INTEGRATED ASSESSMENT OF SPATIAL CLIMATE CHANGE IMPACTS IN FLANDERS – MIRRORED TO THE DUTCH EXPERIENCES

VALORISATION PRODUCT 1

(Integratierapport over ruimtelijke effecten van klimaatverandering in Vlaanderen, met een toets vanuit de Nederlandse ervaringen)

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1 SAMENVATTING

INLEIDING

Dit rapport is het eerste valorisatie product (VP1) van het wetenschappelijk project Ccaspar (www.ccaspar.ugent.be) of voluit “Klimaatveranderingen en veranderingen in ruimtelijke structuren”.

CcASPAR is een interdisciplinair wetenschappelijk en strategisch basisonderzoek Project (SBO), gefinancierd door het Agentschap voor Innovatie door Wetenschap en Technologie (IWT).

Dit rapport beschrijft in beknopte vorm de actuele status van de kennis over de ruimtelijke effecten van klimaatverandering in Vlaanderen, gespiegeld aan de Nederlandse ervaringen. De scenario's die gebruikt zullen worden bij de toekomstige werkzaamheden worden weergegeven.

PRIMAIRE EFFECTEN VAN KLIMAATVERANDERING

De stijging van de gemiddelde **temperatuur** in België de vorige eeuw is niet uniform en kwam voor in twee relatief abrupte fasen, er wordt een aanzienlijke stijging gezien rond 1910 en zeer belangrijke verandering aan het einde van 1980. In beide gevallen is een stijging waargenomen van ongeveer één graad. De trend laat zien dat de laatste vorst dag alsmaar eerder komt dan het vorige jaar. Er is geen informatie beschikbaar over de evolutie van de geografische verschillen van de temperatuur in Vlaanderen. Binnen het CCI-HYDR project (http://www.kuleuven.be/hydr/CCI-HYDR.htm) werden scenario's voor de gemiddelde en extreme temperaturen in België ontwikkeld met een tijdshorizon van 2100 (klimaatperiode 2070-2100), gebaseerd op het neerschalen van de Europese klimaat-modellen. Deze scenario's zullen worden gebruikt in Ccaspar. Ondanks de onzekerheden, kan duidelijk worden gezien dat de klimaatverandering voor een zeer aanzienlijke stijging van de temperatuur zal zorgen, met een maximale stijging in de zomer. Regionale scenario’s zullen in Ccaspar worden berekend met behulp van de "perturbationtool", een instrument ontwikkeld in het CCI-HYDR project (Ntegeka et al.., 2009), met behulp van een regionale dataset van het huidige lokale klimaat.

Jaarlijkse **neerslag**metingen door het KMI in Ukkel van 1833 tot 2007 (KMI, 2009) wijzen op een zeer aanzienlijke toename in 1910, gekenmerkt door 7% stijging van de jaarlijkse neerslag. In België zal de verwachte toekomstige evolutie van de neerslag drastisch verschillen tussen winter en zomer. Ongeacht enige verschillen tussen de resultaten van verschillende studies, kan worden geconcludeerd dat de prognoses voor de evolutie van de neerslag in de winter tijdens de 21e eeuw een matige stijging laten zien. De verandering in de zomerneerslag is complexer: er zou minder regen vallen (lagere volumes neerslag in de zomer), maar zware zomerstormen kunnen meer extreem en vaker optreden, hoewel niet alle klimaatmodellen het eens zijn over dit laatste (Ntegeka et al., 2008a , b). Verschillende studies hebben al uitgewezen dat de veranderingen in stormen met hoge intensiteit van neerslag groter zouden zijn dan verwacht op basis van de veranderingen in de gemiddelde neerslag, wat neerkomt op een versterkte reactie (Tank, 2004). De CCI-HYDR scenario's, die zullen worden gebruikt in Ccaspar, geven aan dat de neerslagpatronen verplaatsen in de richting van drogere zomers. Voor de zomer worden echter aanzienlijk verschillende resultaten tussen de regionale en globale klimaat modellen vastgesteld. Aanzienlijke onzekerheden bij de voorspelling van neerslagwijzigingen zijn een gevolg van zowel de grenzen van de hedendaagse modellen en de belangrijke natuurlijke variabiliteit van neerslag, vooral in de zomer (Marbaix en van Ypersele, 2004). De mogelijke verandering in de neerslag toont ook kleine regionale verschillen binnen België. In de kustregio is de wijziging 10% hoger dan in het binnenland, zowel voor de zomerperiode als de winterperiode. Voor de zomer betekent dit dat de daling van de neerslag minder sterk is in de kustregio (het toekomstige klimaat is dichter bij het huidige klimaat). In de winter resulteert dit in een extra toename van de neerslag van 10% in de kustregio (Brouwers et al., 2009).

Als de temperatuur stijgt, neemt ook het proces van **verdamping** toe. Voor elke 1 ° C stijging van de temperatuur op aarde is er een toename met 7% in de vochtcapaciteit van de atmosfeer. Veel meer vocht in de atmosfeer leidt uiteindelijk tot veranderingen in neerslagpatronen. In alle berekenignen van de potentiële evapotranspiratie (PET) wordt een verschuiving naar hogere waarden gedurende het hele jaar verwacht (Baguis et al.., 2009) in de CCI-HYDR scenario's.

In het CLIMAR-project (zie o.a. Ozer et al., 2008; Van den Eynde et al., 2008) werd de trend van het jaarlijkse gemiddelde zeeniveau (MSL) vanaf 1929 tot en met 2001 in Oostende geanalyseerd. De MSL variëren tussen 2,172 m (in 1929) en 2,357 m (in 2001). Hoewel de variabiliteit van jaar tot jaar hoog is, is het zeer duidelijk dat het gemiddelde zeeniveau aanzienlijk is toegenomen tijdens deze periode. Als verschillende relaties (zoals lineaire, tweede en derde graad polynomen) gehanteerd worden voor een extrapolatie van de zeespiegel tot 2100, levert dit absolute waarden tussen 20 cm en 200 cm op voor de **zeespiegelstijging.**

Hoewel de impact van de opwarming van de aarde op het vóórkomen van extreme regionale meteorologische omstandigheden en extreme hydrologische omstandigheden onzeker blijft, is een tendens naar vaker voorkomen van **extreme gebeurtenissen** verwacht, maar nog niet gekwantificeerd (IPCC, 2001b; EMA, 2005a). Een analyse van de windgegevens werd uitgevoerd in het kader van het CLIMAR project, maar leverde geen duidelijke aanwijzingen van veranderingen in windpatronen.

Een lange periode zonder neerslag, of met bijna geen regenval, zal van invloed zijn op verschillende sectoren van onze samenleving. Het concept van droogte is echter niet eenvoudig en gemakkelijk te definiëren. Over een langere periode speelt zeker het regenvaltekort een cruciale rol in de karakterisering van de ernst van de droogte, maar ook andere parameters (zoals wind, temperatuur, hoeveelheid water in de bodem aanwezig) spelen een belangrijke rol. KMI (2009) bestudeerde de evolutie van de langste periode zonder opvallende neerslag gedurende 14 dagen gedurende de 20e eeuw: de trend analyse toont geen significante evolutie van deze parameter in de 20e eeuw. Terwijl en doordat droogte een interpreteerbaar begrip is, afhankelijk van het gebied van onderzoek, zijn er geen "**droogte**" scenario's als zodanig beschikbaar in Vlaanderen. Op basis van onze huidige kennis, werden nog geen scenario studies over droogte-effecten op de geografische schaal van Vlaanderen gerapporteerd, behalve voor laagwater in bevaarbare rivieren (Brouwers et al., 2009). Het concept van droogte, met name in onze twee gevalstudies, zal een onderwerp van onderzoek in WP1 worden.

Rivierafvoeren worden bepaald door vele factoren, zoals klimaat, landgebruik, bodemtype en debietregeling. Dit complexe systeem van een groot aantal factoren zal met elkaar interageren en uiteraard worden beïnvloed door de veranderingen van temperatuur, neerslag en verdamping, als gevolg van klimaatverandering (KINT, 2001). In (Brouwers et al., 2009) werd het effect van door klimaatverandering geïnduceerde neerslagveranderingen op de debieten van rivieren en **overstroming**sfrequentie (met het huidige landgebruik) gesimuleerd voor de bevaarbare rivieren. De resultaten waren verschillend voor winter en zomer: alleen voor het hoogste scenario, is er een duidelijke toename van het overstromingsrisico; voor het laagste scenario is er een duidelijke afname van het overstromingsrisico. De toename van het aantal en de omvang van overstromingen (vooral langs de rivieren in de winter) is relatief beperkt. Piekafvoeren in de rivieren zouden toenemen met een maximum van 35% in het meest ongunstige scenario. Deze stijging kan lokaal leiden tot frequentere en meer uitgebreide overstromingen. In het rapport vermelden we in iets meer detail drie interessante case studies over veranderingen in patronen van overstromingen als gevolg van klimaatverandering, (deels) met landgebruik scenario's en de impact op de waterhuishouding.

SECUNDAIRE EFFECTEN VAN KLIMAATVERANDERING

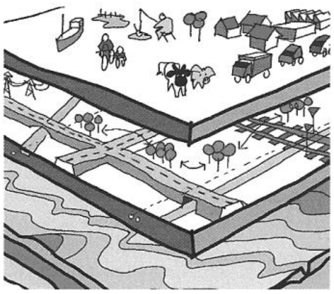
In Ccaspar richten we ons op 3 secundaire effecten van de klimaatverandering met een "**ruimtelijke aard**": de impact op de natuurlijke systemen, de impact op het landschap en de impact op de menselijke activiteiten.

Natuurgebieden in Vlaanderen zijn zeer klein en ingebed in een intensief gebruikt stedelijk of agrarisch landschap. Naast versnippering, veroorzaken ook verdroging en bemesting een afname van de kwaliteit van de leefomgeving. Dit heeft uiteraard negatieve gevolgen voor de biodiversiteit. De extra stress van de klimaatverandering impliceert dat een adequate ruimtelijke aanpassing van het landschap een conditio sine qua non wordt voor het aanpakken van de versnipperingsproblemen. De grote klimaatzones verschuiven en krimpen onder de invloed van een verhoogd broeikaseffect. Vanwege hun beperkte adaptief vermogen, worden veel ecosystemen kwetsbaar bevonden voor deze veranderingen. De aanwezigheid van deze veranderingen is geen probleem op zichzelf. Het wordt echter wel belangrijk bij soorten die geen gelijke tred kunnen houden met de klimaatveranderingen (De Bruyn, 2005). In het algemeen kan men stellen dat met name activiteiten in de lente eerder optreden. Voorbeelden hiervan zijn de bloei van bloemen, leggen van eieren, lente-migratie, ... Een onderzoek naar de migratie van vogels (15 soorten) had als gevolg dat hun eerste aankomstdatum tussen 1985 en 2004 vervroegde met ongeveer 8 dagen. Naast observaties in het voorjaar wordt ook een uitstel van een aantal activiteiten in het najaar opgemerkt. Als gevolg van stijgende temperaturen, verschuiven soorten hun habitats naar het noorden. Inheemse soorten die alleen beperkt aanwezig waren en waarvan de optimale ecologische omstandigheden voornamelijk gelegen waren in de zuidelijke regio's, komen nu zeer vaak voor (bijvoorbeeld bepaalde soorten libellen). Seizoensgebonden en geografische verschuivingen zijn de meest bestudeerde gevolgen van de klimaatverandering in de natuur. Echter zijn er nog meer effecten (De Bruyn, 2005): a) de samenstelling van de gemeenschappen kan drastisch veranderen. Als gevolg hiervan kunnen nieuwe (concurrerende) interacties worden gecreëerd binnen deze gemeenschappen; b) de klimaatverandering kan leiden tot een grote kans op insectenplagen, met een uitzonderlijke omvang van de schade (Gan, 2004; Hodar & Zomaro, 2004); c) hogere frequentie van extreme weersomstandigheden, zoals onweer, kan negatieve gevolgen hebben op het sterftecijfer en de voortplanting.

De Overeenkomst van de Europese Landschapsconventie omschreef het **landschap** als "een gebied zoals waargenomen door mensen, waarvan het karakter het resultaat is van de actie en interactie van natuurlijke en / of menselijke factoren" (Raad van Europa, 2000). Net als Pedroli (2009) kunnen we de effecten van de klimaatverandering in verschillende categorieën onderverdelen. Allereerst hebben we de primaire effecten, zoals de verandering in temperatuur, neerslag en stormen. Deze primaire effecten hebben sommige secundaire gevolgen. Bijvoorbeeld overstromingen, tekort aan water in de bodem, verzilting, enz. In een volgende stadium beïnvloeden deze secundaire effecten natuur, landbouw, recreatie en toerisme, enz. door hittestress, biotische en abiotische kwetsbaarheid (bijvoorbeeld het uitsterven van bepaalde plant of diersoorten), enz. Wanneer we al deze primaire, secundaire en tertiaire effecten optellen, krijgen we het totale effect op het landschap. In het rapport wordt meer detail gegeven over temperatuur, neerslag, verandering in kooldioxide, stormen en verandering van de zeespiegel als factoren die van invloed zijn op het landschap, maar nu een verandering ondergaan door de klimaatverandering. Er is nog quasi geen literatuur beschikbaar die zich specifiek bezighoudt met de gevolgen van de klimaatverandering op het Vlaamse landschap. Het begrijpen van de invloed van de klimaatverandering op het landschap - een holistisch fenomeen – moet noodzakelijkerwijze bestaan uit kennis over de verschillende aspecten van waaruit het landschap is opgebouwd. Al deze landschappelijke elementen zijn niet lineair met elkaar verbonden, maar zijn onderdeel van een complexe entiteit met dynamische interactie tussen de verschillende componenten. Het is heel moeilijk om de effecten van klimaatverandering op bv. een ankerplaats te bepalen. Gezien een ankerplaats bestaat uit verschillende elementen, zoals bossen, meren, landbouwvelden, de specifieke kenmerken van dorpen, etc. moet men de invloed op elk individueel element bestuderen, en niet te vergeten de complexe interacties tussen deze verschillende elementen. Veranderingen in het waterpeil van het meer of rivier kan bijvoorbeeld ernstige gevolgen hebben voor de biodiversiteit, voor de gewassen en zelfs voor de mens. Tot slot kunnen we zeggen dat het niet eenvoudig is om vast te stellen wat de invloed is van klimaatverandering op het landschappelijk erfgoed. Aan de ene kant heb je erfgoedelementen die heel klein zijn, bijv. een eenzame boom, een holle weg, dus op deze schaal ligt het moeilijk om de invloed van de klimaatverandering op het element te begroten. Aan de andere kant hebben we een aantal grote beschermde gebieden waar verschillende elementen communiceren met elkaar en een belangrijke rol spelen. Hier moeten we in het achterhoofd houden dat de verschillende effecten elkaar kunnen beïnvloeden.

In de derde paragraaf van dit hoofdstuk worden de relevante potentiële secundaire effecten van klimaatverandering (PSIcc) op de structuur van **de menselijke activiteiten** (SHA) in de ruimtelijke ordening besproken. De structuren van menselijke activiteit zijn vastgelegd in het Ruimtelijk Structuurplan Vlaanderen voor de periode 2002-2007 (RSV, 2004) als: stedelijke gebieden (en stedelijke netwerken), platteland (niet-stedelijke gebieden), de sectoren van economische activiteit en de lijninfrastructuren. Er zijn enkele belangrijke vertrekpunten om de Vlaamse SHA te beschrijven in relatie tot de mogelijke effecten van klimaatverandering. Ten eerste, Vlaanderen maakt deel uit van een internationale delta, wat betekent dat er een specifieke watergerelateerd fysische systeem is. Ten tweede, Vlaanderen heeft een unieke gefragmenteerde ruimtelijke structuur door de verspreide SHA over het hele grondgebied. Als gevolg daarvan, ten derde, deze ruimtelijke morfologie heeft een hoog mobiliteitgedreven karakter en genereert veel netwerken (bijvoorbeeld wegen, spoorwegen, elektriciteitsnetten, riolering, …). We concluderen dat deze onderliggende structuur met een watergerelateerde en uitgebreid nederzettingspatroon bepalend is voor de mogelijke gevolgen van klimaatverandering voor Vlaanderen. Daarnaast concluderen we dat de secundaire effecten optreden wanneer de primaire effecten in contact treden met gevoelige - in het geval van WP4- SHA. De effecten kunnen een impact hebben op zowel de bebouwde structuur zelf (bijv. wegen die verschuiven onder de invloed van temperatuur) als over de werking van de structuur (bijv. files wanneer het sneeuwt, onbereikbare fabriek door een overstroming). Daartoe is een raamwerk uitgewerkt over de bebouwde structuur en het functioneren van deze structuur die verder zal toegepast worden in Ccaspar.

STRUCTUUR

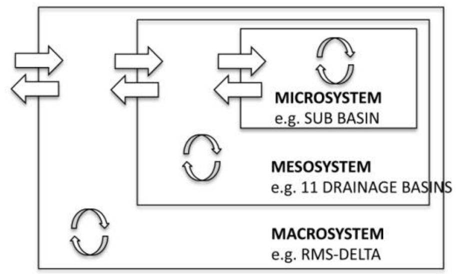


3. Bezetting: Structuren die een hoge mate van verandering hebben, zijn veranderingen die vooral plaats vinden binnen een generatie (10 tot 40 jaar)

2. Netwerken: Structuren die hoge initiële kosten en lange levensduur hebben, belangrijke veranderingen in deze lagen duren ongeveer 20 tot 80 jaar

1. Substraat: Structuren die een lange geschiedenis hebben en kwetsbaar zijn, belangrijke veranderingen vereisen al snel meer dan een eeuw

FUNCTIONERING



Figuur 1 - Links: De lagenbenadering deelt de bestaande ruimte in in 3 lagen met een andere tijdsschaal (Mirup, 2003)

Aanvullende informatie over stedelijke gebieden en potentiële effecten (bv. stedelijk hitte-effect) kan teruggevonden worden in dit rapport.

VERWACHTE ONTWIKKELING VAN DE SOCIAAL-ECONOMISCHE VARIABELEN

Toekomstige kwetsbaarheid kan niet voorspeld worden uitsluitend op basis van de klimaatscenario's, veranderingen in de **sociaal-economische omstandigheden** dragen ook bij (Ribeiro et al., 2008). Scenario's zijn een gebruikelijk instrument om mogelijke toekomsten te illustreren. Aangezien we niet kunnen weten wat de toekomst inhoudt, kan dit instrument u helpen om mogelijke veranderingen van de huidige situatie in de toekomst mogelijk zijn. De voorspelling van de sociaal-economische scenario's is niet makkelijk want het is een gevolg van een zeer complexe set van aansturende factoren. De recente financiële crisis bijvoorbeeld heeft eens te meer aangetoond dat dergelijke onverwachte gebeurtenissen met een enorme impact op de socio-economische situatie in de wereld kunnen voorkomen en moeilijk te voorspellen zijn. Twee omstandigheden kunnen worden beschouwd, bij het maken van de voorspellingen, ten eerste een gemiddelde of meest waarschijnlijke scenario, gebaseerd op de meest redelijke evolutie van de relevante sociaal-economische indicatoren. Een ander zou het worst case scenario van de evolutie van de sociaal-economische samenleving zijn, dat wil zeggen met de meest verwoestende effecten voor een bepaald beleidsterrein; een dergelijk scenario is zeker van belang bij beleidsoefeningen op een langere tijdschaal.

Als het gaat om globale (of nationale) sociaal-economische **scenario's**, worden een aantal klassieke belangrijke parameters meestal beschouwd (zie Berkhout en Van Drunen, 2007). De eerste is de economische ontwikkeling, meestal met inbegrip van de mate van ontwikkeling (bv. groei van het BBP) en de aard van de economie in termen van de handelsstromen en overheidsregulering en de levering van diensten (bijv. geglobaliseerde versus regionale economie, open versus gereguleerde economie). De tweede dimensie is de aard van bestuur. Dit is meestal gerelateerd aan de relatieve invloed van de nationale regeringen ten opzichte van internationale organisaties (bijv. VN, EU) en eventuele particuliere bedrijven (multinationals). De derde dimensie heeft betrekking op technologische veranderingen.

Scenario's worden vaak gebruikt als een manier om te gaan met **onzekerheid**. In een dergelijk geval wordt geen uniek scenario van de toekomst beschouwd, maar meerdere scenario's worden onderzocht die samen een breed scala van mogelijke toekomsten vormen (Van Drunen en Berkhout, 2009). Een ander belangrijk begrip is dat de scenario's vaak gebaseerd zijn op de extrapolatie van de huidige trends. De extrapolatie houdt in dat eventuele discontinuïteiten (onverwachte gebeurtenissen of veranderingen veel sneller dan op dit moment) niet worden beschouwd. Dergelijke onverwachte gebeurtenissen (bijvoorbeeld natuurrampen, financiële middelen, enz.) kunnen een grote invloed hebben op de samenleving en zijn vaak belangrijke drijfveren voor verandering.

Onlangs heeft de Milieuverkenning 2030 (Van Steertegem Ed., 2009), de Natuurverkenning 2030 (Dumortier uitg., 2009) en de onderliggende studies van het Federaal Planbureau (Hertveldt, 2009) prognoses ontwikkeld voor een aantal sociale, economische en ecologische indicatoren voor het jaar 2030 (en deels tot 2060). De belangrijkste conclusies van deze studie zijn opgenomen in dit verslag en vergeleken met de Nederlands-WLO-scenario's op regionale geografische schaal voor het jaar 2040 (WLO, 2006). Demografische en sociaal-economische trends worden voorgesteld in dit rapport. Bovendien graaft het verslag in het beperkte aantal van beleidsoefeningen die zijn uitgevoerd voor de toekomstige ruimtelijke ontwikkeling in Vlaanderen in 2030.

Niettemin is er behoefte aan een **lange termijn indicatie** van verandering in sociaal-economische variabelen. Dit is vooral het geval in de effectbeoordelingen t.o.v. van klimaatverandering want de gevolgen van klimaatverandering worden waarschijnlijk beperkt in de komende decennia, maar zullen des te meer uitgesproken zijn in de tweede helft van de 21e eeuw. Bovendien, het verschil tussen de scenario's voor klimaatverandering is ook beperkt voor de komende decennia (mede omdat een derde van de opwarming halverwege deze eeuw zal te wijten zijn aan al veroorzaakte klimaatverandering). We brengen ten eerste verslag uit over de werkzaamheden die zijn uitgevoerd in Nederland in dit opzicht. Twee voorbeelden uit Nederland zijn onder andere een studie van Jonkhoff et al. (2008) en Van der Hoeven et al. (2008). Beide studies proberen de evaluaties over de impact van de klimaatverandering te ondersteunen door extrapolatie van bepaalde parameters van de WLO-scenario's tot 2100. Resultaten van studies in België zijn schaars. Het Federaal Planbureau is overgegaan tot een lange termijn prognose van demografische parameters naar het jaar 2060, als onderdeel van een studie over de vergrijzingsproblematiek (Federaal Planbureau, 2008). In het CLIMAR-project is een andere poging gedaan maar de resultaten waren nog niet publiek op het tijdstip van sluiting van dit verslag. Het eindresultaat van een lange termijn sociaal-economische scenario moet worden gezien als een "wat-als" : "als deze omstandigheden heersen in 2100, zal dit resulteren in een dergelijke situatie". Gezien dit beperkingen oplegt, worden lange-termijn scenario's dan ook waarschijnlijk het best gebruikt om de (brede) bandbreedte van mogelijke toekomsten te illustreren, en niet zozeer om individuele scenario's te verkennen en hieraan een bepaald belang te hechten.

Scenario's in CCASPAR

In een vijfde en laatste hoofdstuk wordt een overzicht gegeven van de klimaatverandering en sociaal-economische scenario's die in de Ccaspar project worden gebruikt door de verschillende werkpakketten.

