed by K.U.Leuven – Hydraulics Division.

Research project 'Adaptation options for the Flemish agricultural sector (in Dutch: Adaptatiemogelijkheden Vlaamse Landbouw)', for the Flemish Department of Agriculture & Fisheries, Monitoring & Study department, executed by K.U.Leuven – Bioengineering faculty.

Research project 'Impact of climate change on high and low flows and on water availability along Flemish rivers (in Dutch: Effect van klimaatwijzigingen op afvoerdebieten in hoog- en laagwatersituaties en op de globale waterbeschikbaarheid)', for Flanders Hydraulics Research (WL) of the Flemish Authorities of Belgium, executed by K.U.Leuven – Hydraulics Division.

Research project 'Climate scenarios for Flanders (in Dutch: Klimaatscenario's voor Vlaanderen)', for the Flemish Institute for Nature and Forest Research (INBO), executed by the Royal Meteorological Institute of Belgium, K.U.Leuven – Hydraulics Division and the Dutch Royal Meteorological Institute (KNMI).

Research project SUDEM-CLI 'The impact of climate change on river hydrology and ecology: case study for interdisciplinary research', for Belgian Federal Science Policy Office, Research programme Science for a Sustainable Development, executed by UA, K.U.Leuven and UCL.

Research project 'Flood damage and risk calculation for MIRA (in Dutch: Risico op schade door overstromingen for MIRA)', for the Flemish Environment Agency, executed by UGent, Geography Research Group.

Project SAFECoast, for Interreg IIIB North Sea, (for Flanders) executed by Flanders Hydraulics Research and the Coast Unit; http://www.safecoast.org/.

Research Training Network SeaMocs 'Applied stochastic models for ocean engineering, climate and safe transportation', for the European Commission, (for Belgium) executed by the K.U.Leuven and KNMI; http://www.maths.lth.se/seamocs/.

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