Het is belangrijk op te merken dat er niet zoiets is als "een goed scenario." Het is ook niet exact te concluderen dat het "-scenario in het midden" meer waarschijnlijk is en dus een betere keuze dan een "minimum of maximum"-scenario. Het is belangrijk om zich af te vragen welke effecten u wilt bestuderen: bijvoorbeeld als u meer geïnteresseerd bent in droogte-problemen, is het interessant om scenario's te overwegen met een meer extreme verstoring van de waarden van de temperatuur en een sterkere toename van de evapotranspiratie, ...

Een belangrijk element van het Ccaspar project is echter dat we ons niet beperken tot "algemeen aanvaarde of waarschijnlijk" scenario's. Algemene scenario's moeten ook worden durven doorvertaald worden naar meer extreme verhaallijnen voor toepassing in bijvoorbeeld gevoeligheids- en kwetsbaarheidskaarten. De tijdshorizon is immers bepalend voor de haalbaarheid van een duurzame oplossing.

2 INTRODUCTION

2.1 Aim of this report

This report is the first valorisation product (VP1) of the scientific project Ccaspar (www.ccaspar.ugent.be) Climate Changes and Changes in Spatial Structures.

CcASPAR is an inter-disciplinary academic and Strategic Basic Research Project (SBO) financed by the Agency for Innovation by Science and Technology (IWT).

This report describes in a concise form the actual status of knowledge on the spatial impacts of climate change in Flanders, mirrored to the Dutch experiences. The scenarios that will be used in future work are reported. The report does not make an attempt to gather all relevant references or literature sources or act as a complete overview of the state-of-the-art literature. The report focuses on results with use value within the Ccaspar project.

2.2 Climate change adaptation as a response to a global challenge

Carbon dioxide (CO_2) is an unavoidable waste product from the combustion of fossil fuels, which has been emitted into the atmosphere in increasing quantities since the industrial revolution. It significantly raises the average temperature and affects the climate.

The concentration of CO_2 has risen by 30% in roughly 250 years. In order to try to determine the possible consequences of increasing greenhouse effect, the United Nations set up the Intergovernmental Panel on Climate Change (IPCC) in 1988, grouping most of the world's specialists in a rigorous process of expert assessment. The IPCC makes climate change projections based on different socioeconomic scenarios and the outcome of different climate models and other research is analyzed.

Although many uncertainties persist, the work of the IPCC has led to a number of convincing conclusions. In particular, with regard to man's impact on the climate: "*Most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations*".

As shown in Figure 1, IPCC also confirms that it has increased confidence in the capacity of models to project future climatic trends. Having considered the results of all the models and scenarios, the IPCC projects an average global rise in temperature of 1.4 to 5.8°C for the period 1990-2100. The temperature has never risen as quickly over the last 10,000 years at least and the temperatures feared for 2100 have probably never been reached long before mankind.

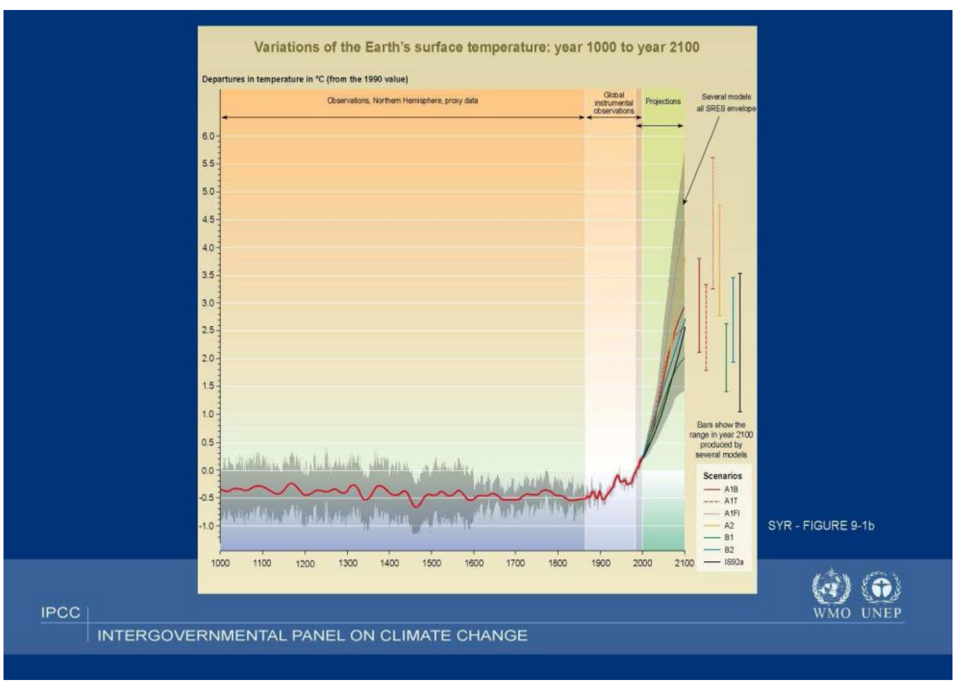


Figure 1 Evolution of the average world temperature between 1000 and 2100 (IPCC, 2001c)

A rise in temperature is not the only sign of climate change. The IPCC projections show a tendency towards increased precipitation, with considerable disparities according to the season and region.

Another consequence is sea level rise, following the thermal expansion of water bodies on the one hand, and the melting of glaciers as well as the ice sheets of Greenland and the Antarctic, on the other. Considerable uncertainty surrounding this subject remains with a projected rise in ocean levels ranging between 9 and 88 cm for the period 1990-2100.

Together, the warming and melting of continental ice sheets would have the capacity to increase the average sea level by up to 8 m over the next 1,000 years in an "average" scenario. Finally, climate change could cause major "surprises" such as a change in ocean circulation with the probable halting of the Gulf Stream, which would reduce global warming at our latitudes and could lead to a possible cooling in Northern Europe. The shutdown of the Gulf Stream does not figure in the projections between now and 2100, but current knowledge does not permit this possibility to be excluded in the longer term.

The United Nations Framework Convention on Climate Change (UNFCCC) identifies two responses to climate change: mitigation of climate change by reducing greenhouse-gas emissions and enhancing sinks, and adaptation to the impacts of climate change. Most industrialized countries have committed themselves, as signatories to the UNFCCC and the Kyoto Protocol, to adopting national policies and taking corresponding measures on the mitigation of climate change and to reducing their overall greenhouse-gas emissions (United Nations, 1997).

An assessment of current efforts aimed at mitigating climate change, as presented by the Working Group III Fourth Assessment Report (WGIII AR4), Chapter 11 (Barker et al.,2007), shows that current commitments would not lead to a stabilization of atmospheric greenhouse-gas concentrations. In fact, according to the Working Group I Fourth Assessment Report (WGIAR4), owing to the lag times in the global climate system, no mitigation effort, no matter how rigorous and relentless, will prevent climate change from happening in the next few decades (Christensen et al., 2007; Meehl et al., 2007).

Adaptation is therefore unavoidable (Parry et al., 1998). Chapter 17 of IPCC fourth assessment report presents examples of adaptations to climate change that are currently being observed, but concludes that there are limits and barriers to effective adaptation. Even if these limits and barriers were to be removed, however, reliance on adaptation alone is likely to lead to a magnitude of climate change in the long run to which effective adaptation is no longer possible or only at very high social, economic and environmental costs. For example, Tol et al. (2006) show what would be the difficulties in adapting to a five-meter rise in sea level in Europe. It is therefore no longer a question of whether to mitigate climate change or to adapt to it. Both adaptation and mitigation are now essential in reducing the expected impacts of climate change on humans and their environment (IPCC, IVth Assessment Report, 2007).

2.3 Impacts of climate change on global and European level

Many areas in the world are already struggling today with the adverse effects of an increase in global average temperatures of 0,76 °C since 1850. Without an effective global climate change mitigation policy, best estimates for global warming in the 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 4AR, Working Group I, 2007) range from 1.8°C to 4°C compared by 2100 to 1990 levels. This is three to six times the temperature increase the globe has experienced since pre-industrial times. Even the low end of a business as usual scenario would take the temperature rise since pre-industrial times above 2°C. Over the last three decades climate change has already had a marked influence on many physical and biological systems worldwide:

- Water: Climate change will further reduce access to safe drinking water. Glacier melt water
- currently supplies water to over a billion people; once it disappears, populations will be under pressure and are likely to migrate to other regions of the world, causing local or even global upheaval and insecurity. Although total precipitation would increase, drought-affected areas are likely to increase due to more irregular rainfall patterns and longer periods without rainfall.
- Ecosystems and biodiversity: Approximately 20 – 30 % of plant and animal species assessed so far are likely to be at increased risk of extinction if increases in global average temperature exceed 1.5 – 2.5°C.
- Food: Climate change is expected to increase the risk of famine; the additional number of people at risk could rise to several hundred millions.
- Coasts: Sea level rise will threaten the Nile delta, the Ganges/Brahmaputra delta and the Mekong delta and displace more than 1 million people in each delta by 2050. Small Island states are already affected.
- Health: Climate change will have direct and indirect impacts on human and animal health. The effects of extreme weather events and an increase in infectious diseases are amongst the most important risks to be taken into account. Climate sensitive diseases are among the most deadly worldwide. Diarrhoea, malaria and protein-energy malnutrition alone caused more than 3.3 million deaths globally in 2002, with 29 % of these deaths occurring in Africa.

The effects of climate change in Europe and the Arctic are already significant and measurable. Climate change will heavily affect Europe's natural environment and nearly all sections of society and the economy. Because of the non-linearity of climatic impacts and the sensitivity of ecosystems, even small temperature changes can have very big effects. Europe has warmed by almost 1°C in the last century, faster than the global average. A warmer atmosphere contains more water vapour but new precipitation patterns differ strongly from one region to another. Rainfall and snowfall has significantly increased in northern Europe, whereas droughts are more frequently observed in Southern Europe. Recent temperature extremes, such as the record-breaking 2003 summer heat wave are consistent with man-made climate change. While single weather events cannot be attributed to a single cause, statistical analyses have shown that the risk of such events has already increased considerably as a consequence of climate change. There is overwhelming evidence that almost all natural, biological and physical processes (e.g. trees are blossoming earlier, glaciers are melting) are reacting to climatic changes in Europe and worldwide. More than half of Europe’s plant species could be vulnerable or threatened by 2080. The most vulnerable areas in Europe are as shown in Figure 2 and Figure 3.

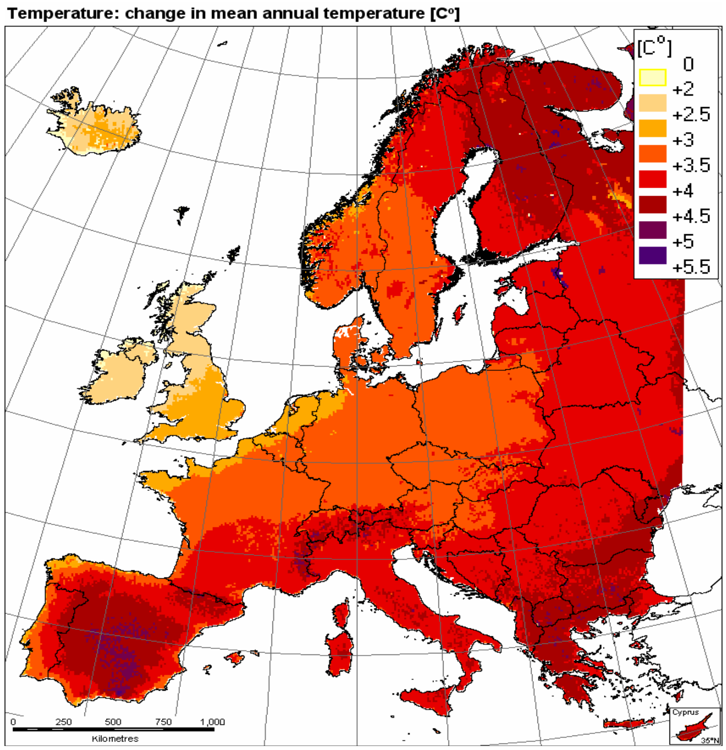


Figure 2 Change in mean annual temperature by the end of this century (European Commission, 2007)

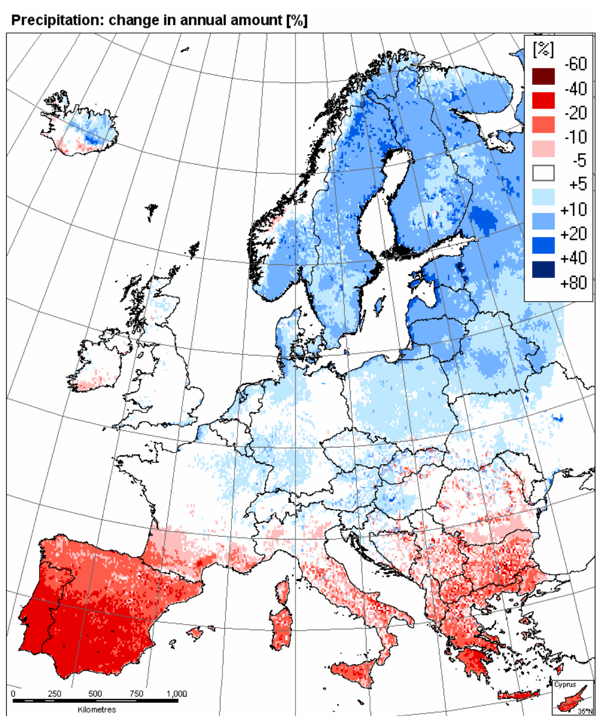


Figure 3 Change in mean annual precipitation by the end of this century (European Commission, 2007)

- Southern Europe and the entire Mediterranean Basin due to the combined effect of high temperature increases and reduced precipitation in areas already coping with water scarcity.
- Mountain areas, in particular the Alps, where temperatures increase rapidly leading to widespread melting of snow and ice changing river flows.
- Coastal zones due to sea level rise combined with increased risks for storms.
- Densely populated floodplains due to increased risks for storms, intense rainfall and flash floods leading to widespread damages to built-up areas and infrastructure.
- Scandinavia where much more precipitation is expected and a larger part in the form of rain instead of snow.
- The Arctic region where temperature changes will be higher than in any other place on Earth.

Many economic sectors depend strongly on climatic conditions and will feel the consequences of climate change on their activities and businesses directly: agriculture, forestry, fisheries, beach and skiing tourism, and health. Reduced water availability, wind damages, higher temperatures, increased bushfires and greater disease pressure will lead to damage to forests. Increase in frequency and intensity of extreme events such as storms, severe precipitation events, sea floods and flash floods, droughts, forest fires, landslides cause damage to buildings, transport and industrial infrastructure and consequently impact indirectly on financial services and insurance sectors. Even damage outside the EU could significantly

affect its economy, e.g. reduced timber supply to European processing industries. Changing climate conditions will for instance affect the energy sector and energy consumption patterns in several ways:

- In regions where precipitation will decrease or where dry summers will become more frequent, water flow for cooling of thermal and nuclear power plants and for hydropower production will reduce. The cooling capacity of water will also decrease because of the general warming of water and discharge thresholds may be crossed.
- River flow regimes will be altered due to changed precipitation patterns and in mountain areas due to reduced ice and snow cover. Silting of dams for hydropower may accelerate due to increased risks of erosion.
- Demand for heating will drop but the risk of power disruptions will raise as summer heat pushes up demand for air-conditioning resulting in an increased demand for electricity.
- Increased risk for storms and floods may threaten infrastructure of the energy sector and other sectors.

Major transport infrastructure with long lifetimes such as motorways, railways, waterways, airports, ports and railway stations, its functioning and related means of transport are weather and climate sensitive and therefore affected by a changing climate. For example:

- Sea-level rise will reduce the sheltering effect of breakwaters and quays wall.
- Risks for damage and disruption due to storms and floods but also due to heat waves, fires and landslides are generally expected to increase (European Commission, 2007).

A number of studies have reported significant changes in climate and associated effects all over the world. Examples of observed and projected changes in Europe are provided in Table 1.

Table 1 Observed and projected climate changes (EEA, 2007)

Climate variable	Observed change	Projected change (without mitigation)	References
Temperature	Global: increase 0.76 °C in last 100 years 1990s warmest decade for 150 years; 1998 and 2005 warmer than any individual year since 1850	Global: best estimated increase 1.8–4.0 °C during this century (range 1.1–6.4 °C)	IPCCa,b, 2007;
	Europe: increase 1.1 °C, winters increase more than summer, largest increase over Iberian Peninsula, south-east Europe and Baltic States	Europe: mean increase 2.1–4.4 °C by 2080 (range 2.0–6.2 °C) with larger increases in eastern and southern Europe.	EEA, 2006; Schröter, 2005.
Precipitation	Global: trends highly variable in space and time have been observed during the last century Northern Europe: 10–40 % more precipitation South and east Europe: 20 % less precipitation	Northern Europe: annual precipitation increase 1–2 % per decade. Decrease in summer precipitation Southern Europe: Overall decrease in annual precipitation. 5 % decrease in summers.	IPCCa,b, 2007; JRC, 2005; Klein Tank *et al.*, 2002.
Extremes	Temperature extremes are more intense and more frequent than some decades ago	Heat waves are expected to increase in frequency and severity in a warmer world	Klein Tank, 2004; Meehl and Tebaldi; 2004, Moberg and Jones, 2005; Stott *et al.*, 2004.
	Globally, more intense and longer dry periods Significantly more wet days in mid and northern Europe, fewer wet days in southern Europe More heavy rain events in most parts of Europe, strongly linked to the North Atlantic Oscillation Increasing trend in consecutive dry days	More frequent extreme precipitation events in entire Europe. Northern Europe: more frequent summer droughts, despite more intense precipitation events during these periods. Southern Europe: more droughts in all seasons.	Alexander *et al.*, 2006; Frei *et al.*, 2006; Haylock and Goodess, 2004.
Sea level	Sea levels rose by 0.17 m during 20th century 1.8 mm year^{-1} 1961–2003 3.3 mm year^{-1} 1993–2003	0.2–0.6 m by 2100. Increased Greenland-Antartic melt may add 0.1–0.2 m to this Larger values can not be excluded (due to factors not yet sufficiently understood)	IPCCa,b, 2007.

3 PRIMARY IMPACTS OF CLIMATE CHANGE

3.1 Temperature

3.1.1 Average temperature

The average surface temperature has increased by about 0.95°C in the last 100 years for Europe with the 1990's being the warmest decade in the instrumental record. From different models and for various scenarios, which provide input for impact studies, a global average temperature rise from 1.4 to 5.8 °C is calculated for the 1990-2100 period with an average increase of 3°C.

Figure 4 shows the evolution of the average annual temperature at Ukkel (Belgium) between 1833 and 2007 (KMI, 2009). The increase in temperature is not uniform and it occurred in two relatively abrupt stages, considerable increase is seen around 1910 and very significant change at the end of 1980. In both cases, the increase observed was about one degree. The different periods of relative stability are shown by horizontal segments for each period.

From seasonal temperature trends it can be observed that the average temperature in winter and spring shows very abrupt remarkable warming around 1910 and at the end of 1980. The summer and autumn temperature also shows two very remarkable periods of warming at around 1925 -1930 and at the beginning of the 1980. The data analysis performed by KMI for other stations, digitized from the mid-1950s shows a rising trend after 1980. It was observed that 2007 was the warmest year since the KMI started taking observations at Ukkel.

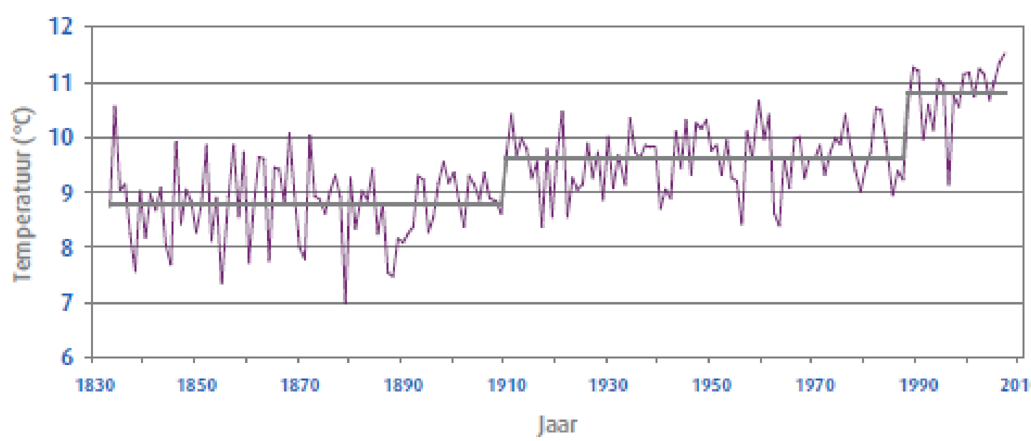


Figure 4 Average annual temperature (in ° C) at Ukkel from 1833-2007. The red curve shows the annual values and the black horizontal lines shows the different periods of relative stability for each period (KMI, 2009)

3.1.2 Extreme temperatures

The increase in minimum temperatures during the 20th century is reflected in the data of the first and the last frost day in the course of a year (KMI, 2009). Figure 5 shows the evolution of the last frost day at the end of the winter from 1901-2007. The trend shows that the last frost day is coming earlier than expected every year. The statistical analysis of the observations shows two remarkable drops, the first abrupt change around 1930 and the second one in 1980.

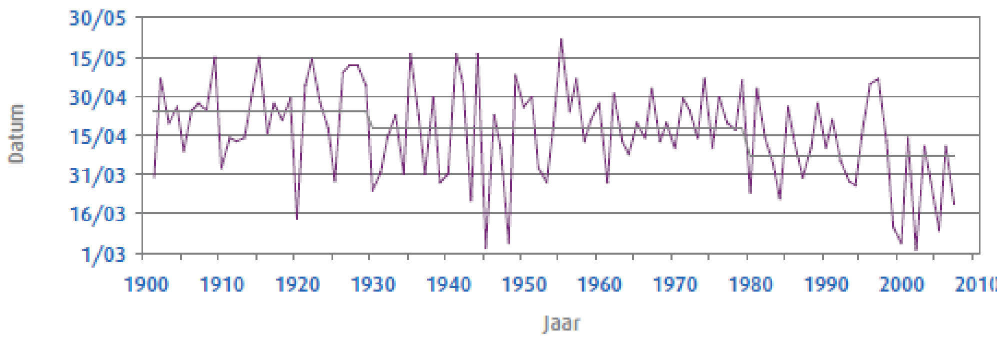


Figure 5 Date of last frost day (minimum temperature below 0 °C) at the end of winter in Uccle between 1901 and 2007(KMI, 2009)

Similarly data for the first frost day is also analyzed and Figure 6 shows the annual trend of the date of the first frost day at the start of winter which is also consistent with the rise in temperatures from 1901 through 2007. It can be clear from the plot that there is a relatively abrupt and remarkable jump in 1955, based on the statistical analysis.

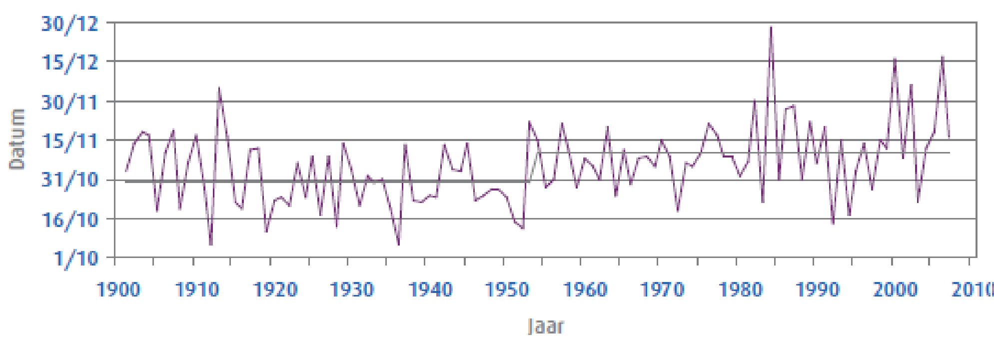


Figure 6 Date of first frost day (minimum temperature below 0 °C) at the beginning of winter in Uccle between 1901 and 2007 (KMI, 2009)

3.1.3 Geographical differences

The historical data analysis in (KMI, 2009) was only reported for the station of Ukkel (Sint-Joost-ten Node before 1886), as this is the only station with a very long series of measurements in comparable conditions.

Hence no information is available on geographical differences of temperature evolution within Flanders.

3.1.4 Scenario's

Climate scenarios are projections that try to give a consistent and coherent picture of possible future climate. But they are no long-term weather forecasts. In that sense they do not make a statement about the weather on a given day, one month or one year, but only about averages and the probability of extremes in the future. The climate scenarios may thus provide a picture of changes in temperature, precipitation, wind and other climatic variables for climate period of 30 years (KMI, 2009).

3.1.4.1 General scenario's for Flanders

Within the CCI-HYDR project (http://www.kuleuven.be/hydr/CCI-HYDR.htm) scenario's for temperature in Belgium were developed with a time horizon of 2100 (climate period 2070-2100), based on downscaling of European climate models.

Figure 7 shows the temperature trends based on the CCH-HYDR scenarios (high, mean and low) which all indicate an increase in average monthly temperature in Uccle. The climate reference frame from 1961 to 1990 is used for generating scenarios for the period from 2071 to 2100 (Baguis et al., 2009). The figures on temperature increase for the three scenario's are given in Tables 2-4, together with the precipitation scenarios.

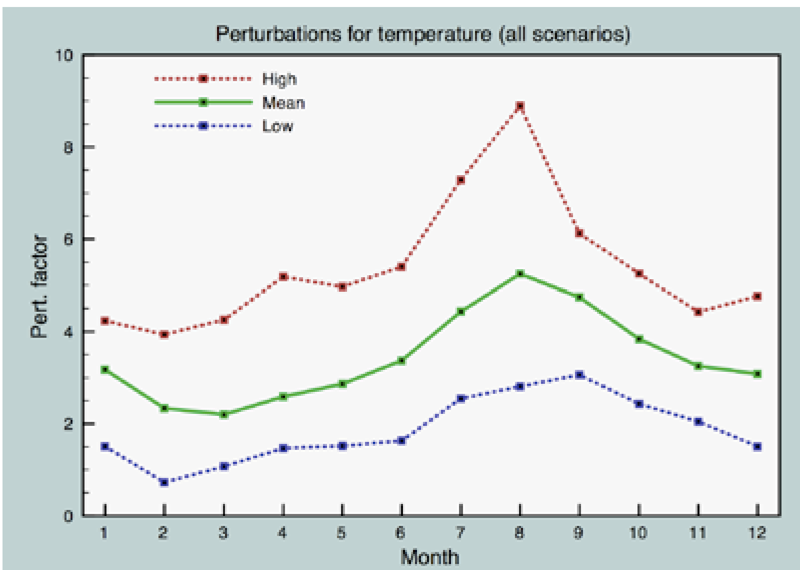


Figure 7 Increase in average monthly temperatures in Uccle for the CCI -HYDR climate scenarios, reference period 1961-1990 to the scenario period 2071-2100 (Baguis et al., 2009)

It is apparent from Figure 7 that the highest increase in temperature is observed in the month of August (more than 8 degree C). It shows a rising trend for every season with steep increase during the summer months.

The “uncertainty” between the different scenario’s is quite large. For instance, in the month of January, the increase in temperature for the low scenario is 1.5 and for the high scenario the value is 4.2 ^{o}C. This corresponds to an "uncertainty band" of 2.7 ^{o}C. In August this band gets wider with a width of 6.1 ^{o}C. Despite of these uncertainties, it can be clearly seen that the climate change signals for a very significant increase in temperature.

Increase in temperature is also analyzed for the 10% and 90% percentile to observe the impact of climate change on extreme temperature days (hot or cold days). The 10% percentiles are the values that match the 10th percentile of the coldest day as shown in

Figure 8. For the 10% percentile, the largest increase is observed for the winter and autumn. The effect of this increase is a drastic decrease in the number of frost days.

For the 90% percentile as shown in

Figure 9, the strongest increase is observed for the summer which means that the summers are going to be much warmer than today (Baguis et al., 2009).

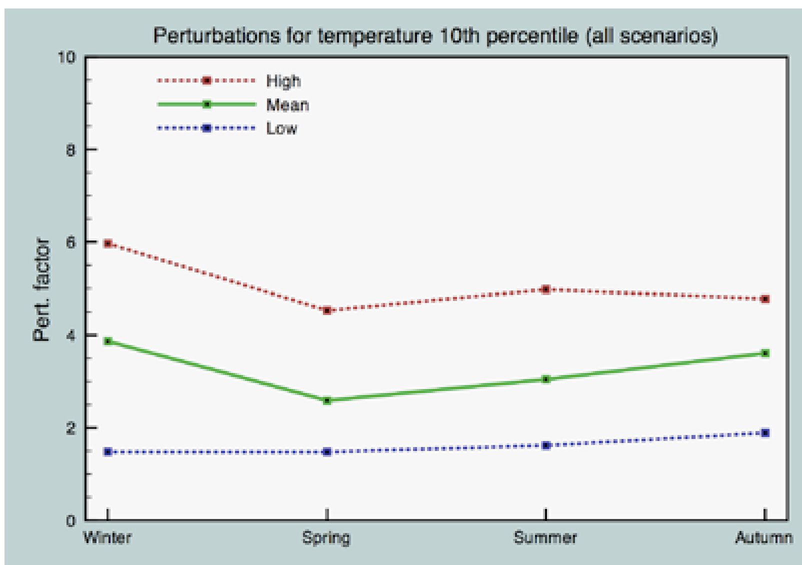


Figure 8 Increase in the 10% percentile of the monthly average temperature at Ukkel for CCI-HYDR climate scenarios, reference period from 1961-1990 and scenario period from 2071-2100 (Baguis et al., 2009)

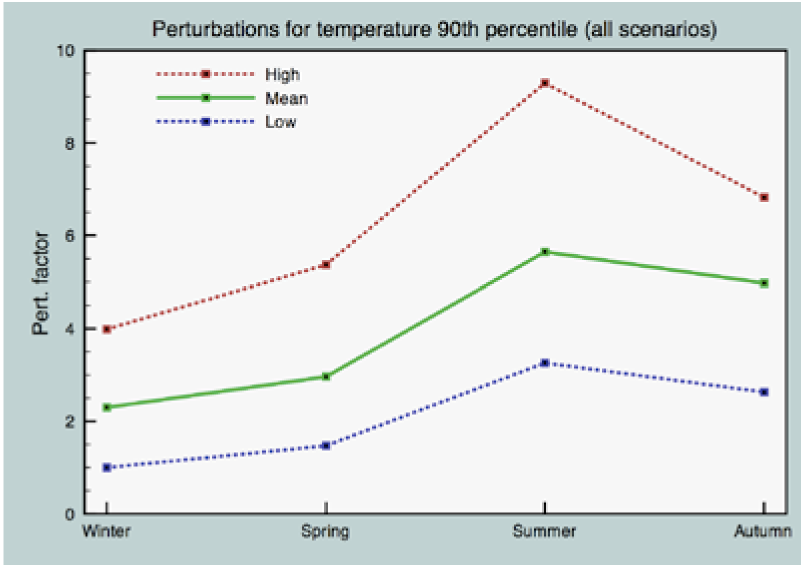


Figure 9 Increase in the 90% percentile of the monthly average temperature at Ukkel for CCI-HYDR climate scenarios, reference period 1961-1990 and scenario period 2071-2100 (Baguis et al., 2009)

Table 2 Values for the 3 scenario's of monthly average temperature at Ukkel for CCI-HYDR climate scenarios, reference period 1961-1990 and scenario period 2071-2100 (Baguis et al., 2009)

Low	Mean	High
1.508	3.175	4.233
0.726	2.337	3.939
1.072	2.198	4.255
1.467	2.586	5.182
1.517	2.864	4.97
1.629	3.371	5.4
2.546	4.435	7.288
2.81	5.246	8.892
3.062	4.745	6.124
2.431	3.84	5.251
2.047	3.253	4.426
1.504	3.082	4.768

Table 3 Values for the 3 scenario's of the 10% percentile temperature per season at Ukkel for CCI-HYDR climate scenarios, reference period 1961-1990 and scenario period 2071-2100 (Baguis et al., 2009)

	All scenarios		
Season	Low	Mean	High
Winter	1.481	3.868	5.966
Spring	1.479	2.59	4.53
Summer	1.62	3.044	4.979
Autumn	1.889	3.61	4.781

Table 4 Values for the 3 scenario's of the 90% percentile temperature per season at Ukkel for CCI-HYDR climate scenarios, reference period 1961-1990 and scenario period 2071-2100 (Baguis et al., 2009)

	All scenarios		
Season	Low	Mean	High
Winter	1	1.952	3.52
Spring	1.472	2.434	3.748
Summer	3.259	4.704	6.039
Autumn	2.63	3.911	4.917

3.1.4.2 Regional scenarios

Regional scenarios can be calculated using the "perturbation tool" , an instrument developed in the CCI-HYDR project (Ntegeka et al., 2009), if a regional dataset for the local climate is available. We will present results for the case studies of the Campine Region and the Coast in chapter 5.

3.2 Precipitation

3.2.1 Average Precipitation

Historical records in Europe reveal very different regional evolutions in annual precipitation. The precipitation has increased in northern Europe by 10 to 40% while in southern Europe it has decreased by 20% from 1900 to 2000 (EEA, 2005a).

In Belgium, expected future evolution of precipitation varies drastically between winter and summer time. Regardless of some differences between the results from various studies, it can be concluded that projections for the evolution of winter precipitation during the 21st century show a moderate increase. A study (Beersma, 2004) mentions an increase of winter precipitation by 3-13% in 2050 (Floodsite, 2006).

The change in summer precipitation is more complex: there would be less rain (lower precipitation volumes in the summer) but the severe summer storms can be more extreme and more common, although not all climate models agree on the latter (Ntegeka et al, 2008a, b). Summer precipitation would decrease by maximum 3% or remain constant (d'Ieteren et al., 2004). Such a possible decrease in precipitation combined to an increase in temperature would lead to losses of availability of water. (Adapt, 2008). The rainfall and their evolution are interesting for many sectors, such as those dealing with the occurrence of high tides and floods, the sizing of the sewerage networks, supply of drinking water and agriculture.

A recent thorough overview of the climate change effects in Flanders on precipitation and other water management related indicators is given in (Brouwers et al., 2009).

Figure 10 shows a plot of the annual rainfall measurements taken by KMI at Ukkel from 1833 till 2007 (KMI, 2009). It indicates a very significant increase in 1910, characterized by 7% increase in the annual rainfall. An increase of approximately 15% i.e. about 760 mm to 810 mm per year was observed for the winter and spring precipitation.

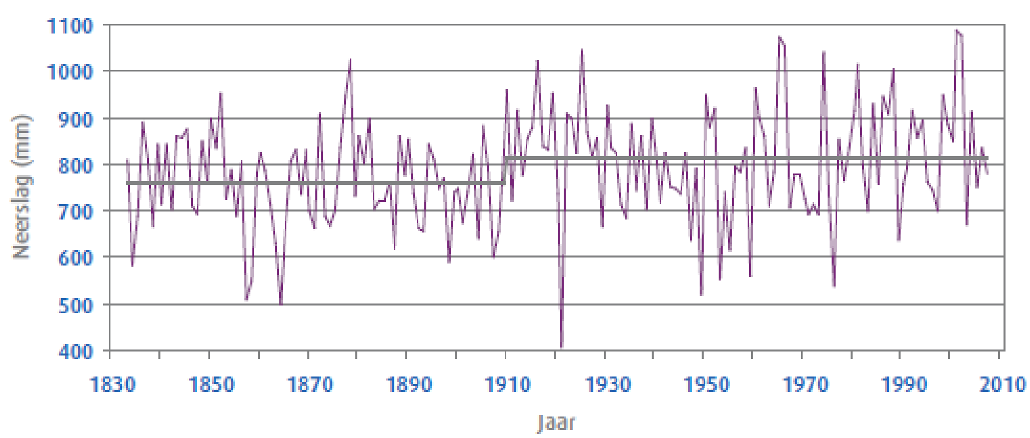


Figure 10 Annual rainfall at Sint-Joost-ten-Node/Ukkel for the period of 1833-2007 (KMI, 2009)

3.2.2 Extreme Precipitation

Storm frequencies have increased in recent decades, but recorded storm intensities are no higher than they were in the early 20th century (IPCC, 2001b). In many European regions, the future trend towards extreme rainfall is also expected to be more pronounced than the average change. Several studies have already revealed that for wet areas, the changes in the high intensity events are larger than expected on the basis of the changes in the average precipitation amounts, implying an amplified response of the wet extremes (Tank, 2004).

In order to get a better picture on whether the frequency of heavy rainfalls is expected to rise in Belgium or not, additional studies will be required to quantify the evolution (Commission Nationale Climat, 2006). According to Können (2001), in 2100, Flanders is expected to experience an increase in number and intensity of rain showers by 10 to 40% (Floodsite, 2006).

KMI (2009) analyzed the number of days with abundant rainfall. Figure 11 shows the evolution of the number of days with daily rainfall exceeding 20 mm during the summer at Ukkel since 1901. Intense rainfall is usually observed in the summer due to intense thunderstorms in a short period of time. Figure 11 shows no significant trend for this type of precipitation. During the last three years, the highest values for number of days with daily precipitation of 20mm were observed, but it is too early to jump to any conclusion.

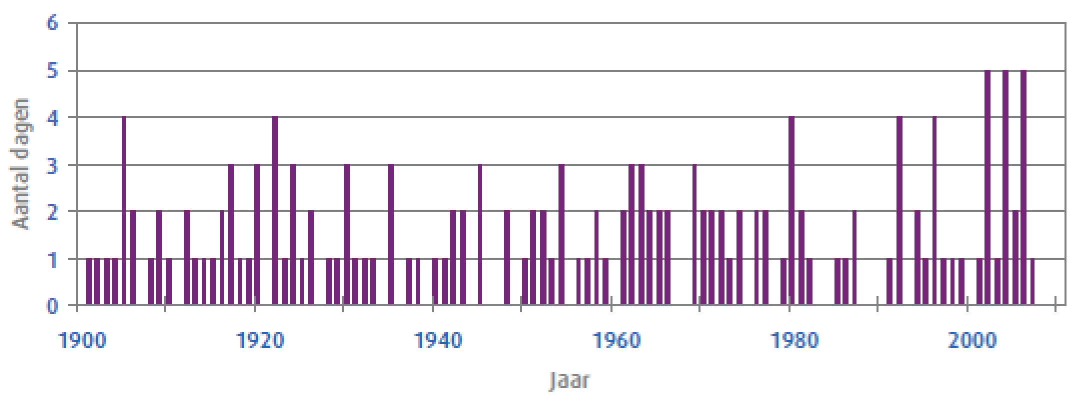


Figure 11 Number of days with a daily rainfall of 20 mm in Uccle during the summer season, from 1901 through 2007 (KMI, 2009)

In addition to the average monthly precipitation the probability of occurrence of extreme precipitation events was also studied in (Ntegeka et al, 2008a). 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.

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 et al., 2008a). 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.*, 2008a).

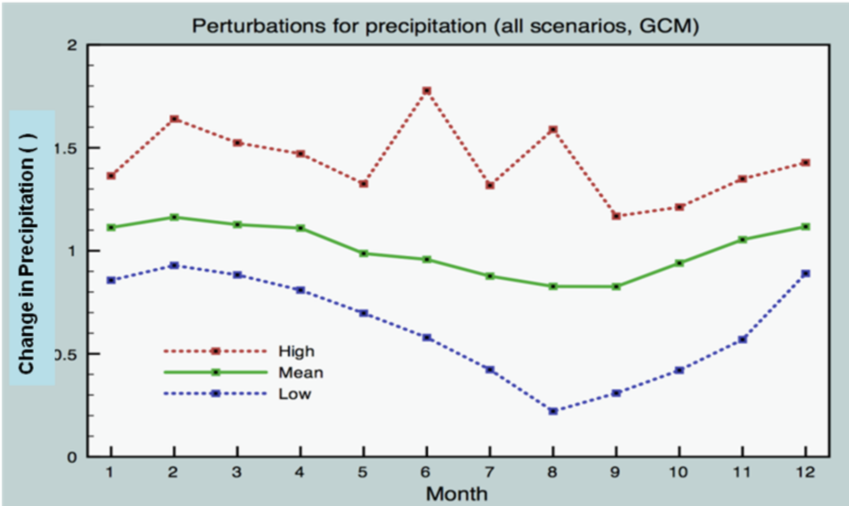
3.2.3 Scenario's

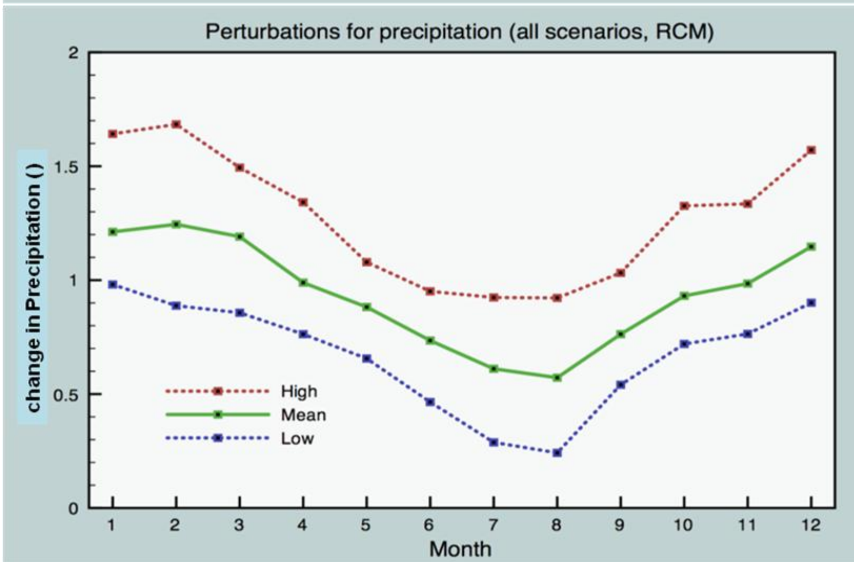
3.2.3.1 General scenario's for Flanders

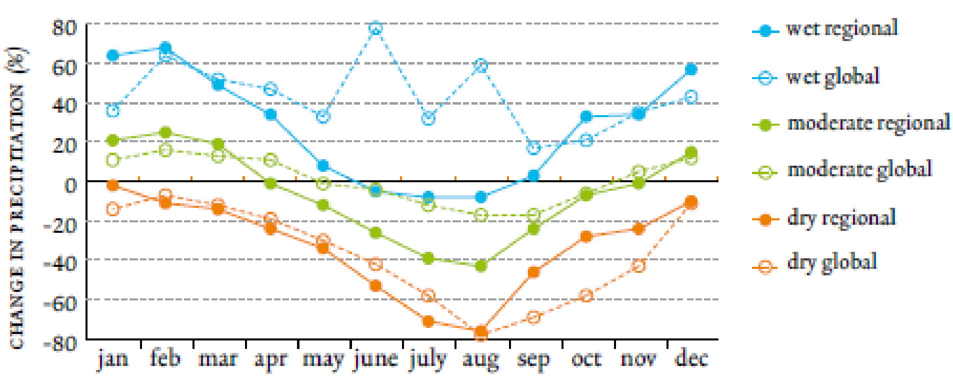
Within the CCI-HYDR project (http://www.kuleuven.be/hydr/CCI-HYDR.htm) scenario's for precipitation in Belgium were developed with a time horizon of 2100 (climate period 2070-2100), based on downscaling of European climate models.

By comparison of the regional (RCM) and global climate models (GCM), there is an indication that global climate models shows wider range of precipitation changes.

It can be seen from Figure 12 that for all scenarios (both the regional and global climate model runs) the precipitation patterns move toward drier summers. For the summer, however, significantly different results between the regional and global climate model runs. The regional runs (with the emission scenarios A2 and B2) for almost all runs show a precipitation decrease in summer, while the global climate model runs show an increase in summer for the high scenario.







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

Figure 12 Relative change in monthly rainfall at Uccle for CCI-HYDR climate scenarios for GCM and RC, reference period 1961-1990 and scenario period 2071-2100 (2 top figures Baguis et al. 2009, last figure Brouwers et al. 2009)

The most significant decrease in summer precipitation is found for the low-climate scenario in the month of August.

Considerable uncertainties in prediction of precipitation changes are a consequence of both the limits of contemporary models and the important natural variability of precipitation, especially in summer (Marbaix and van Ypersele, 2004). In particular, the evolution of precipitation is likely to be affected by more uncertainty than other climate parameters, because precipitation has a higher natural variability (d'Ieteren et al., 2004). For more details about the development of the scenario's and the statistical uncertainties, the reader is referred to (Ntegeka, 2008b). Table 5 summarizes the temperature and precipitation changes together for the monthly changes (to 2100) according to the CCI-HYDR high, medium and low climate scenarios. For further analysis, a choice will have to be made between the output of RCM and GCM runs.

Table 5 Perturbation factor for monthly rainfall in Ukkel for the CCI 3-hydr climate scenarios(reference period 1961-1990 to the scenario period 2071-2100) (Baguis et al. 2009)

	Monthly precipitation (regional climate model runs)			**Monthly precipitation (global climate model runs)**		
	Low	Mean	High	Low	Mean	High
1	0.98	1.21	1.64	0.86	1.11	1.36
2	0.89	1.25	1.68	0.93	1.16	1.64
3	0.86	1.19	1.49	0.88	1.13	1.52
4	0.76	0.99	1.34	0.81	1.11	1.47
5	0.66	0.88	1.08	0.7	0.99	1.33
6	0.47	0.74	0.95	0.58	0.96	1.78
7	0.29	0.61	0.92	0.42	0.88	1.32
8	0.24	0.57	0.92	0.22	0.83	1.59
9	0.54	0.76	1.03	0.31	0.83	1.17
10	0.72	0.93	1.33	0.42	0.94	1.21
11	0.76	0.99	1.34	0.57	1.05	1.35
12	0.9	1.15	1.57	0.89	1.12	1.43

Climate scenarios for urban drainage impact investigations (intense storm events with short duration) have also been constructed by the CCI-HYDR consortium. One observes a shift in the intensity-duration-frequency relationships (IDF-relationships) used as the basis for the design storms. IDF relationships summarize the statistical information contained in rainfall time series. They indicate how the rainfall intensity averaged over a given period ("aggregation level ") increases with increasing return period (average time between two successive crossings of the rainfall intensity).

For example, the present rainfall intensity with a return period of 1.5 months will correspond in the high-climate scenario with a return period of 1 month. A current rainfall intensity return period of 2 years corresponds in the high-climate scenario to a return period of 1 year. More information can be found in (Willems, 2009).

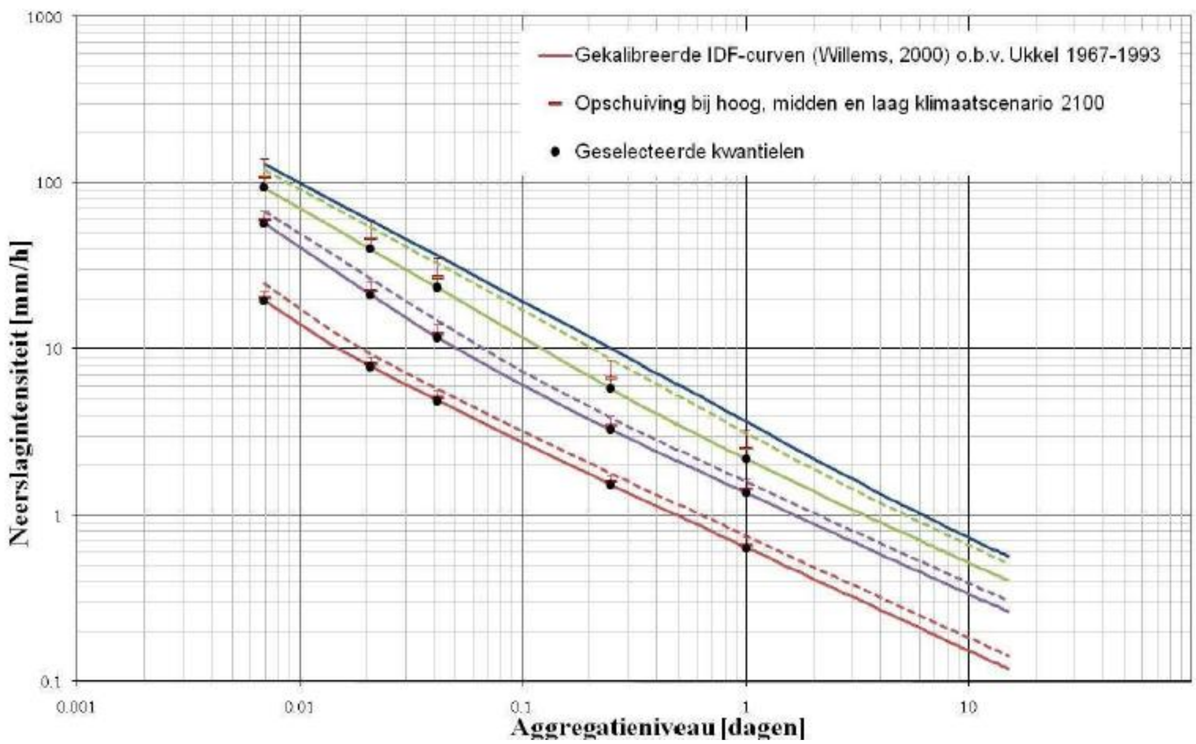


Figure 13 Influence of climate change on IDF curves (Brouwers et al. background document, 2009)

3.2.3.2 Regional scenarios

The possible change in precipitation also shows minor regional differences within Belgium (Figure 14). 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 (Brouwers et al., 2009).

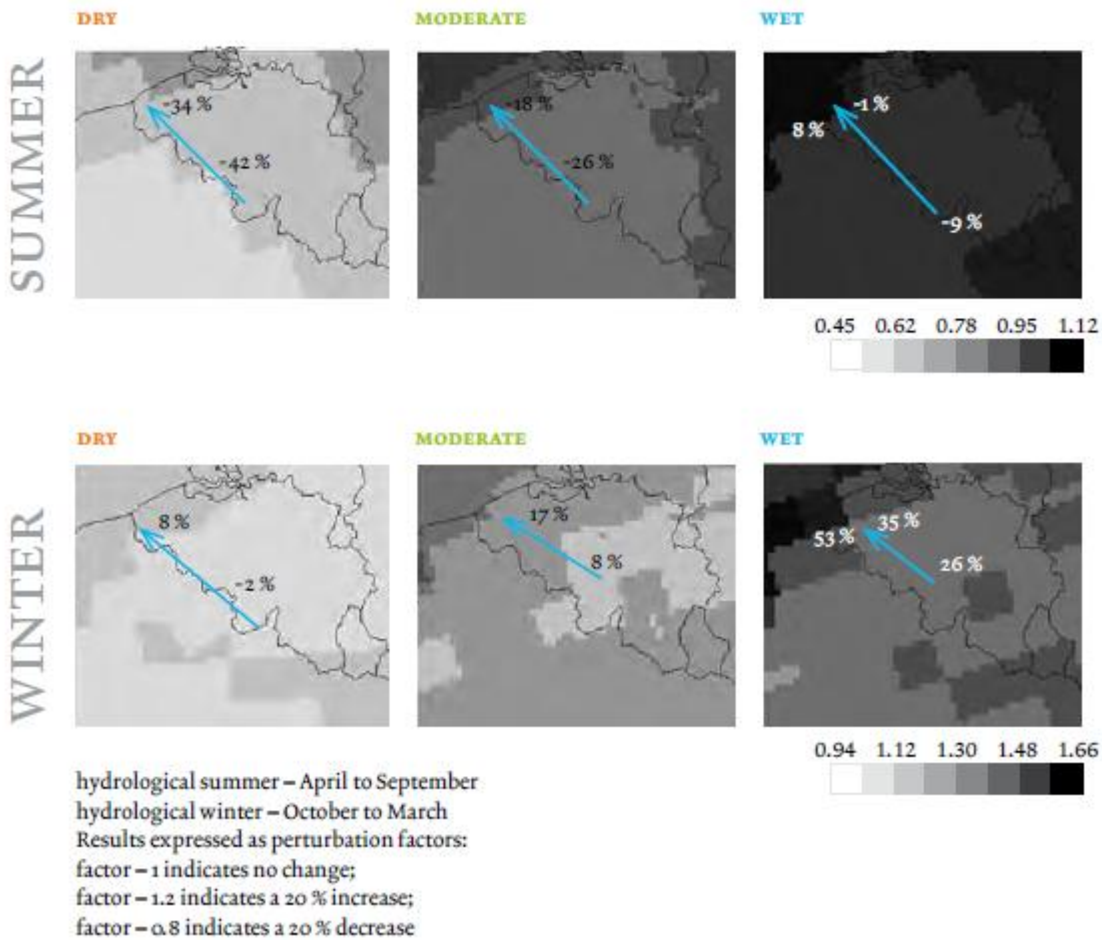


Figure 14 Regional differences for the average seasonal precipitation according to the three climate scenarios , Belgium, scenario period 2071-2100 compared to the 1961-1990 reference period (Brouwers et al., 2009)

Regional scenarios can be calculated using the “perturbation tool” , an instrument developed in the CCI-HYDR project (Ntegeka et al., 2009), if a regional dataset for the local climate is available. We will present results for the case studies of the Campine Region and the Coast in chapter 5.

3.3 Evaporation

As temperature increases so does the process of evaporation. In addition the moisture holding capacity of the atmosphere increases with temperature. For every 1 °C increase in global temperature there is a 7% increase in the moisture holding capacity of the atmosphere. And more moisture in the atmosphere ultimately leads to changes in rainfall patterns.

3.3.1 General scenario's for Flanders

Within the CCI-HYDR project (http://www.kuleuven.be/hydr/CCI-HYDR.htm) scenario's for potential evapotranspiration (PET) in Belgium were developed with a time horizon of 2100 (climate period 2070-2100), using 4 classical PET calculation techniques. In all cases of potential evapotranspiration (PET) calculation techniques, a shift to higher values is expected throughout the year (Baguis et al., 2009). This is clearly seen in Figure 15 , which further shows graphically the uncertainty due to the method of calculation.

The two Monteith variants closely follow each other and produce higher perturbations during the autumn and winter months than the two other methods. Accordingly, the PET perturbations produced by the use of the Idso formula and the model output for the LWnet method are also quite similar.

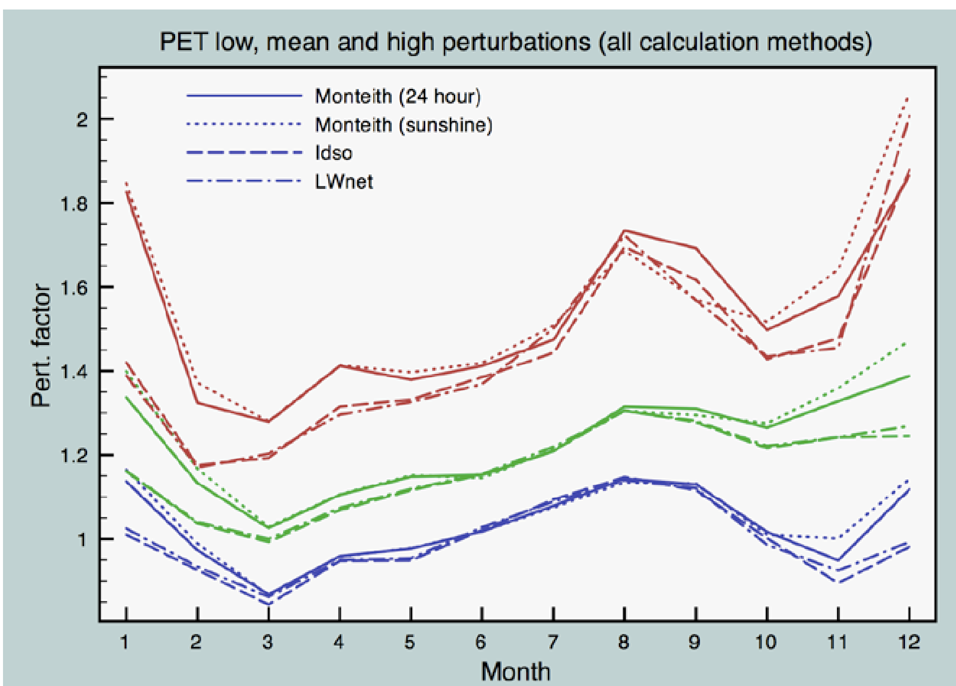


Figure 15 Perturbations for all the PET calculation methods used in CCI-HYDR (Baguis et al, 2009)

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 (Brouwers et al., 2009).

Table 6 Monthly PET perturbations from RCM data and for each calculation method (Baguis et al., 2009)

PET perturbations from RCM data												
	Monteith 24h			Monteith daylight			Idso			LWnet		
Month	Low	Mean	High	Low	Mean	High	Low	Mean	High	Low	Mean	High
1	1.137	1.337	1.826	1.165	1.399	1.846	1.01	1.161	1.42	1.025	1.162	1.389
2	0.973	1.133	1.324	0.989	1.167	1.372	0.926	1.037	1.175	0.934	1.04	1.17
3	0.868	1.026	1.279	0.867	1.029	1.28	0.844	0.993	1.193	0.862	1	1.203
4	0.959	1.105	1.412	0.958	1.106	1.413	0.948	1.069	1.315	0.95	1.074	1.296
5	0.977	1.148	1.379	0.978	1.151	1.397	0.949	1.116	1.332	0.954	1.119	1.326
6	1.018	1.152	1.412	1.018	1.145	1.419	1.021	1.153	1.385	1.028	1.155	1.369
7	1.079	1.209	1.474	1.075	1.213	1.508	1.094	1.21	1.443	1.089	1.219	1.501
8	1.143	1.315	1.734	1.135	1.305	1.686	1.147	1.306	1.695	1.14	1.305	1.723
9	1.13	1.31	1.692	1.132	1.295	1.57	1.116	1.278	1.617	1.121	1.281	1.568
10	1.017	1.265	1.497	1.01	1.275	1.517	1.002	1.216	1.428	0.986	1.221	1.434
11	0.949	1.328	1.578	1.001	1.359	1.641	0.895	1.242	1.477	0.925	1.242	1.455
12	1.118	1.388	1.865	1.143	1.472	2.062	0.981	1.245	1.878	0.993	1.269	2.007

3.3.2 Regional scenarios

Regional scenarios can be calculated using the “perturbation tool” , an instrument developed in the CCI-HYDR project (Ntegeka et al., 2009), if a regional dataset for the local climate is available. We will present results for the case studies of the Campine Region and the Coast in chapter 5.

3.4 Sea level rise

3.4.1 Observed trends

This paragraph makes extensive use of the research efforts made in the Climar – project (see Ozer et al., 2008; Van den Eynde et al., 2008; www.arcadisbelgium.be/climar, among other references).

Based on tide gauge data, global average sea level rose between 10 and 20 cm during the 20th century (IPCC, 2001a). In Europe, increases in sea level were measured between 0.8 and 3 mm per year (European Commission, 2006). Tide gauge data for the Belgian coast indicate a relative sea level rise from 2 mm/year for high water, 1.5 mm/year for mean sea level and 1mm/year for low water over the past century (Van Cauwenberghe, 2000). The change in sea level is mainly provoked by two mechanisms: changes in water temperature and melting of ice caps and glaciers (den Ouden et al., 2004).

Although sea level rise is very likely to continue in the future, regional realities can be quite diverse. Sea level rise in Western Europe will not deviate much from the world average. It is predicted that the Belgian surface will decline by about 5 cm over the next century (Beersma, 2004; IPPC, 2001a; Marbaix and van Ypersele, 2004).

Extreme high water levels will be observed with higher frequencies as a result of sea level rise and these frequencies may be further increased during extreme events, like storms. Rise in sea level increases the probability of erosion and inundations along the coast line. In Belgium, the sea breaking through the coast line, induced by sea level rise, could bring inland flooding up to 20 km, potentially affecting 200000 people. Protection of the coast line, as a response to sea level rise, however, will inevitably affect existing habitats too.

In addition, sea level rise might induce salt water intrusion which can affect the quality and the quantity of fresh water reserves, ecosystems and food production. As sea level rise influences tidal rivers, the increase in high water levels in the river Scheldt caused by sea level rise is several times larger than sea level rise itself (IRGT-KINT,2004; MIRA, 2005).

As an output of the CLIMAR project, annual mean sea level (MSL) trend from 1929 through 2001 at Oostende is shown in Figure 16 . The MSL vary between 2.172 m (in 1929) and 2.357 (in 2001). Even though the variability from year to year is high, it is very clear that the average sea level has increased significantly during this period. This is further confirmed by the fact that the average value in this period is equal to 2.257 m which is significantly lower than the latest average value of 2.294 m calculated by the Agency for Maritime Services and Coast (MDK) for the period from 1982 to 2000 (Ozer et al., 2008).

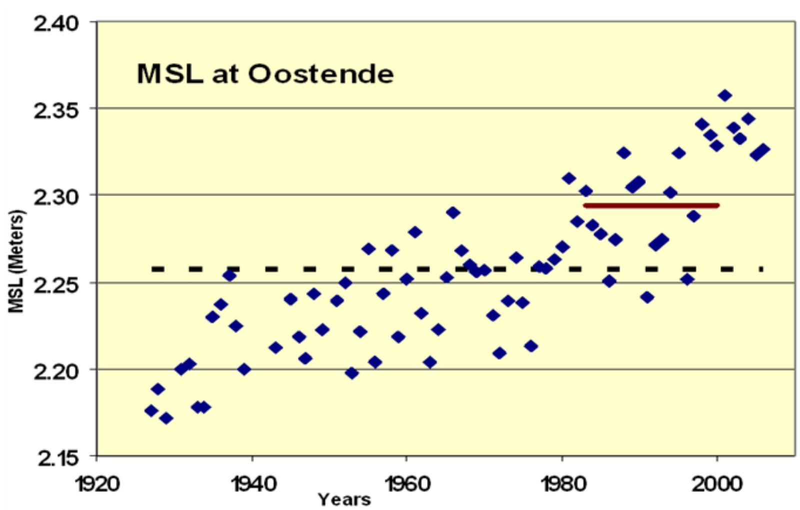


Figure 16 Average sea levels (TAW) in Ostend between 1927 and 2006 (Ozer et al., 2008)

3.4.2 Scenario's

If various relationships like linear, second and third degree polynomial are used for an extrapolation of the sea levels till 2100, it yield values between 20 cm and 200 cm as shown in Figure 17.

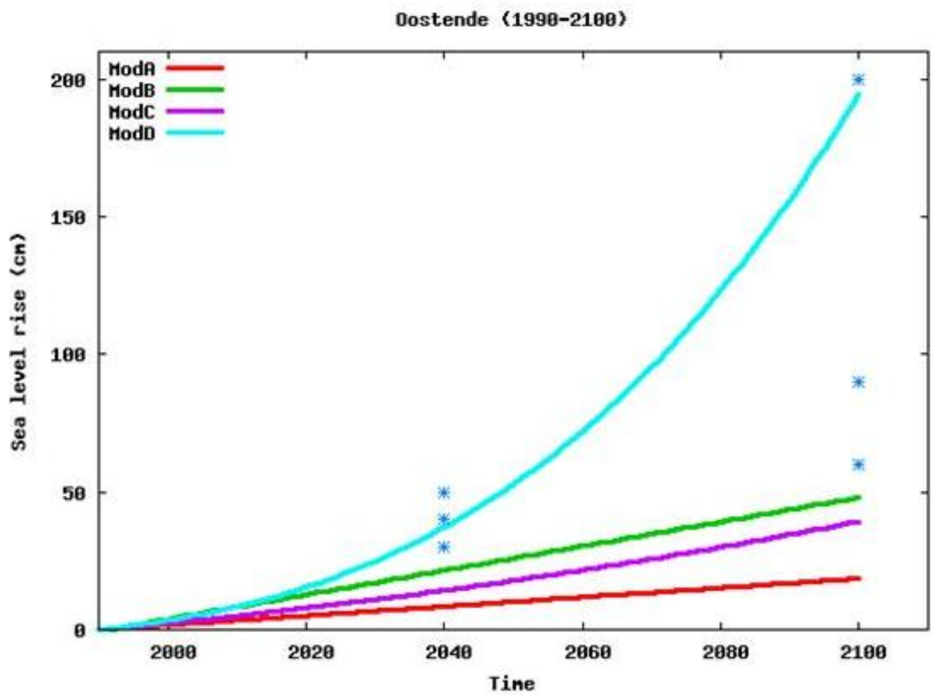


Figure 17 Extrapolation of rising sea levels based on different relationships to Oostende. Model A-Linear relationship, Model B – Stepwise linear, Model C – Second degree polynomial and Model D – third degree polynomial (Ozer et al., 2008)

In the CLIMAR project (Van den Eynde et al., 2008) three scenario's for mean sea level rise were retained. In Table 7 and Table 8 the scenarios are presented for 2040 and 2100. The scenario for 2040 is simply a linear interpolation of the values for 2100.

Table 7 Climate change scenarios 2040 (Van den Eynde et al., 2008)

	M/M+	W/W+	Worst
Mean sea level	+ 30 cm	+ 40 cm	+ 100 cm

Table 8 Climate change scenarios 2100 (Van den Eynde et al., 2008)

	M/M+	W/W+	Worst
Mean sea level	+ 60 cm	+ 93 cm	+ 200 cm

3.5 Storminess

3.5.1 Observed trends

Even though the impact of global warming on the occurrence of extreme regional meteorological conditions and extreme hydrological conditions remains uncertain, a tendency towards more frequent extreme events is expected but not quantified yet (IPCC, 2001b; EEA, 2005a).

An analysis of wind data was carried out in the framework of the CLIMAR project: a statistical analysis of the data available for wind measurements in the (near) the Belgian Part of the North Sea for a period from the first available to the most recent measurements (Van den Eynde et al., 2008). Results on wind direction are as follows: both the wind component to the North and the wind component to the East are increasing over time, but the wind component to the East at a higher pace. This indicates therefore a change over time of the wind direction moving from West winds to South-West winds. The analysis also shows that the strongest winds occur in the months November to February, but no clear seasonal difference in wind direction occurs. More details on variation in wind direction can be found at (Van den Eynde et al., 2008).

The longest series of wind measurements available for Belgium is provided by KMI at Uccle (KMI,2009). Figure 18 illustrates the evolution of the annual average wind speed since 1880. The analysis of these data indicates that the average wind speed in the region of Brussels remained relatively stable until 1960, but decreased by more than 10% since the 60's. However, this result should be interpreted with caution.

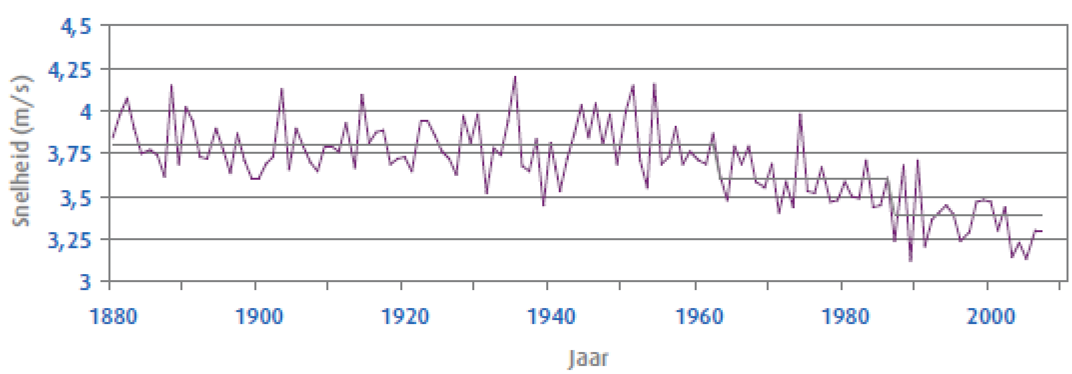


Figure 18 Annual average wind speed at Sint-Joost-ten-Node/Ukkel during the period 1880-2007 (in m/s) (KMI, 2009)

3.5.2 Scenario's

Climate scenarios for wind speed, in addition to the CCI-HYDR project, were derived by KMI-KUL in a project for INBO (Baguis et al, 2009). Figure 18 shows the high, medium and low climate scenarios used in this project for grid locations closest to Ukkel, Belgium. In the winter months, the wind increases by 10 to 20% while during the summer months, there are no indication of increase or decrease.

Perturbation factors calculated for the scenario period 2071-2100 are compared with the values in the reference period 1961-1990.

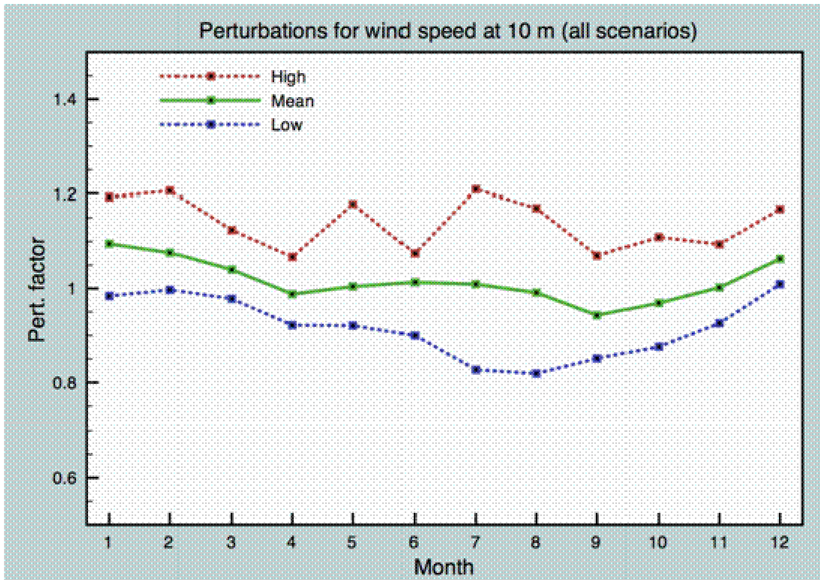


Figure 19 CCI-HYDR based climate scenarios for monthly average wind speed to Ukkel scenario in the period 2071-2100 (Baguis et al., 2009)

3.6 Drought

3.6.1 Observed trends

A long period without precipitation, or with almost no rainfall, may affect different sectors of our society. The concept of drought is not simple and easy to define. As the rainfall deficit seen over a longer span, it plays a crucial role in characterizing the severity of the drought, but other parameters, (such as wind, temperature, amount of water present in the soil) also play an important role and could be helpful with the scale and impact assessment.

KMI (2009) studied evolution of the longest periods without striking precipitation for 14 daily during the 20th century. Figure 20 illustrates the six warmest months of the year during the longest period without any significant rainfall since 1901. The trend analysis shows no significant evolution of this parameter during the 20th century. It's worth mentioning that the observations shows 37 consecutive days without rain from March 30th through May 5th 2007. 2009 has been the “most dry year” in Belgium since the recordings.

A similar result was obtained by KMI when studying the evolution of the longest duration of a period without any significant daily rainfall during the coldest period of the year. No significant evolution was observed during the 20th century.

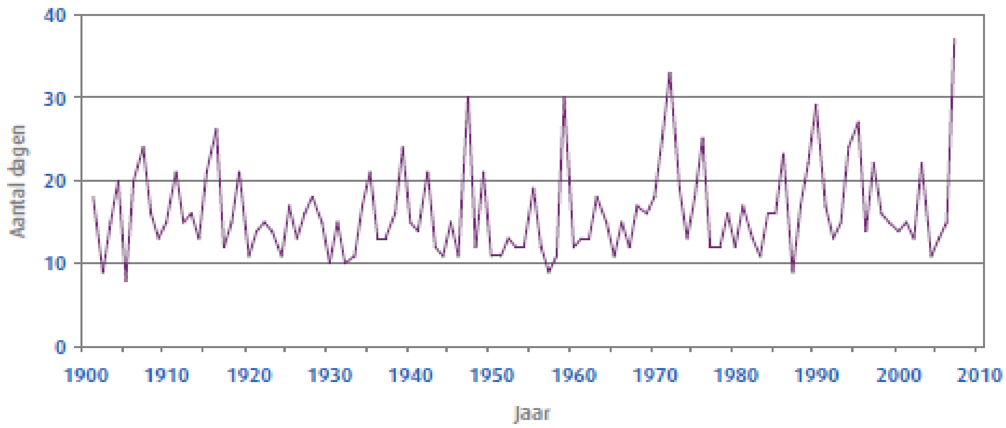


Figure 20 Duration (in days) of the longest period without significant rainfall (daily quantities of less than 0.5 mm) during the six warmest months of the year Uccle during the period 1901-2007(KMI, 2009)

3.6.2 General scenario's for Flanders

As drought is a interpretable concept depending on your area of research, there are no "drought" scenarios as such available in Flanders. A drought scenario will consist of a combination of scenarios of temperature, precipitation, evapotranspiration, … It is clear that higher temperatures, longer periods without precipitation and higher evapotranspiration values will lead to more serious drought problems. Whether to consider the annual, monthly, daily, … value for each of these indicators, depends on the concept of drought and the impact of drought on which sector of actor you want to study.

Up to our current knowledge, no scenario studies on drought effects on the geographical scale of Flanders have been reported, except for the low flows in navigeable rivers (Brouwers et al., 2009). 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).

The concept of drought, especially for low water flows in rivers flowing through our two case study areas, will be a topic of research in WP1 during the two next years.

3.7 Inland flooding

3.7.1 Observed trends

River discharges are determined by many factors such as climate, land use, soil type and flow regulation. This complex system of numerous factors interacting with each other will obviously be affected by the changes of temperature, precipitation and evapotranspiration, resulting from climate change (IRGT-KINT, 2001).

For most of Europe, flood hazard is considered as likely to increase (EEA, 2005a), with considerable increase in flood risk in coastal areas (IPCC, 2001b). Climate change will lead to increased winter floods in most of Europe. The winter precipitation will rise due to higher temperature and therefore it will provoke rapid run-offs and a higher flood risk (EEA, 2005a).

In Belgium, changes in mean river discharges are found to be either positive or negative, according to diverse climate change scenarios. The result depends on the balance between increased precipitation and higher evapotranspiration. This annual drainage change may be in between 5% increase and 30% decrease (National Climate Commission, 2002).

Regarding extreme events, the frequency of recorded floods in Belgium has already increased during the last decades. Major inundations took place in 1995, 1998, 2002, 2003, 2005 and in November of 2010. Land use planning is obviously partly responsible for those floods, but variations in winter precipitation and increased frequency of heavy rainfalls will still amplify flood risk (National Climate Commission, 2006). The changes in flood frequency and intensity will affect important life and financial losses all over Europe (EEA, 2005b).

Tu et al. (2005a) reports that flood peaks in the Meuse River and some of its tributaries have significantly increased since the end of the 1970s or the early 1980s, mainly as a consequence of causal precipitation. Hence, future increases in groundwater levels and river discharges are expected to take place, especially in winter, as a result of the change in precipitation (Commission Nationale Climat, 2002; Marbaix and van Ypersele, 2004). Although more studies are needed concerning the detailed effects of climate change on flood risk in Belgium, various analyses provides an insight into the most probable evolutions. Gellens and Roulin simulated impacts of climate change on surface water flow for eight Belgian catchments (Gellens and Roulin 1998). Relative values enable to compare impacts on rivers with very different discharges but the effects are inevitably enhanced during low flow stages.

3.7.2 Scenario studies

The river discharges (and hence probably the flood frequencies) for Belgian catchments show rising trend for most climate change scenarios (Gellens and Roulin, 1998). Figure 21 illustrates the damping effect in summer. Indeed, though the (GFDL mixed stationary) scenario is characterized by a high increase in temperature and a slight rise in summer precipitation, the simulated results show a small decrease in surface runoff due to the higher rise in effective evapotranspiration simulated.

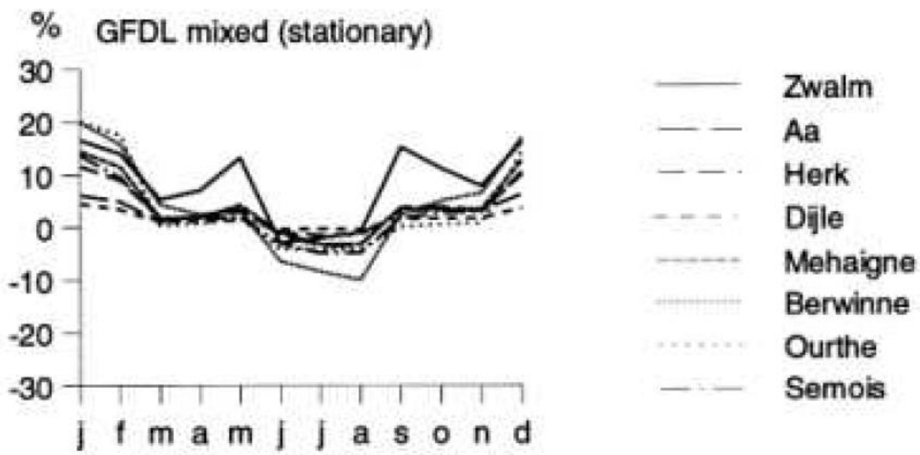


Figure 21 Relative change in monthly values of surface flow, for eight Belgian catchments, under climate change conditions (Gellens and Roulin, 1998)

In (Brouwers et al., 2009) the effect of climate change induced precipitation changes on discharge in rivers and flood frequency (with current land use) was simulated for navigable rivers. The results were different for winter and summer :

- Only for the highest scenario, there is a clear increase of flood risk ; for the lowest scenario there is a clear decrease of flood risk;
- 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.
- 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 %.

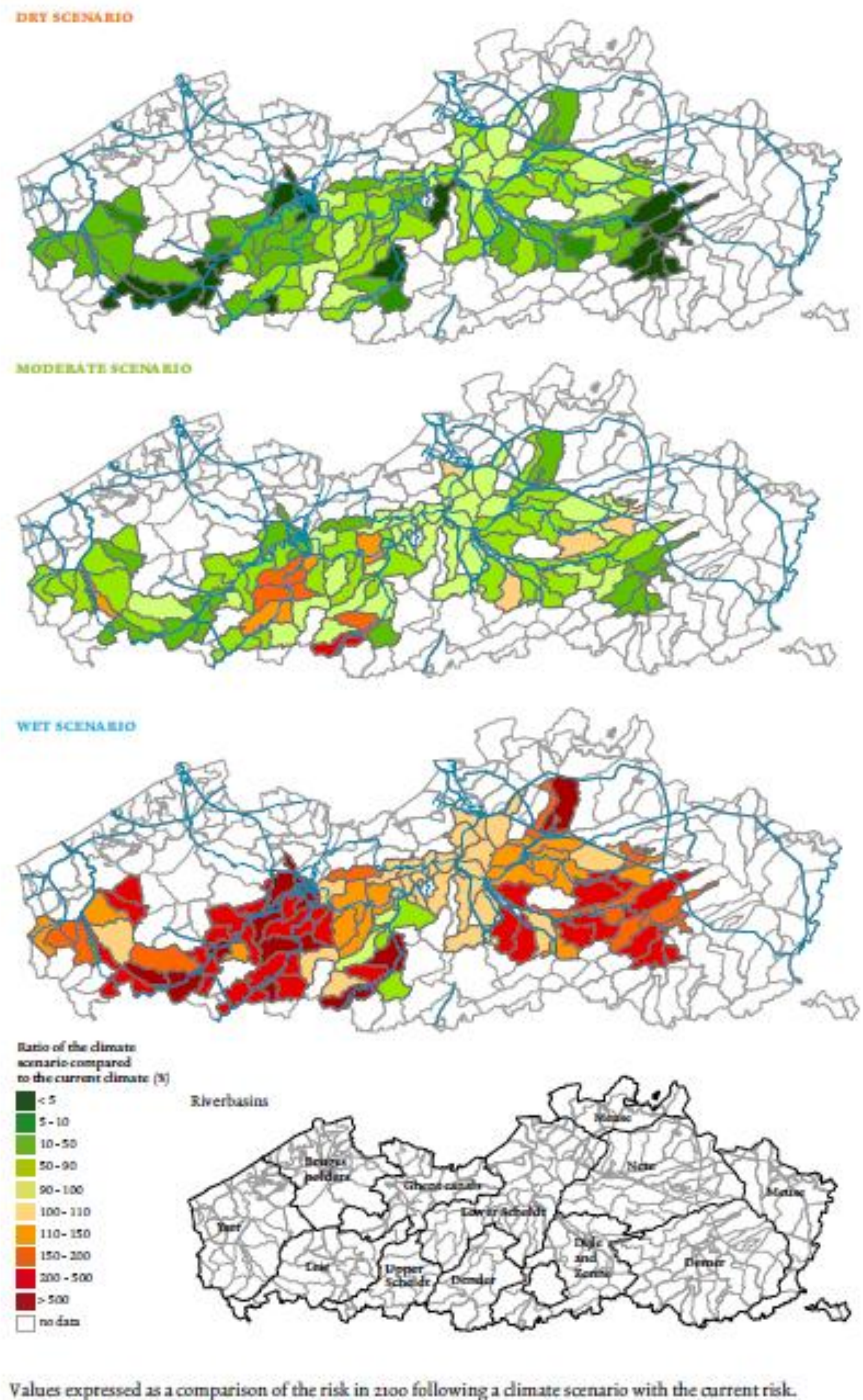


Figure 22 Evolution of the risk of flooding with the current land use as a result of the three climate change scenarios by 2100 (Brouwers et al., 2009)

3.8 Case studies of impact of climate change on water management in Flanders

We briefly report here on three interesting case studies dealing with climate change scenarios, (partly) with land use scenarios and the impact on water management.

The studies illustrate the need for further research on the interaction between climate change, socio-economic evolutions, water and land use management.

3.8.1 Impact of urban expansion and climate change on peak flows in the Molenbeek catchment

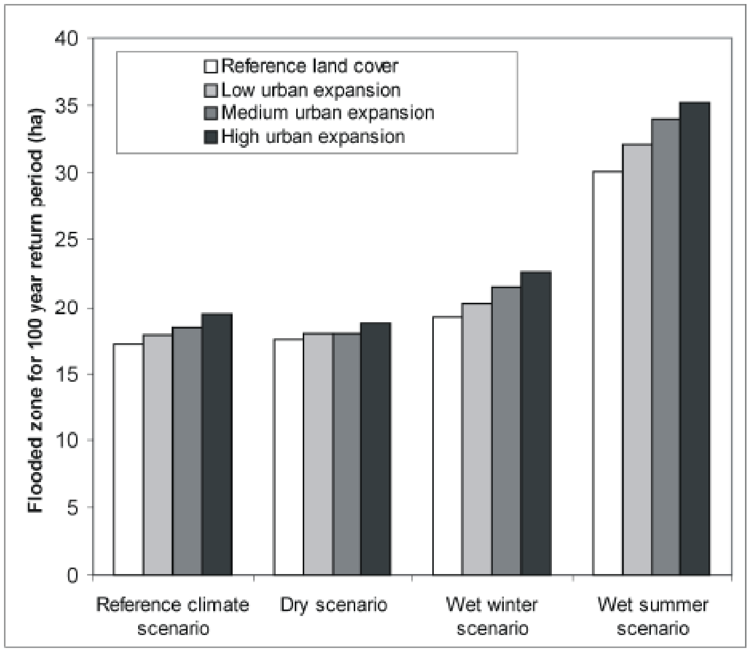
This case study can be consulted in detail in (Poelmans, 2010).

This study investigated the potential impact of land cover change (urban expansion), climate change and the combined impact on the peak flows and the spatial extent of floods in a small-scale suburban Molenbeek catchment, situated near the city of Leuven in the center of Belgium.

In this study a lumped rainfall-runoff model was used to calculate the impact of land cover change and climate change. In order to simulate the impact of urban expansion and climate change in the near future, the hydrological model was fed with possible scenarios of urban expansion, rainfall and potential evapotranspiration for the year 2050.

After running the model using the urban expansion and climate change scenarios separately, the results suggest that climate change may cause larger changes in peak flows in comparison with the urban expansion scenarios. It remains a point of investigation whether the choice of the lumped model is partly the reason for this. The climate change scenarios are reported upon in previous paragraphs of this chapter 2. We will comment on the urban expansion scenario's in chapter 4 of this report.

The different climate change scenarios result in a broad range of results for the peak flows as shown in Figure 23: future peak flows will increase (on average) with more than 30% under a wet summer scenario, while they will decrease with almost 18% under a dry scenario. Or, a peak flow that under the present circumstances shows a return period of 10 years, will occur every 2.5 years under the wet summer scenario, while it will occur approximately once in every 25-30 years under the dry scenario. The results from the different urban expansion scenarios, on the other hand, are relatively consistent: an increase of the built-up land in the catchment between 70% and 200% will cause an increase of the peak flows between 6% and 16%. Or, the return period of a peak flow that presently shows a return period of 10 years, will decrease to 5 years under the high urban expansion scenario and to 8.5 years under the low urban expansion scenario.



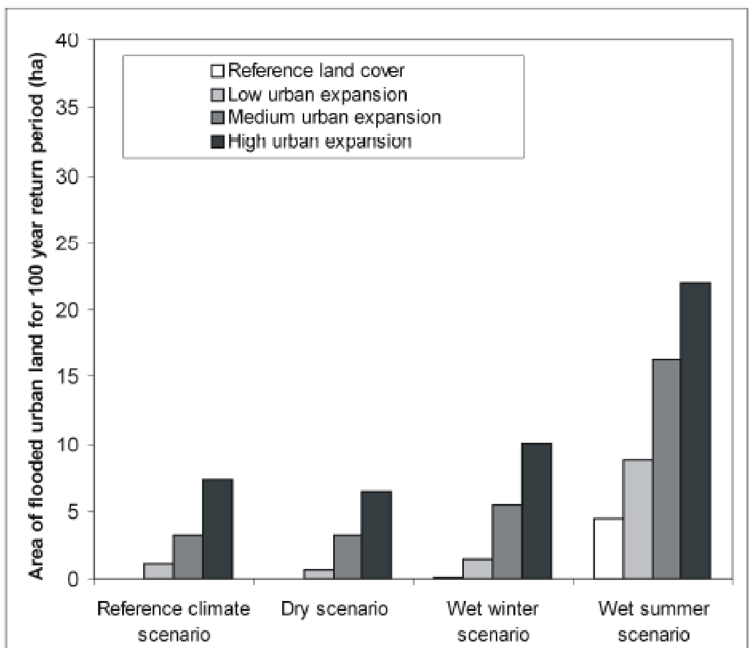


Figure 23 Changes in flooded area in the Molenbeek catchment for a 100-year return period (upper) and changes in urban area within a 100-year flooded zone (bottom)

When combining the dry climate change scenario and with the urban expansion scenarios, the decreasing flows caused by the dry scenario will be partly counterbalanced by the increasing runoff from built-up land. On the other hand, when combining the wet scenarios with the urban expansion scenarios, the impacts caused by both driving factors will amplify each other: the increased peak flows caused by a wetter climate will be even higher in a highly urbanized landscape. When looking at the flood frequency and flood extent, similar conclusions can be drawn. The general future trend of the flooded area is primarily determined by the applied climate change scenario. On the contrary, possible damage related to floods is mainly influenced by possible land cover changes within the floodplain: the total area of urban land that is expected to be inundated by a 100- year flood event will increase from 0.1 ha to 4 ha under the wet summer scenarios, while under the high urban expansion scenario the total area is expected to increase to 7 ha.

This finding has important implications for spatial planning by policy makers and for land use and water management activities that try to limit the risk related to flooding by implementing new land use policies and water management strategies.

3.8.2 The impact of climate change on groundwater resources in the Kleine Nete

This case study was carried for the INBO-institute and can be consulted in detail in (Dams et al., 2009).

The aim of this project was to investigate the sensitivity and effects of future land-use and climate changes on the groundwater resources. A modeling approach that integrates available land-use and climate change scenarios into a groundwater flow model was followed in this study. This approach comprises a coupling of the hydrological model WetSpa and the groundwater flow model Modflow.

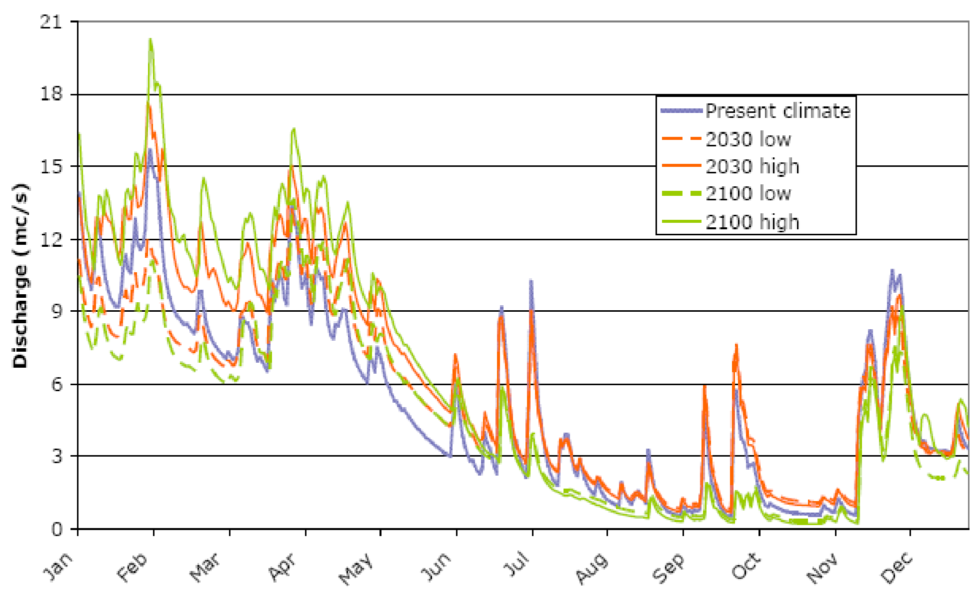


Figure 24 Comparison of the discharge predicted by the calibrated WetSpa model assuming different climate scenarios and the same land-use map

Two climate change scenarios were fed to the Kleine Nete WetSpa model: a scenario which is expected to have a high impact and a scenario with a low expected impact on the hydrology. For the high impact scenarios WetSpa predicts a significant increase in total river discharge during winter and spring, while in summer the discharge will decrease as shown in Figure 24. The same trend is observed for the low impact scenarios but with milder changes in comparison to the current condition. Also changes in land use by 2030 were introduced into the WetSpa model. With regard to the total discharge, the impact of the land-use changes is low. This is not remarkable, as the changes in land use were not extreme, only look at a time horizon of 2030 and only highlight differences in implementation speed of nature areas that are already designated as nature areas. Simulated hydrographs show that the land-use changes influences only the peak discharge, which increase slightly.

The impact of the climate changes on the average groundwater head, as a result of the Wetspa modeling, is much more profound than the impact of the land-use changes.

For the low impact scenario the average groundwater head changes are still relatively moderate, up to 20 cm higher or lower, for the high impact scenario the groundwater head can rise up to more than 1 meter. The high impact scenario predicts the highest increases near the basin boundaries or near the Campine ridge. For the low impact climate change scenarios the changes in depth are much less and can be both up- or downwards.

For the scenarios analyzed in this project, the simulations show that the water balance of the catchment is more sensitive to changes in climate conditions than to land-use changes. This is however function of the specific changes in land use chosen and the relative short time horizon of 2030 for these land use changes.

3.8.3 The impact of climate change on flooding in the Dender catchment

This paragraph reports very concise on a Belspo funded research project that focused on climate change and flooding. Details can be found in the final report of the project (Giron et al., 2010) or in summary in (De Sutter & De Smet, 2008).

The overall objective of this project is to develop and demonstrate an efficient management tool being a cost benefit analysis based instrument for the integrated assessment of adaptation measures. The project consists of two parts, the first one being a "general introductory study" and the other, a "case study" for which the methodology is refined. The case study location is the Dender basin which is situated in the Scheldt catchment in Belgium. The CCI-HYDR project critically contributes to the ADAPT project as it provides the flood maps for the Dender case study and provides a basis for estimating the perturbations/changes in peak discharges necessary for modeling the effects of climate change for the Ourthe case study. The outputs of the CCIHYDR project thus are an input for the ADAPT project.

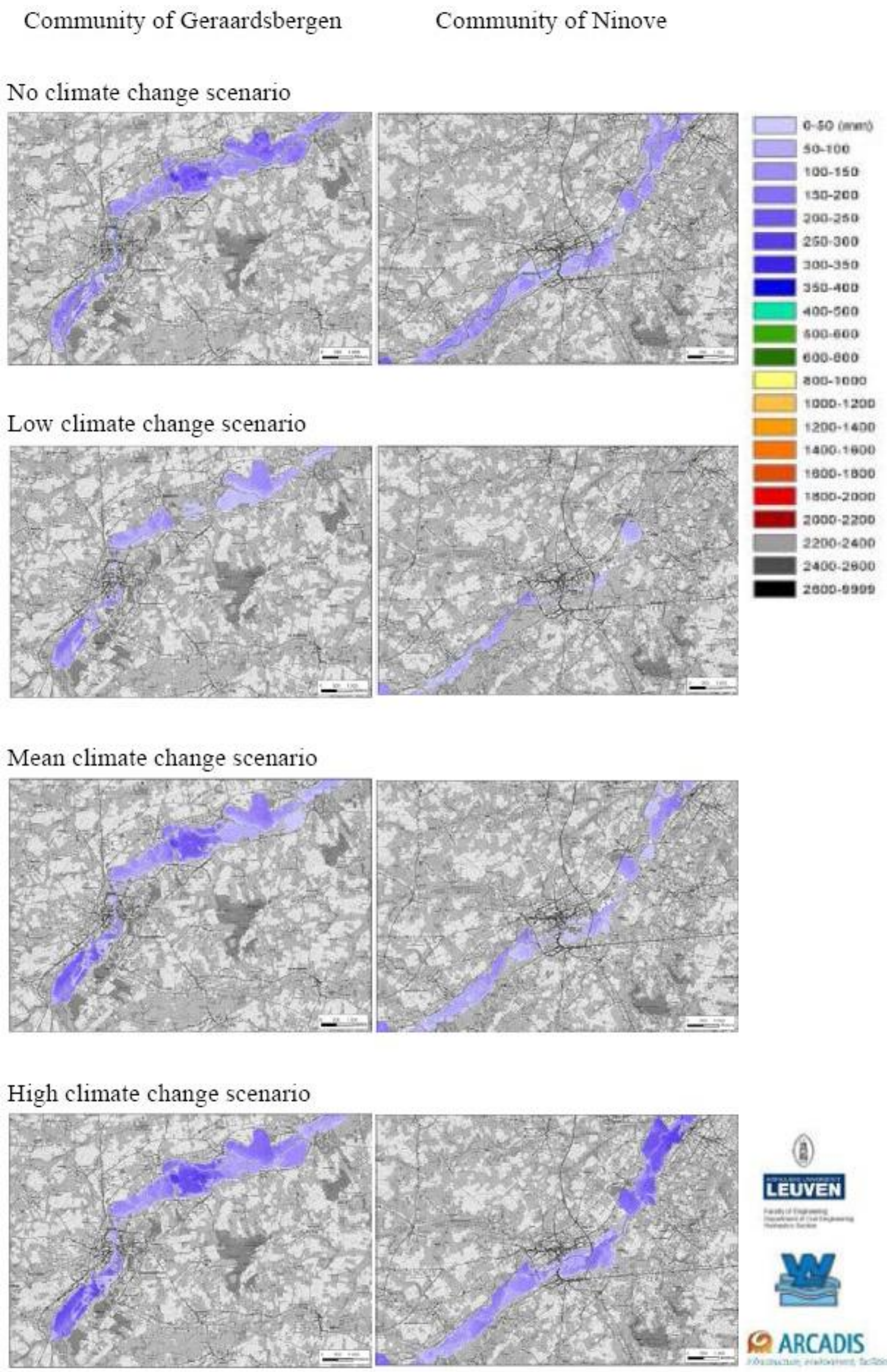


Figure 25 Inundation depth (in mm) for a return period of 100 years

The output of the lumped hydrological models, which have been run with the perturbed input series of rainfall and evapotranspiration and thus accounts for climate change effects, is used as the upstream boundary condition for the hydraulic model. The simulation results of inundation depth in the Dender basin (communities of Geraardsbergen and Ninove) for a 100 year return period are shown in Figure 25. Simulations have been provided for a situation without climate change as well as for the low, mean and high climate change scenario. From the model results it appears that only the high climate change scenario implies higher inundation depths. The extent of the inundation remains quasi unchanged as compared to the model results without climate change. In the low climate change scenario both the inundation depth and extent would decrease. It is, however, not possible to attribute chances to the likeliness of the different scenarios.

In general, the impact of the climate change scenarios on peak discharges is rather unclear. The trend on peak discharges seems to be dependent on the relative importance of the increase in winter rainfall versus the decline in summer rainfall, and the relative importance of the rainfall trends versus the increase in evapotranspiration. What is clear from the simulation is that the problem of low flows will increase to a greater extent than the problem of peak flows.

4 SECONDARY IMPACTS OF CLIMATE CHANGE

4.1 Changes in spatial-natural structure

4.1.1 Aim of this chapter

One of the work packages in the CcASPAR-project has its focus on the spatial nature structures, the impact of climate change on them and the possibility to create a more robust spatial nature structures towards these changes. In the chapter given below, a brief description of impacts of climate change on Flemish spatial nature structures is held. One has to keep in mind that stress, caused by climate change has to be put in the light of an already heavily affected nature by human-being. Contrary to historical migration, species nowadays have to deal with a badly fragmented landscape during their migration. As a result, many habitats which are climatological suitable, are not situated in the dispersion radius of certain species. Species with a low adaptive capacity and/or dispersion capacity are much more vulnerable for extinction due to habitat degradation and fragmentation by human-being. Examples can be found within pollinators of plants, butterflies, grasshoppers, amphibians and reptiles.

Nature reserves in Flanders are very small and embedded in a intensively used urban or agricultural landscape. Next to fragmentation, desiccation and manuring are resulting in a decrease of habitat quality. This has off course negative consequences for biodiversity. The extra stress of climate change implicates that a adequate spatial connection of the landscape becomes a condition sine qua non for tackling the dispersion problems. After a disturbance, a species' population recovers more easily in a well-connected spatial landscape (Vos et al., 2006). Warren et al. (2001) investigated species of butterflies and proved that species with a well-developed dispersion capacity or species with a less-fragmentated habitat (generalists) expanded their occurrence under the influence of climate change, comparing two periods (1970 – 1982 and 1995 – 1999). Contrary to immobile species or species with a very specific habitat.

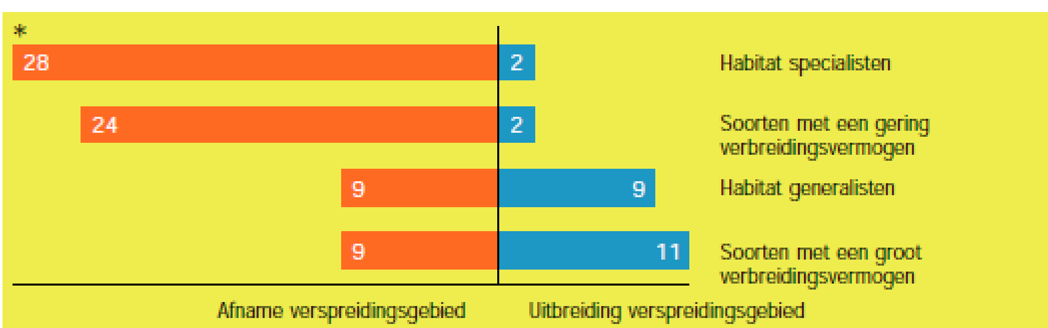


Figure 26 Expansion of butterflies between 1970-1982 and 1995-1999 in the UK.
Red bars: decrease; blue bars: increase. Rows from top to bottom: 'habitat specialists', 'species with a low dispersion capacity', 'habitat generalists', 'species with a high dispersion capacity' (Warren et al, 2001 in Vos et al, 2006).

Species which cover long distances between their winter and summer habitat, e.g. migratory birds, are also exposed to more risks because their stopping places are threatened to become unsuitable.

The text gives some more detail on the (extra) impact climate change will have on the contemporary stress of spatial nature structures.

4.1.2 Introduction

The large climate zones are shifting, shrinking of expanding under the influence of an increased greenhouse effect. Due to their limited adaptive capacity, a lot of ecosystems will become vulnerable for these changes. They can catch irreversible damage. Glaciers, corals, mangroves, boreal and tropical woods are examples of endangered ecosystems. This can have serious consequences for biodiversity. Leemans & Eickhout (2003) proved on the global scale that, with a temperature increase of 1°C, already 10% of the worldwide ecosystems will be affected. If the increase is 2°C or 3°C, this percentage becomes respectively 16% and 22%.

A research which covered the worldwide trends of phenology (i.e. seasonal activities like egg-laying, trees which bud out, waking up from hibernation, seasonal migration) showed that out of 667 species, 62 % already advanced their activities, 27 % showed no trend and 9 % had their activities later (Parmesan & Yohe, 2003). Particularly plant species (over 70 %) and amphibians (75 %) showed a trend towards advancing. The average advancing time per decade was 2,3 days.

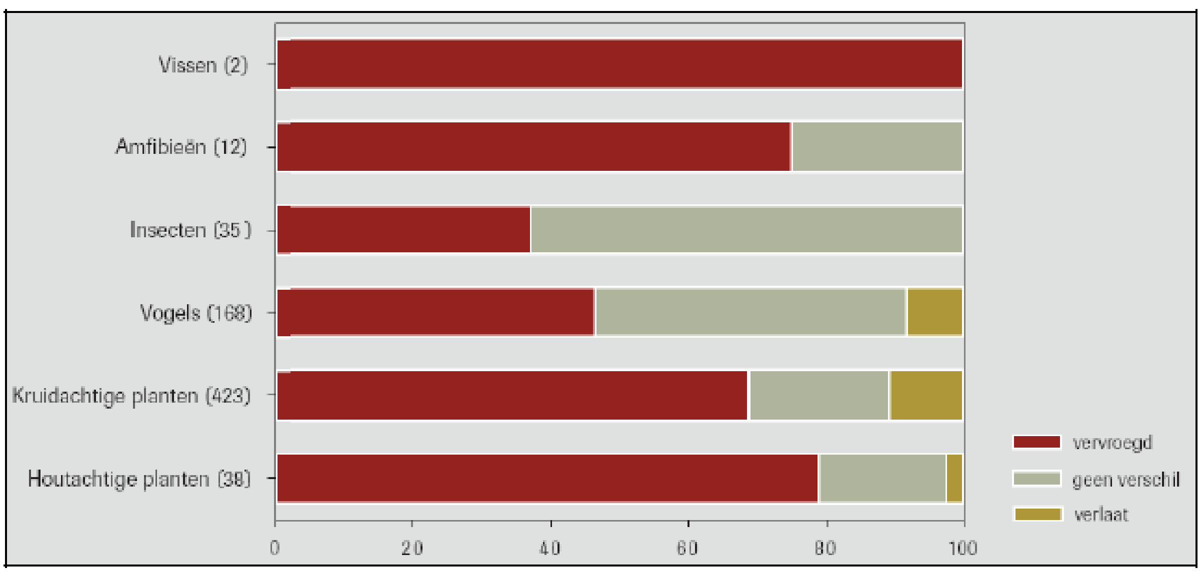


Figure 27 Trends in phenology. Red: earlier; grey: no trend; yellow: later Rows from top to bottom: fish, amphibians, insects, birds, herbal plants, woody plants. (De Bruyn, 2005, based on Parmesan & Yohe, 2003).

Parmesan & Yohe (2003) investigated also the geographical shifts which occur by climate change. Their research covered 1046 species and showed that more than half of them relocated their territory towards the poles, caused by the increased temperature. Species which showed no changes need more research because there can be several reasons.

- The species is really not vulnerable for climate change.
- The species is vulnerable but there are not sufficient data.
- The species is vulnerable but other factors impede dispersion. E.g. species with a limited dispersion capacity. This can be characteristic for the species or caused by habit fragmentation (habitat patches are not laying within reach for a certain species).

Global scale patterns can be derived from elderly studies concerning the impact of climate change on spatial nature structures. These patterns are clearly caused by climate change since they are characterized by a large extent, a prediction-possibility, an unequivocal pattern and a stronger response if climate change increases. The presence of these changes isn't a problem in itself. However, it becomes important when species cannot keep pace with the climate changes (De Bruyn, 2005).

Seasonal and geographical shifts are the most studied nature effects of climate change. However, besides them, there are some more effects (De Bruyn, 2005):

- Due to the difference in vulnerability to temperature shifts between different species, the composition of communities can change dramatically. As a result, new (competitive) interactions can be created within these communities. Put in other words, the disappearance of certain species can have an indirect effect on species which are less climate vulnerable;
- International research has proved that climate change can lead to a major chance of plagues of insects, with an exceptional amount of damage (Gan, 2004; Hodar & Zomaro, 2004). This is caused by higher winter temperatures which results in a higher chance of survival of plague species;
- Extreme weather events, such as thunder storms, will occur more as a result of climate change. These events can have negative consequences on mortality rates and reproduction rate. The population size will be faced with extreme ups and downs and the chance of extinction increases. If these disturbances occur in quick succession, extinction of species will be the result (Foppen et al., 1999; Vos et al., 2006)

Climate change doesn't solely influence native species. Also exotic species will be affected and they can cause disturbances in other ecosystems.

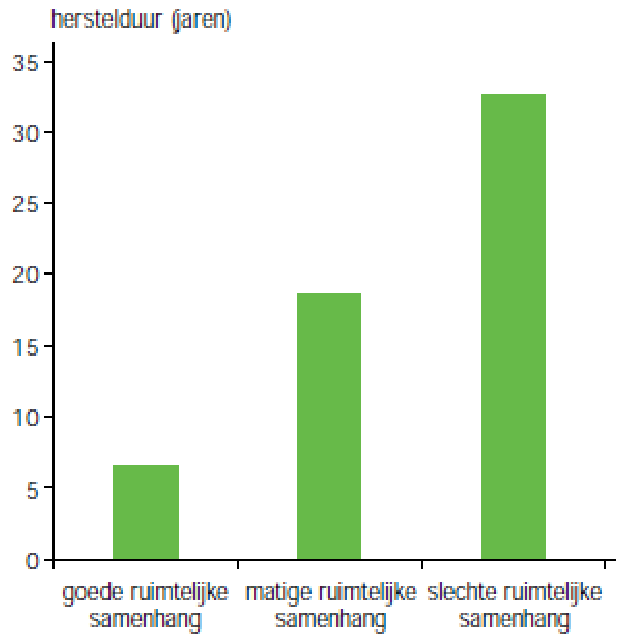


Figure 28 The link between connectivity (bad, moderate and good) and recovery time (in years) after a disturbance (Foppen et al, 1999).

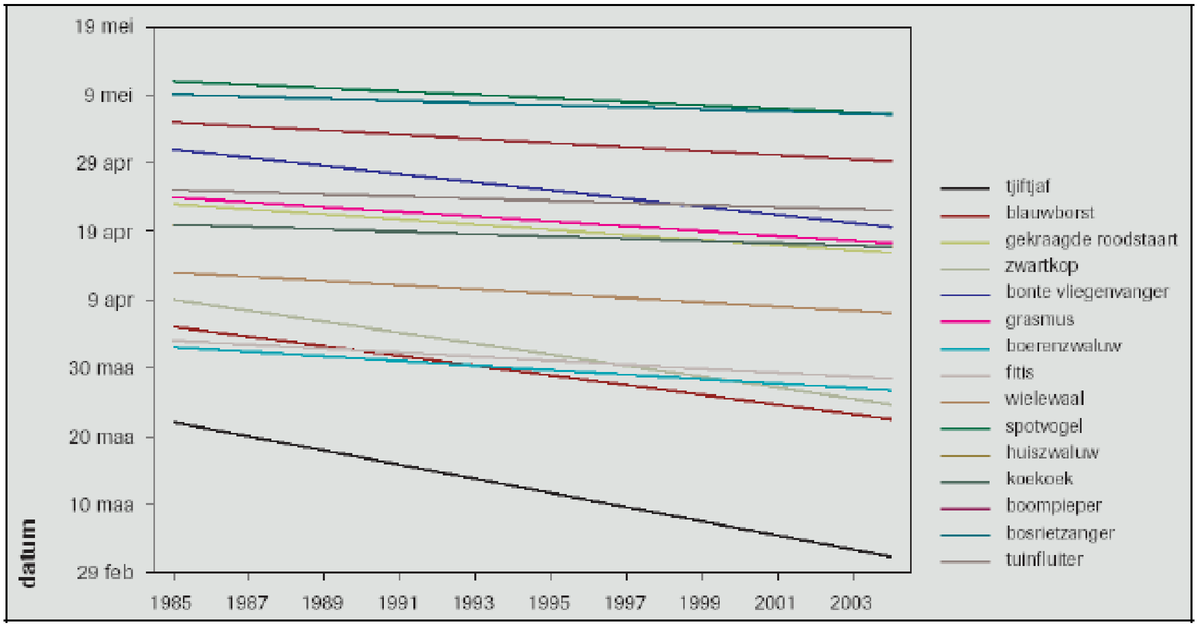
4.1.3 Effects of climate change on Belgian ecosystems

The existing Belgian spatial nature structures and species will also have to deal with climate change influences. The ecological niche of certain species will be affected by a changing environment. In particular, species of the cold regions, who are mainly located on the plateaus of the Ardennes and the lower Campines, are endangered. Their specific requirements seem to disappear due to climate change, resulting in a disappearance of certain ecological niches and their species out of the Belgian territory. The global temperature rise will probably result in a expansion of species which prefer warmer habitats such as Submediterranean (and even Mediterranean) species. We are talking about species that are already fragmented present in Belgium or the neighboring regions. It is even possible that thermofilic and xerophilic species will appear. The species of the cold regions are mainly represented among the fresh water fishes and mosses and they will be gradually replaced by species which are more adapted to a warmer environment. If climate change becomes more intense, even species of the moderate regions can be affected and disappear in the long run.

The flora and fauna in the North Sea is also subject to climate change. There are several factors which indicates that the North Sea is dealing with a temperature increase, especially along the coasts (Kerckhof, 2004). Reid et al. (2001) discovered already during the eighties that plankton which prefer warm environments is competing and chasing away plankton of the cold environments. Acorn barnacles are also indicators for changes in the water; the Mediterranean acorn barnacle is nowadays already widespread in our harbours (Kerckhof, 2002). On the other hand, one can remark the strong decrease of cold water species such as cod, haddock and halibut. However, the effect of climate change is difficult to distinguish from natural fluctuations of populations, and other severe stressors like fishery (e.g. cod) and eutrophication. However, if one considers solely the commercial species, the shrimp can indicate some environmental changes. Despite the stabilization of fishery-stress, shrimp populations are clearly decreasing in the southern parts of the North Sea and the north-eastern part of the Channel (Kerckhof, 2004). It seems that the southern border of the shrimp habitat is moving towards the north.

4.1.3.1 Seasonal shift

In general one can state that especially activities which are spring-bound occur earlier. Examples are the blooming of flowers, egg-laying, spring-migration,… These activities run parallel to the mean spring temperature increase and can have severe consequence concerning (mis)matching (e.g. caterpillars are already gone during the growth of great tit's youngs. As a result it starves to death). In our regions, organisms are also advancing their activities (De Bruyn, 2005). A research regarding migration of birds (15 species) had as a result that their first arrival date between 1985 and 2004 advanced for almost 8 days.



Bron: De Bruyn, 2005 op basis van Leysen & Herreman, 2004.

Figure 29 Advanced arrival date of 15 migration birds (1985 – 2004) (De Bruyn, 2005, based on Leysen & Herreman, 2004).

Next to observation for the spring, a postponing of some autumn activities was noticed: an average of 3 days later over the last 30 years (Menzelet et al., 2006). Research derives following relationships between the variation of temperature and phenological shifts: advancing of spring- and summer phenomena with 2,5 days per degree of temperature increase and a postponing of colorization of leaves with 1 day per degree of temperature increase.

4.1.3.2 Shifting dispersion

Due to increasing temperatures, species are shifting their habitats to the north. Native species which occurred only in a scattered way and whose optimal ecological conditions were mainly situated in southern regions, are now very common (e.g. certain species of dragonflies). Climate change causes not only shifts in native species. Exotic species can also be affected and cause troubles in our regions. If temperature rise becomes more intense, one can expect that these species will expand further towards natural ecosystems. Changes of this kind of shifting dispersion can be modeled if sufficient data are available. This is only the case for hatching birds and day butterflies. In both cases, one notices certain species which will probably disappear due to climate change. However, there are also some other new species which will possibly appear. This depends on the availability of habitats and the dispersion capacity of the species (Dumortier ed., 2009). One can question whether this trend is positive because the new species are in general not endangered and characterized as generalists with a large area of occurrence, a high mobility and a high adaptation capacity.

4.2 Changes in landscape because of climate changes

4.2.1 Introduction

The European Landscape Convention defined the landscape as "an area as perceived by people, whose character is the result of the action and interaction of natural and/or human factors." (Council of Europe, 2000). This definition contains a link to the dynamic character of the landscape. This dynamic character is due to the driving forces for landscape change. One of the driving forces are the calamities, which can be defined as (natural) disasters which can cause damage (BRON). Examples of calamities are hurricanes, forest fires, flooding, etc. Some (parts) of the calamities are influenced by the climate what means that climate change has an clear effect on the landscape. This is also proposed by Pedroli (2009) who says that "*the driving forces influence the landscape through a series of cause and effect chains; climate change e.g. works through a multitude of effects on landscape*".

Zonneveld (1985) sees the landscape as an open system. This system consists of three 'spheres': the noösphere, the biosphere and the abiotic sphere. Each of these spheres encloses some specific elements which are correlated with each other and influence the landscape. He distinguishes three main components: substrate, mankind and climate. These elements determine the functioning of the other elements like air, soil, animals, plants, etc. The combination of all those elements affects the landscape, as well as the past, the present and the future landscape. All this fits into the idea of the holistic landscape, which means that the landscape exists because of the integration of all those effects. The landscape itself is more than just the sum of all those elements (Antrop, 2007). So, when we discuss the influence of the climate change on the landscape we have to keep in mind that this influence is the results of the integration of the effects on each single component.

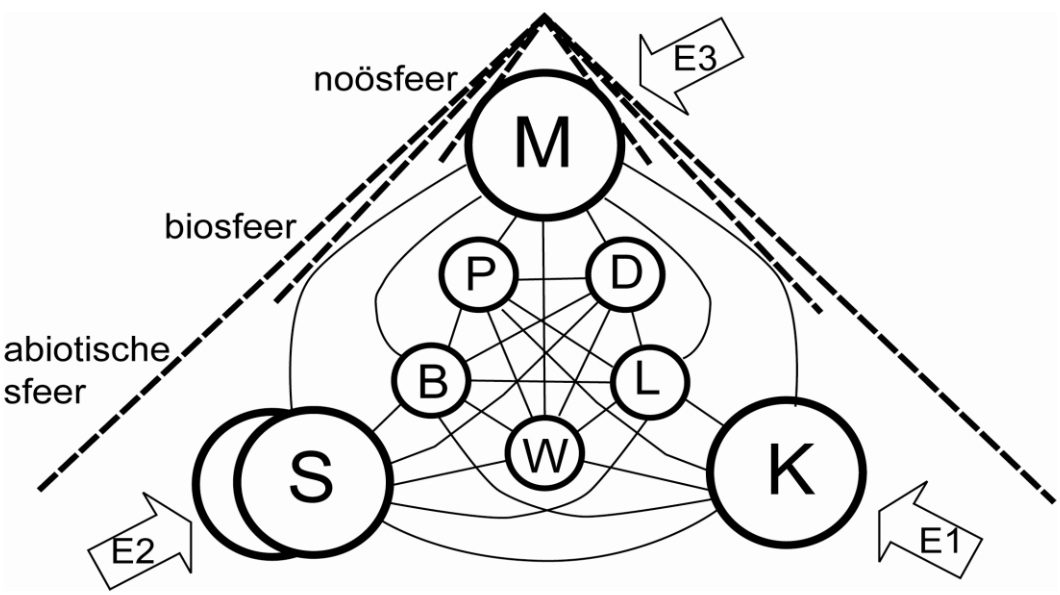


Figure 30 The landscape as an open system (Bron: Zonneveld, 1985)

Just like Pedroli (2009) we can subdivide the effects of climate change into different categories. First of all we have the primary effects like the change in temperature, precipitation and storminess. These primary effects induce some secondary consequences. For example flooding, water shortage in the soil, saltwater intrusion, etc. In a next stadium the secondary effects influences nature, agriculture, recreation and tourism, etc. by heat stress, biotic and abiotic vulnerability (for example the extinction of some plant or animal species), etc. When we combine all these primary, secondary and tertiary effects we become the total effect on the landscape which is the resultant of the effects, whether or not we will have properly adapted to climate change.

4.2.2 Impacts on the landscape

We will discuss the influence of each primary effect on the landscape. Some of them are subdivided into more specific parameters of the climate change. We will consider temperature, precipitation, change in carbon dioxide, storminess and sea level change.

4.2.2.1 Increase in temperature

A global average temperature rise from 1.4 to 5.8 °C (depending on the low or high scenario) is calculated for the 1990-2100 period with an average increase of 3 °C (IPCC, 2007). It is also to be expected that extreme temperatures and heat waves will be more frequent in the (near) future (Schär *et al.* 2004, Van Ypersele and Marbaix, 2004).

A. *Impact on Nature/Biodiversity*

- The change in temperature will induce a northwards movement of species. The area of distribution of species depends on the minimum and maximum temperature which is tolerated by the specific specie (Vos *et al.*, 2007). In the Netherlands and the UK it is demonstrate that many invertebrate animals passed northwards (Van Ypersele and Marbaix, 2004). In addition to this scientist also found the presence of tropic bacterium in more moderate parts of Europe (Briand *et al.,* 2004) and Schumacker recorded a progress in the presence of some thermopiles lichens (Van Ypersele and Marbaix, 2004). According to Parmesan and Yohe (2003), 81% of the 460 species they studied have moved their habitat to the north. For 99 species the northwards shift was about 600 meter each year (Vos *et al.,* 2007). Many studies confirm that the consequences of the climate change on biodiversity become noticeable and today it's quite clear that there is a northwards movement of the thermopiles species (Van Ypersele and Marbaix, 2004). Unfortunately some species will not be able to make this northwards movement (because of the fragmentation of their habitat) which can cause the extinction of that particular specie. The increase of temperature will also lead to the presence of some invasive species which will have a negative impact on the present day fauna and flora (Van Ypersele and Marbaix, 2004).
- Observations in Europe during 30 years demonstrate that some typical spring phenomenons, like the come out of the leaf buds, occur now six days earlier than in the beginning of the observation period. Beside this the discolor of leafs in autumn occurred 4.8 days later (Van Ypersele and Marbaix, 2004). Foreign research confirmed the earlier

development of the leaf of the oak (Askeyex *et al.,* 2005). Also the 'Instituut voor Natuur- en Bosonderzoek' (INBO) showed that the development of the leaf of the oak and beech is temperature sensitive (Dumortier *et al.*, 2007). Because of the earlier start and the later end the change of frost damage will increase which can make the regeneration more difficult (Dolman *et al.*, 2000).

B. Impact on water

- Due to the higher temperatures there will be an increasing risk of eutrophication. The higher temperatures will strengthen the process of the increase of the primary production of algae which are capable to cover whole water surfaces. This can lead to a decrease of the oxygen content of the water and light penetration. Those consequences can affect the livability of fishes and water plants (Townsend *et al.*, 2003).

C. Impact on agriculture

- Worldwide the increase in temperature of 2 – 3 °C will lead to a decrease of the possible agricultural productions. In the moderate regions (where Flanders belongs to) there will be an increase of the possible agricultural production when the increase of temperature will not pass 2 – 3 °C (IPCC, 2007). The increased temperature will lead to an extension of the growing season. In Belgium De Groof *et al.* (2006) determined an advancing of the crop calendar and the fruit trees of about ten to twenty days. However some crops will not resisting those higher temperatures and will have a lower possible production (Van Ypersele and Marbaix, 2004).
- The increase of temperature will also lead to the presence of some invasive species which will have a negative impact on the present day crops and fruit trees (Van Ypersele and Marbaix, 2004).
- The warmer conditions will make it possible for some new crops, for example sunflowers, to be introduced in Flanders (Van Ypersele and Marbaix, 2004).
- Summarizing, it may be said that when the temperature will increase more than 3 °C the profits will change into disadvantages. In this scenario the agriculture in Flanders will have less adaptation strategies to fight the climate change (Van Ypersele and Marbaix, 2004).

D. Impact on cattle

- When there is an increase in temperature of more than 3 °C there will be a decrease in fodder crop which provide less food for the cattle (De Groof *et al.*, 2006). Too high temperatures in the summer can cause heat stress which affects the quality of the pastures in a negative way and results also in a decrease in food for the cattle. On the other hand the higher temperatures and the higher level of carbon dioxide could also have a positive effect on the pastures. They will increase the speed of photosynthesis and due to a more efficient water use of the pastures themselves. All this will increase the pastures production (den Ouden and Vanderstraeten, 2004).
- The cattle could be affected by heat stress when the temperature exceeds a specific threshold value. Because of this the animal production could decrease. The higher

temperatures could also lead to more frequent outbreaks of exotic diseases (Gobin *et al.*, 2008).

E. *Impact on recreation and tourism*
   - A temperature increase in the summer could be quite favorable for the tourism in Flanders. In the UK, the past warm summers have proven that less people spend their holiday in a foreign country and more foreigner people came to the UK (Parry, 2000, Van Ypersele and Marbaix, 2004). In Belgium and the Netherlands they expect an increase of daytrips and short holidays. People will look up for forests and places full of water to cool down.
   - The increase in tourism also has some negative effects on the landscape. The beaches have to be recovered because of the higher erosion and, in combination with the higher temperatures, the tourists will cause more forest and heath land fires (Dolman *et al.,* 2000; Van Ypersele and Marbaix, 2004; de Jonge, 2008). Furthermore the water level of the rivers in the summer will decrease even more then nowadays which can cause problems to the water tourism (Dolman *et al.,* 2000; Van Ypersele and Marbaix, 2004 ; de Jonge, 2008).

F. *Impact on landscape heritage*
   - Due to the temperature rise some typical elements of e.g. an anchor place can change. This temperature change can also lead to more fragmented landscapes (Vos *et al.,* 2010). Beside that forest fires can destruct protected areas or buildings.

4.2.2.2 Increase of carbon dioxide

According to the IPCC there will be an increase of greenhouse gasses by 25 to 90% (for a range of socio-economic storylines) between 2000 en 2030. They also predict an increase of the CO_2-level by at least 50% at the end of this century (http://www.ipcc-data.org/ddc_co2.html, September 20, 2010).

A. *Impact on nature/biodiversity*
   - The increase of CO_2 will improve the photosynthesis of plants which promote the growth. It is remarkable that the deciduous trees will profit more from this increase than the coniferous trees (Hughes, 2000; Marbaix, 2006).

B. *Impact on agriculture*
   - An increase of $C0_2$ will improve the photosynthesis of plants which promote the growth. Depending on the source the agricultural production will improve with 10 to 30% (Dolman *et al.*, 2000; Bresser and Berk, 2005).

4.2.2.3 Decrease of summer precipitation

d'Ieteren *et al.* (2003) states that the summer precipitation would remain constant or decrease with a maximum of 3%. This decrease in combination with the increase in temperature would lead to losses of availability of water (Gobin *et al.,* 2008).

A. *Impact on nature/biodiversity*
   - The decrease in summer precipitation in combination with higher summer temperatures will provide a higher evaporation and a decrease in river flow (ADAPT, 2008; Boukhris *et*

al., 2006). The groundwater reserves could decrease with approximately 8 to 15% which will have a negative impact on the drink water reserves (d'Ieteren *et al.*, 2003).

- The low river flows in summer and the high fluctuations between winter and summer river flow could also reduce the water availability for aquatic life in riverine ecosystems and wetlands (Woldeamlak *et al.*, 2007).
- The (longtime) absence of water could also affect trees, especially beech and birch (van Ierland *et al.*, 2001). Besides this the trees are in dry circumstances also more sensitive for forest fires (Van Ypersele and Marbaix, 2004).

B. *Impact on water*

- The decrease of precipitation in summer will show a lowering of the river flow in summer by as much as 20 to 70% (Willems *et al.*, 2008). In combination with higher summer temperatures the evaporation rates will increase, potentially leading to drier conditions (Baguis *et al.*, 2010) Woldeamlak *et al.* (2007) demonstrate that more water is lost than can be replenished due to the combination of high evapotranspiration and low precipitation. The annual groundwater levels will decrease by as much as 3 meter. They also demonstrate that land-use plays an important role on the groundwater recharge.
- Low river flows will result in higher concentrates of pesticides en nitrates and they will decrease the water quality (d'Ieteren *et al.*, 2003). The low river flows could also reduce the water availability for aquatic life in riverine ecosystems and wetlands (Woldeamlak *et al.*, 2007).

C. *Impact on agriculture*

- The decrease in summer precipitation in combination with the higher summer temperatures could cause drought stress. Because of this drought stress there could be a decrease in agricultural productions. Beside this there will be an increasing need for irrigation (Van Ypersele and Marbaix, 2004). The drought stress could also strengthen the effect of wind erosion (Dolman *et al.*, 2000).

D. *Impact on cattle*

- A decrease in summer precipitation and too high temperatures in the summer can cause drought stress which affects the quality of the pastures in a negative way and results also in a decrease in food for the cattle (den Ouden and Vanderstraeten, 2004).

E. *Impact on landscape heritage*

- The lack of summer precipitation can affect some archaeological material. High groundwater tables are a good conservation condition for archaeological material. A lower groundwater table can due to the degradation of archaeological material by chemical, biological and physical processes (Howard *et al.*, 2008).

4.2.2.4 Increase in winter precipitation

Most of the sources correspond to each other. They all project an increase of the winter precipitation of 3 to 23% depending of the specific climate scenario (Van Ypersele and Marbaix, 2004).

A. *Impact on water*
   - The higher winter precipitation will cause an increase in river flow by 4 to 28% (Van Ypersele and Marbaix, 2004). This increase induces a higher risk for flooding. The projections of the high water flow for each river depends on the used climate model and the soil, land use, topography and urbanization characteristics of the specific river (Viaene and Mostaert, 2000; Willems *et al.*, 2007). An important parameter is the percentage of paved ground. The higher this percentage, the faster the runoff and the higher the risk for flooding (Willems *et al.*, 2008). Some propose that the increase of river flow will be reduced due to the higher evapotranspiration (Willems *et al.*, 2008).

B. *Impact on agriculture*
   - The increase of precipitation could cause higher soil erosion. Especially the most intensive rain could strengthen this effect. This could also affect the possibility to work on the land (Van Ypersele and Marbaix, 2004).

C. *Impact on landscape heritage*
   - The higher precipitation can cause an increase in river incision and lateral migration. This can destruct parts of archaeological sites and protected heritage like solitaire trees, sunken roads, etc. Especially heritage that is situated in the lower parts and/or near rivers are very sensitive for this kind of destruction. Also the increase in soil erosion can destruct or bury some valuable elements (Howard *et al.*, 2008).

4.2.2.5 Increase in storminess/extreme events

In general a tendency towards more frequent extreme events, which will have mostly adverse effects on natural and human systems, is expected but not quantified yet (IPCC, 2007). In Belgium it is expected that there will be an increase in number and intensity of rain showers by 10 to 40% (FLOODSITE, 2006).

A. *Impact on nature/biodiversity*
   - An increase in intensity and frequency of storms will clearly have an impact on forests, e.g. winter storm 'Lothar' which ravaged France on the 26th of December 1999 and destroyed about 4% of the forests (http://www.absconsulting.com, September 16, 2010)
   - In combination with the increase of carbon dioxide the plant/tree will decrease the biomass of her roots by which the plant/tree will be more vulnerable to storms (windthrow) (Dolman *et al.*, 2000; IPCC, 2007).
   - Heat waves will increase the chance for forest or heath land fires (IPCC, 2007).

B. *Impact on water*
   - Flooding will be caused by big precipitation events by which the peak discharge strongly increased in a short time period. The projected increase in frequency and intensity of storms will enlarge the chance on peak discharges (Dolman *et al.*, 2000; Bresser and Berk, 2005). Heavy precipitation will also have adverse effects on the quality of the surface water and the groundwater (IPCC, 2007).
   - Heat waves can lead to an increased water demand which can influence the water quality in a negative way (IPCC, 2007).

C. Impact on agriculture

- Heavy precipitation will strengthen the on-going soil erosion. This will be negative for as well as the agricultural fields and the streams and rivers. When the sediment, which is rich in organic, nitrogen and nitrate material, comes into the water, it can cause eutrophication (De Groof *et al.*, 2006). The heavy precipitation will also lead to the inability to cultivate land due to waterlogging of soils (IPCC, 2007).
- Heat waves can destroy the crops (IPCC, 2007).

D. Impact on landscape heritage

- Heavy storms can destruct protected monuments (ancient buildings), point relics (solitary tree), protected views of villages and cities, etc.

4.2.2.6 Sea-level rise

The sea level rose between 10 and 20 cm during the 20th century (IPCC, 2007). The tide gauge data for The Flemish coast indicate a sea level rise of 1,5 mm/year. The IPCC project in the period 1999 – 2099 a sea level rise between 0,18 and 0,59 cm depending on the different scenarios (IPCC, 2007).

A. Impact on nature/biodiversity

- The sea level rise can affect the natural condition by salt water intrusion of estuaries and freshwater systems (IPCC, 2007). This could be deadly for some freshwater fauna and flora.

B. Impact on water

- The higher sea level can decrease the freshwater availability due to saltwater intrusion (IPCC, 2007). This could affect the food production and the drink water availability (IRGT-KINT, 2004).

C. Impact on landscape heritage

- The sea level rise can affect the landscape heritage e.g. the flooding of the protected views of villages and cities, the change in view, structure and dynamics of anchor places that are situated in lower areas, etc (Beniston, 2008).

4.2.3 Conclusion

To understand the influence of the climate change on the landscape, which is a holistic phenomenon, it is necessary to consider the influence on the different aspects from which the landscape is built. All those landscape elements are not linear connected to each other but are part of a complex entity with dynamic interactions between the different components. It is quite difficult to detect the effects of climate change on e.g. an anchor place. Such an anchor place is set up by different elements like forests, lakes, agriculture fields, specific types of settlement, etc. so that we have to consider the influence on each individual element without forgetting the complex interactions between those different elements. Changes in the water level of the lake or river can have for example serious consequences for the biodiversity, for the crops and even for human being. To conclude we can say that it is not easy to determine the influence of climate change on the landscape heritage. On the one side you have heritage elements that are quite little, e.g. a solitary tree, a sunken road so that is hard to project the influence of the climate change. On the other hand we have some large protected areas where different elements interact with each other and play an important role. Here we have to combine the different effects and keep in mind that the different effects can affect each other.

4.3 Changes in structures of human activities due to climate change

4.3.1 Introduction to the Flemish condition

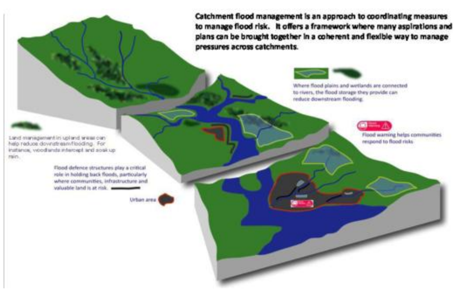
In this section the relevant potential secondary impacts of climate change (PSIcc) on the structures of human activities (SHA) for spatial planning are discussed. Various theoretical en practical studies have been conducted so far on climate change impacts and adaptation in Flanders/Belgium. The process of integrating all this knowledge is in progress and new research is underway. The results on the PSIcc are part of ongoing research and therefore this section is a research in progress.

The Flemish policy plan, 'the Spatial Structure plan Flanders' is the departure point for work package 4 within the CcASPAR research project to assess the PSIcc on SHA. The structures of human activity are defined in the Spatial Structure Plan Flanders for the period 2002-2007 (RSV, 2004) as: urban areas (and urban networks), rural areas (non-urban areas), the areas of economic activity and line infrastructures, (i.e. roads, railways, waterways, pipelines and electricity grids). For these 4 key components the desired spatial structure based on four spatial principles, (i.e. de-concentrated clustering; gates as the engine for development; infrastructures as a basis for binding character and location of activities; and the physical system as structuring component), is formulated in the RSV.

There are some important points of departure to describe the Flemish SHA in relation to the possible effects of climate change. First Flanders is part of an international delta, which means it has a specific water related physical system. It is widely recognized that delta's worldwide, where high population densities, rich agricultural resources, high-value infrastructure, and large freshwater flows that converge at the sea, are potential flashpoints for the climate challenges. Secondly, Flanders has a unique fragmentized spatial structure due to the scattered SHA all over the territory. See for example Figure on which are shown all buildings in Flanders. As a consequence, third, this spatial morphology has a high mobility driven character and generates a lot of networks (e.g. roads, railroads, electricity grids, sewerage grids). For all clarity the buildings as seen on Figure 33 are certainly not all the SHA and the white patch in the centre is the Brussels Capital Region.

First - Flanders is part of the Rhine-Meuse-Scheldt-delta. Two of these international river basins, the Meuse and the Scheldt, flow through the Flemish territory, see Figure 32. As mentioned above, one of the basic Flemish spatial principles in the RSV, as being part of this delta, is that the physical system is characterized by stream and river valleys structures space. Operating at the level of the rural areas, spatial structuring of the physical system means that the intrinsic characteristics of the existing physical system are the guiding framework for spatial development defining features of the structure of nature, forest, agriculture and housing.

Figure 31 shows in abstraction an example of such a stream or river catchment –here an example of the Scottish Government to indicate the importance of water management - that structures the Flemish territory. As seen on Figure 32 the whole territory of Flanders is veined with such stream and river valleys. When the settlement pattern (all buildings in Flanders) of Figure 33 is taken into account in relation to the morphology of the physical system shown in Figure 31, it becomes logical that integrated water management can be considered as a key factor for spatial development. Nevertheless the spatial development derailed through history, with building in floodplains as an example par excellence and is now one of the challenges to counter in relation to potential climate change effects.



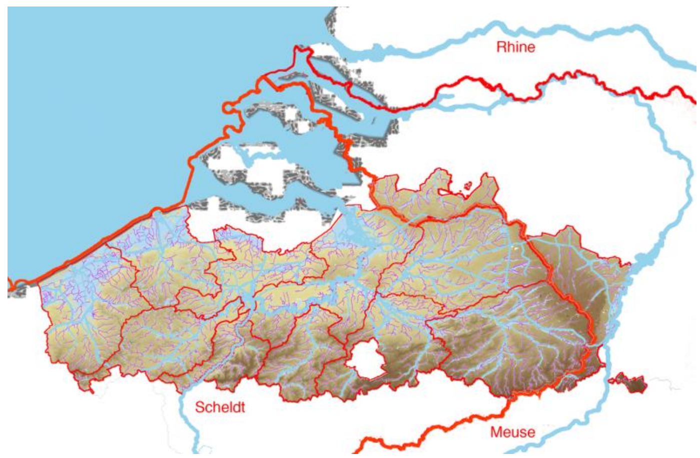


Figure 31 - Left: Example of a river catchment + water management (Scottish Government)

Figure 32 - Right: Flanders as part of the RMS-delta + digital elevation model Flanders with 11 river basins in red, rivers (category 1, 2, 3) and the natural flood areas and recent flooded areas in blue (Ghent University -AMRP)

Second - A historically developed spatial spread followed by unbridled suburbanisation and internal and European/global external development pressure have given Flanders a highly idiosyncratic spatial morphology. This so-called 'nebular city' is characterised by endless overlapping construction forms that often severely deface existing open spaces. One result of this characteristic morphology is that space becomes highly fragmented, a phenomenon that has not come to a halt. The fragmented space is also in direct proportion to the increased pressure on available space because new or additional developments generate an even greater demand for space. The SHA are literally to be found everywhere on the Flemish territory, however in different shapes, formats and densities, but the complete territory is somehow covered with SHA.

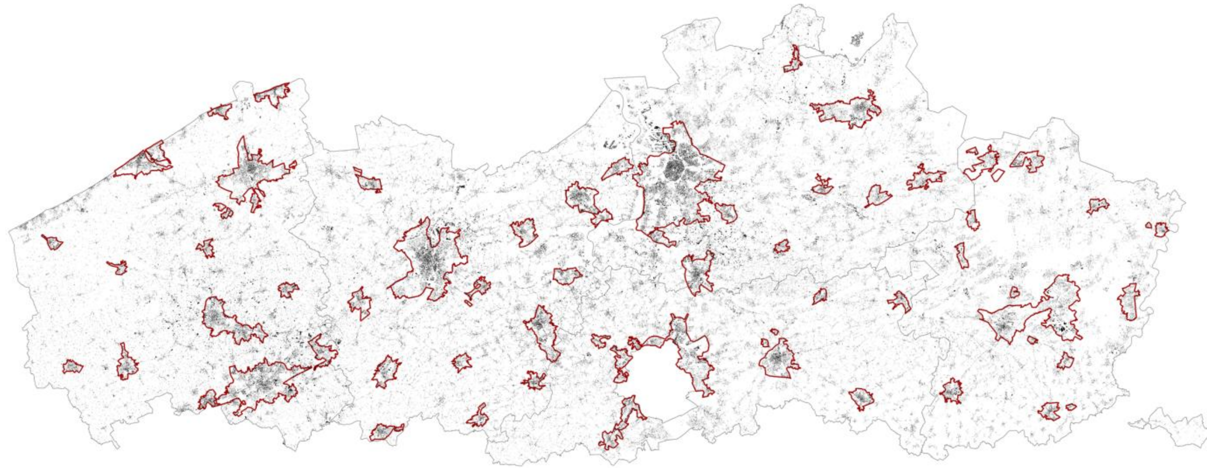


Figure 33: All buildings in Flanders - Kadvec 2005, urban areas in red (Ghent University - AMRP)

Third - The last point of departure from a spatial planning point of view is that the overall structure of Flanders, as it exists today, has a high mobility driven character. Referring to its fragmentized state, the accessibility is determined by mobility. Mainly the ribbon development and the encouraged spatial segregation of functions generate a lot of (auto)mobility. In other words, Flanders has a high car driven structure. Although there is a qualitative public transport (e.g. train, bus, tram), it is almost impossible to retain the same accessibility trough public transport for the whole territory.

Figure 34: Primary and secondary roads in Flanders in combination with aggregated morphological nucleuses (blue), urban areas in red (Ghent University - AMRP)

Figure 34 gives an impression of the roads needed to ensure the accessibility of the scattered settlement structure (here in function of the readability of the map only the primary and secondary roads are shown). Within the RMS delta, Flanders/Belgium lies at the intersection of economically strong regions such as the Dutch Randstad to the north, the German Ruhr region to the East, London to the west and the Paris and Lille-Roubaix-Tourcoing urban zones in France to the south. (RSV, 2004 and L. Boelens, 2008) As a result of its location, Belgium is, to a great extent, a transit country. Flanders alone has around 6,000km in main and regional roads (not including local roads) that simultaneously connect and divide the spaces between settlement structures.

Another example of Flanders network generating structure as a result of its spatial lay-out is shown in Figure 35, which gives an impression of the waste water structure, part of the integrated water management.

Figure 35: Wastewater infrastructure in 4 different areas in Flanders - Ostend, Mol, Sint-Niklaas and Geraardsbergen (Vlaamse Milieumaatschappij, 2010)

A direct consequence of the spatial settlement structure in Flanders is that wastewater treatment requires a huge investment, both financially and in time and space. In Figure 35 we see four different reference areas for Flanders: the area around Ostend at the coast in the West, the area around Mol in the east, the area around Sint-Niklaas in the north and the area around Geraardsbergen in the southern part of Flanders.

The orange shading represents 'central region', which is connected to a wastewater treatment plant. The green coarse shading stands for 'collectively optimized area' and is like the orange areas also connected to a wastewater plant. The green fine shading represents 'collective area to optimize' and the red shading stands for; 'to be optimized individually sewage treatment facility', the so called IBA's.

The maps clearly show that a lot still must be optimized with all the necessary investments as a consequence. During the optimization and beyond, it is likely that the settlement structure in the orange and green coarse shading will be compacted. This is the return on investment benefit, but it also enhances the fragmentation of space. The next question is whether this spatial organization is desirable when we look ahead in the long term? When densifying the settlement structure according to this pattern, the proportion of hardening increases. This in itself brings more water in the circuit that needs to be treated with the result that the capacity of the wastewater treatment needs to be adjusted, with the corollary additional investments. For information and clarity, Flanders is developing a separate sewerage system since 1996.

4.3.2 Potential impacts of climate change

4.3.2.1 A climate change framework

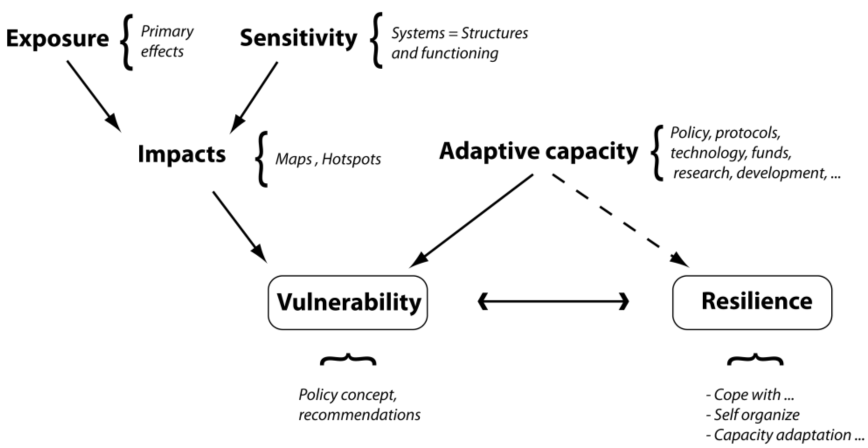


Figure 36: Climate Change Adaptation Framework according to IPCC (Bernstein L et al., 2007); Füssel and Klein (Füssel and Klein, 2006); Adger (Adger, 2006) (Verhofstede, 2010)

What is adaptation to climate change? When we look into the literature, the following framework can be applied. In Figure , vulnerability is determined by the exposure to primary effects of climate change, the sensitivity of the structures of human activity and the adaptive capacity of system under stress. Exposure and sensitivity determine the impacts of climate change, these are the secondary effects of climate change.

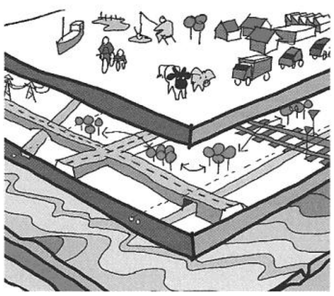
As a reminder, the social and spatial characteristics of the system are decided in its sensitivity, i.e. factors and driving forces. These are the socioeconomic, environmental, demographic and political factors, that are in turn controlled by drivers, such as the degree of economic diversification, the degree of education, etc. Mitigation enables to adapt the exposure side, while adaptation enables to adapt the sensitivity of a system. The CcASPAR-project focuses on adaptation, although it's not right to disconnect both concepts.

4.3.2.2 Structures of human activity and their functioning

From the previous, we conclude that the substratum with the complete water related system and the extensive settlement pattern, that is network generating in itself, is decisive for the potential impacts of climate change for Flanders. From above mentioned framework we conclude that the secondary effects occur when primary effects intervene with sensitive – in the case of WP4 –SHA. The effects may have an impact on both the built *structure* (e.g. roads that are pushed under the influence of temperature) and on the *functioning* of the structure (e.g. traffic congestion when snowing, unattainable factory by a flood). Certain structures exhibit certain robustness, but they can be vulnerable in their functioning. It arises to investigate the SHA on this duality.

To do so a structure and functioning analysis has to be applied. Figure 37 shows the layer approach (Mirup, 2003) to analyze and describe the structures in different layers, which are respectively: the substratum (including the water related system), the network and the occupation layer. Each layer is accorded to a 'time-dimension' in relation to its development time and inertness to change.

STRUCTURES



3. **Occupation**: Structures that have a high rate of change, changes are taking place mostly within a generation (10 to 40 years)

2. **Networks**: Structures that have high upfront costs and long lead times, significant changes in these layers take approximately 20 to 80 years

1. **Substratum**: Structures that have a long history and are vulnerable, important changes require quickly over a century

FUNCTIONING

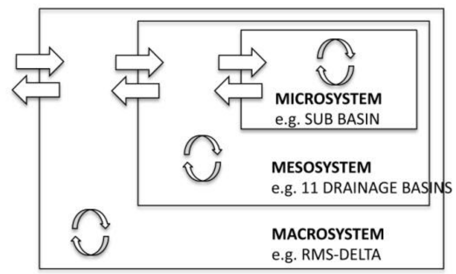


Figure 37 - Left: The Layer approach puts the existing space into 3 layers with a different time scale (Mirup, 2003)

Figure 38 - Right: The system-scale approach (Ghent University – AMRP own processing of the example of State of the art climate in the city - KvK)

To investigate the functioning, a system-scale approach is applied. Figure 38 shows this understanding (Rijke et al., 2009) The departure point of view to look at any given system starts as a principle at the meso-scale. The arrows represent the system relations to a lower micro-scale-system, a higher macro-scale-system and the internal system interactions. The arrows stand for any kind of transport of goods or power fields in between the different scales and the considered scale itself (e.g. water, energy, mobility, waste, pollution, etc. but also different kind of services like ecosystem services)

Figure 39 shows the considered SHA taken into account in WP4. There are 7 main categories, which are divided into several sub-categories. The subdivision accords to their spatial morphological appearance. What the occupation layer is concerned, it consists of different land cover classes (e.g. any ribbon mesh size can contain as well hardened surface as garden coverage). According to Figure 39 , the first 4 categories (I, II, III and IV) are considered as the occupation layer, the next 2 categories (V and VI) belong to the networks and the last category (VII) is part of the substratum. Although it is possible for the latter to divide it in the future as follows: the navigable waterways as part of the networks and the non-navigable waterways as part of the substratum. Further analysis on the meso and micro level has to bring clarity on this matter.

Considered SHA *(WP4: focuses on residential & economic structures of Human Activities)*
(differentiated through properties, e.g. % of hardened surface vs green and blue structure; densities; used materials; relations)

I.	Urban area	I.a.	uban core
		I.b.	urban fringe
		I.c.	urban networks
II.	Ribbons	II.a.	mesh size x
		II.b.	mesh size y
		II.c.	mesh size z
III.	Dots		
IV.	Economic nodes	*(all urban areas are considered as economical nodes)*	
		IV.a.	gates *(e.g. seaport of Antwerp, Zaventem international airport, HST-station Antwerp)*
		IV.b.	economical network *(e.g. economical network Albertkanaal)*
		IV.c.	economic hub outside urban areas and economic networks
V.	Roads	V.a.	roads *(differentiated in categories)*
		V.b.	railroads
		V.c.	tram grids
VI.	Utility networks	VI.a.	sewerage systems
		VI.b.	electricity grids
		VI.c.	natural gas grids
		VI.d.	cable distribution grids *(telephone, internet, cable tv)*
		VI.e.	wireless grids
		VI.f.	other grids *(e.g. industial gas grids)*
VII.	Waterways	VII.a.	navigable waterways *(differentiated in categories)*
		VII.b.	non-navigable waterways *(differentiated in categories)*

Figure 39: Considered Structures of Human Activity (SHA) in WP4

It is in the functioning that the different spatial structures interrelate with each other and gives reason for an integrated system approach. To do so Figure 40 gives way to this approach in relation to the primary effects of climate change according to the previous mentioned climate change framework.

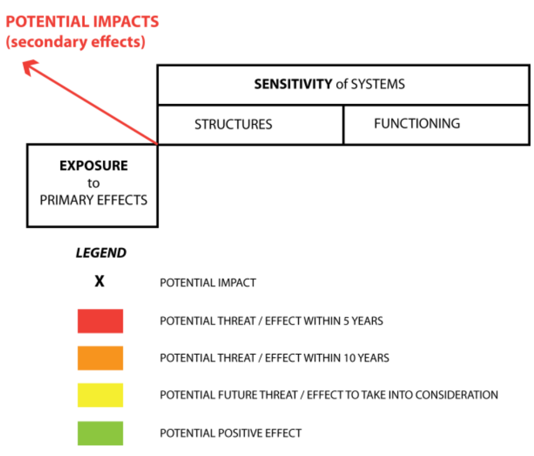


Figure 40: Framework potential impacts (Ghent University - AMRP)

The above-described methodology is not yet applied in the following potential impact cross-table (see Figure 41), because as mentioned before this is a research in progress and this kind of analysis has to be applied in the integrated case studies at meso-scale level, one at the Coast and one in the Kempen region. Afterwards the experiences from the different exercises can be scaled-up to more concrete understanding at macro-scale level. Some effects are added (frost, snow and windless), because they also can affect the structures and the functioning (e.g. windless days in combination with sunshine and higher temperatures may cause summer smog, which can affect human health. This can in turn have an effect on the mobility because of governance rules.)

	OCCUPATION										NETWORKS									SUBSTRATUM	
	Urban area			Ribbons			Dots	Econmical nodes			Roads			Utility networks						Waterways	
POTENTIAL IMPACTS	I.a.	I.b.	I.c.	II.a.	II.b.	II.c.	III.	IV.a.	IV.b.	IV.c.	V.a.	V.b.	V.c.	VI.a.	VI.b.	VI.c.	VI.d.	VI.e.	VI.d.	VII.a.	VII.b.
Potential Sensitiv SHA / Exposure PE	Urban core *	Urban fringe	Urban network	Ribbon mesh size x	Ribbon mesh size y	Ribbon mesh size z	Dots	Gates	Economical network	Other Economic hubs*	Motorways **	Railroads	Tram grids	Sewerage systems	Electricity grids	Natural gas grids	Cable distribution grids	Wireless grids	Other grids ***	Navigable waterways **	Non-Navigable waterways **
Temperature	x	x	x	x	x	x	x	x	x	x	x	x	x		(x)						
Precipitation	x	x	x	x	x	x	x	x	x	x	x	x	x	x						x	x
Evaporation	x	x	x	x	x	x	x	x	x	x				x						x	x
Sea Level Rise	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	(x)				x	x
Strominess	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	(x)	(x)	(x)	(x)	(x)	(x)
Drought	x	x	x	x	x	x	x	x	x	x				x						x	x
Inland Flooding	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x					x	x
Frost	x	x	x	x	x	x	x	x	x	x	x	x	x								
Snow	x	x	x	x	x	x	x	x	x	x	x	x	x								
Windless	x	x	x	x	x	x	x	x	x	x	x										

* Inclusive historical nucleuses
** Differentiated in subclasses
*** e.g. Industrial gas grids / pipe lines (O2, crude oil, ...)

Figure 41: Potential impacts cross-table (Verhofstede, 2010)

4.3.2.3 Impacts of primary relevance for spatial planning on a regional level

In Figure 42 the relevant impacts for spatial planning at the regional are given (Rannow et al., 2010). In the first column the different potential primary effects are shown which can induce potential impacts. As the connecting lines between the first and the second column indicates, there is no “one on one” relation between the effects and the potential impacts. Figure 42 shows in a very simple and fictitious example how an increase of temperature can induce a cascade of effects. It proves how important it is to consider these climate change effects in an integrated way.

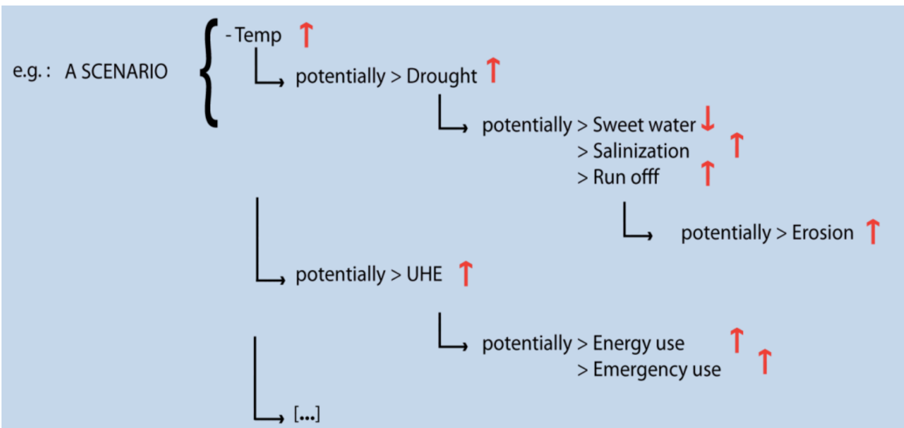


Figure 42: Cascade of potential effects due to an increased temperature (Verhofstede, 2011)

In the second column of Figure 43 18 relevant impacts are listed which need to be taken into consideration when developing spatial planning outcomes. The list is a first version and has to be discussed in the further research. The third column shows whether there are historical references for the impacts or plans and monitors, that are already in place. For example the potential flash floods from rivers are monitored by an instrument that is already in place: “The flood forecast instrument” applied by the Flemish Environmental Agency. In the third column there is also a difference between effects caused by extreme events and by slow changes.

Eventually the intention for the near future is fill in the available input data and put a classification in place to develop on the one hand potential exposure maps (classification of primary impact data) and on the other hand sensitivity maps (classification of sensitivity data).

[PE] - Primary Effects CC	[PSE] - Relevant Potential Secondary Effects for Spatial Planning	[HR] - Historical References and/or Plan in Place	Available data
	Caused by extreme event, increase of:		
Temperature	Flash floods	Flood Prediction System e.g. abundant rainfall November 2010, May and july 2009 were recognised as general disasters	To fill in (...)
Precipitation			
Evaporation	Pluvial floods	e.g. local floods in cities as a consequence of inadequate sewage system. Construction of retention basins at the local level, e.g. Sint-Niklaas	
Sea level rise			
Storminess	Storm surges	e.g. flood 1953, combination of springtide and a North-West storm. Implementation of Sigma plan Scheldt river	
Drought			
	Heat waves	e.g. +3,62% additional deaths during heat wave summer 2003 (4 months)	
Frost [NI]	Urban heat island effects	e.g. n/a - research in progress. It is assumed that the historical cores and nucleuses are potential hot spots for UHE	
Snow [NI]	***Other not included effects caused by extreme event***		
Windless [NI]	Summer smog [NI - *not included in CcASPAR research project*]	e.g. yearly summer smog days - Monitoring by VMM	
	Winter smog [NI]	e.g. yearly winter smog days - Monitoring by VMM	
Other parameters	Ozon [NI]	e.g. yearly ozon days (traffic 90km/h) - Monitoring by VMM	
Hardened Surfaces *(see table)*	Forest fires [NI]	e.g. n/a	
Mobility	Mass movement (avalanges and landslides) [NI]	e.g. n/a	
Population density	***Caused by slow changes***		
	Decrease of Ground water level	e.g. The measurement results of 507 time series were statistically analyzed for the period 1999-2009 (absolute trends, relative to TAW). Approximately 40% showed no statistically significant trend and there are more declines than increases. Falling water tables remain a major problem - VMM	
	Decreased Water availability	e.g. Depending on the method, measurements show that on average each year in Flanders and Brussels between 1100 and 1700 m^3 of water per person is available. Internationally seen this is "very little". The main cause of low water availability is the major population in Flanders and Brussels. The available water must be divided over a large populatiom - VMM	
	Loss of species and biodiversity	e.g. possibility that 18 summer bird species and 16 butterfly species will become more vulnerable due to increased temperature - CPA	
	Increased Erosion (loss of soil)	e.g. Each year some 2 million tons of soil erodes by water. This estimate is based on model calculations taking into account rainfall, soil type, topography and land use. Approximately 0.4 million tons of eroded soil ends up in waterways - VMM	
	Increased Salinisation	e.g. Conductivity measurements of water production locations at the coast show that the freshwater / saltwater boundary as a result of abstraction moves up (less depth will be located). This indicates a salinisation of the coastal area that has important implications for water in this region - VMM	
	Other not included effects		
	increased Energy demand	*e.g. Direct influence:* - Diminution of gas and electricity consumption due to increasing winter temperature. Rise of electricity consumption for cooling due to increase in average summer temperature. Strong fluctuations in energy demand as a consequence of extreme weather conditions. *Influence on operational management:* Potential shortage of cooling water for electricity plants Potential negative influence on productive capacity of wind farms due to increased chances of storms Positive effect on the use of solar energy due to increased hours of sunshine. Unquantified influence on transport and distribution of energy *Possible indirect effects:* Change of consumer perception on energy demand due to more rational energy consumption - CPA	
	Transport	e.g. Potential pressure on road-, rail- and airport infrastructure as a consequence of peaks in temperature, precipitation and increased chance for storminess (e.g. melting asphalt, bursting rails, broken overhead wires due to higher wind velocities or falling trees). Precarious traffic situations as a result of bad weather conditions.	

Figure 43: Relevant potential impacts for spatial planning at the regional scale of Flanders, in accordance with Rannow et al. (Rannow et al., 2010)(Verhofstede, 2011)

4.3.3 Some additional information

4.3.3.1 On urban areas

Urban areas occupy a unique position within the Flemish territory. As well in relation to what is described before, namely the relation to the physical system of streams and river valleys and the water related system (the substratum), as in relation to what is described in the policy plan concerning the development of additional housing and other infrastructures.

Although the urban areas are logically connected to this complex of river and stream valleys, at the same time they are considered as kind of systems on their own. They do not always explicitly follow the logic of the substratum when the built infrastructure reaches urban densities with a high degree of petrified and densely build space. The following Figure shows the urban system-scale approach in relation to climate change effects. Despite the logic that the urban areas also have to be part of a larger system, in the actual developed urban structure this is not always fully reflected, with resulting potential impacts on the (sub)system or related (sub)systems (Figure 44: e.g. wastewater discharge into a river, pluvial flooding).

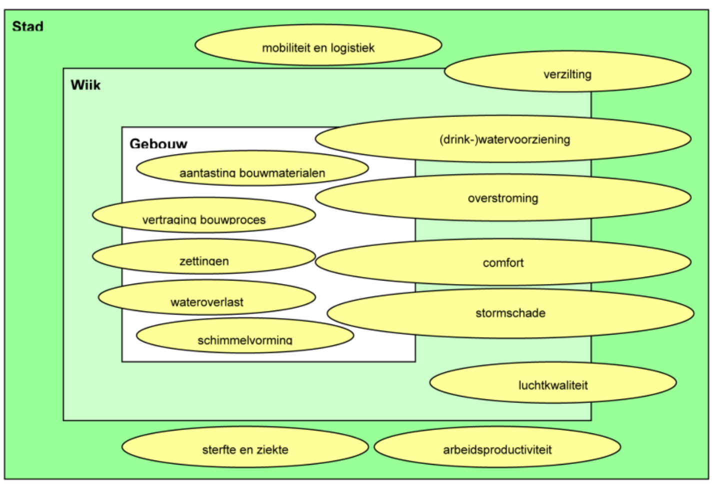


Figure 44: Consequences of climate change in different levels of the city based on Vivian et al. (2005), Van de Ven et al. (2008), Rahola et al. (2008) en Döpp en Albers (2008).(Source: KvK – State of the art: Klimaat in de stad, 2009)

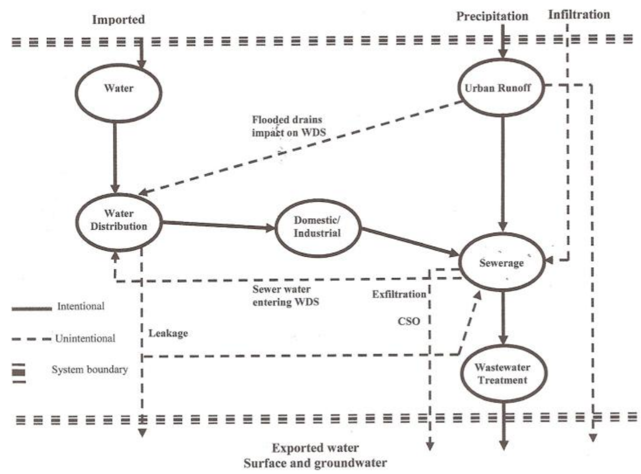


Figure 45: Example of systems and sub-subsystems - The interaction and interconnection of urban water systems (source: Vairavamoorthy, 2008)

4.3.3.2 On potential impacts

Temperature – For the urban areas we take an in-depth look into the urban heat island effect (UHIE) because of the importance of this potential effect and it includes a second primary effect, namely evaporation. To get an insight we look into what the literature says about the UHIE by Gartland Lisa:

"The 'energy balance' explains how energy is transferred to and from the earth's surfaces. The energy balance is based on the first law of thermodynamics, which states that energy is never lost. For a surface on the earth, this means that all of the energy absorbed by the surface through radiation or from anthropogenic heat goes somewhere. Either it warms the air above the surface, is evaporated away with moisture or is stored in the material as heat. The energy balance equation is:

Convection + Evaporation + Heat storage = Anthropogenic heat + Net radiation.

Convection is energy that is transferred from a solid surface to a fluid (i.e. liquid or gas), in this case from the Earth's surface to the air above it. Convection increases when wind speeds are higher, when air becomes more turbulent over rougher surfaces and when temperature differences between the surface and the air are bigger.

Evaporation is energy transmitted away from the Earth's surface by water vapour. The evaporation term also includes evapotranspiration, a more complicated process plants use to keep cool. Both evaporation and evapotranspiration increase when there is more moisture available, when wind speeds are greater and when the air is warmer and drier.

Heat storage depends on 2 properties of materials: their thermal conductivity and heat capacity. Materials with high thermal conductivity are more able to direct heat into their depths. Materials with high heat capacity can store more heat in their bulk. As more heat is stored, the temperature of the material rises.

Anthropogenic heat represents 'man-made' heat generated by buildings, machinery or people. In many areas, especially rural and suburban areas, the amount of anthropogenic energy is small compared to the other terms in the balance equation. In dense urban areas, the anthropogenic term is larger and can be a significant influence on heat island formation.

Net radiation encompasses four separate radiation processes taking place at the Earth's surface, i.e. incoming solar, reflected solar, atmospheric radiation and surface radiation). The *incoming solar* represents the amount of energy radiating from the sun and varies based on season, time of day, amount of cloud cover and the atmospheric pollution levels. *Reflected solar* radiation is the amount of solar energy that bounces off a surface, based on the solar reflectance of the material. White materials reflect more than dark surface materials. *Atmospheric radiation* is heat emitted by particles in the atmosphere, such as water vapour droplets, clouds, pollution and dust. The warmer the atmosphere and the more particles it contains, the more energy it emits. Surface radiation is heat radiated from a surface itself. This term is highly dependent on the temperatures of the surroundings.

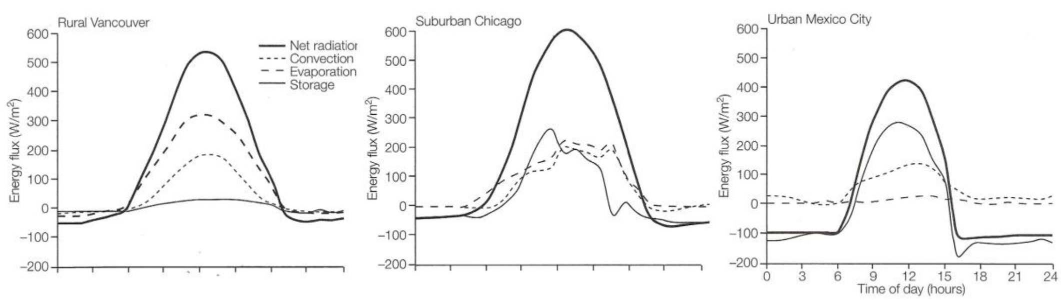


Figure 46: Daily energy balance measurements under clear sky conditions in a rural Vancouver area during the summer of 1983, a suburban Chicago area during July 1992 and an urban Mexico city area during December 1993 – Source: Gartland L., 2008, p17 (Cleugh and Oke, 1986; Grimmond and Oke, 1995; Oke et al, 1999)

Figure 46 shows the daily energy balances for rural, suburban and urban areas in Vancouver, Chicago and Mexico city. Important characteristics of these sites are listed in Figure 47. The most striking distinction between the three plots in Figure is the decrease of evaporation energy from the rural area to the suburbs and finally to the urban area. This change coincides with a decrease in vegetation coverage from 100 per cent of the land area (rural), to 44 per cent (suburban) to a mere 2 per cent (urban). Attending these shifts in evaporation energy is an increase in heat storage during the day and in heat release at night." (Gartland, 2008).

	Rural Vancouver	Suburban Chicago	Urban Mexico City
Land use (2-D view)			
Vegetation and water	100%	44%	2%
Buildings	0%	33%	43%
Impervious pavements	0%	23%	55%
Weather			
Rainfall during study	Yes	Yes	No
Incoming solar (W/m^2/day)	5380	7000	4920
Daily energy balance ratios			
Net radiation/incoming solar	0.66	0.60	0.15
Convection/incoming solar	0.20	0.21	0.23
Evaporation/incoming solar	0.45	0.28	0.03
Heat storage/incoming solar	0.04	0.19	0.31
Heat release/incoming solar	0.03	0.08	0.42

Figure 47: Characteristics of the land use, weather and daily energy balance of a rural Vancouver area, a Chicago suburb and a Mexico City Urban Area - Source: Gartland L, 2008, p18 (Cleugh and Oke, 1986; Grimmond and Oke, 1995; Oke et al, 1999)

Up till now there is not much information on UHE and research is underway for Flanders. Two papers examined the UHIE for the Brussels Capital Region and confirm existence of the UHIE, namely (Van Weverberg et al., 2008) and (Hamdi et al., 2009). The urban heat island (UHI) of Brussels was found to have a significant impact on the temperature record in Uccle. By analyzing the surface energy balance it was revealed that the UHI is mainly caused by a greater storage of energy in the urban fabric during the day and a release of this heat in the evening. The UHI had a significant average impact on the Uccle temperature record during two of the four selected weather situations. The effect amounted to 0.77°C in a cloudy weather situation with westerly winds and to 1.13°C in a clear and calm weather situation. (Van Weverberg et al., 2008)

One of the most important effects due to heat waves is the increased mortality during these periods. Because of the extreme temperatures the chance for the UHIE is severe. As described in the primary effects this potential threat can occur during summer time in the month of August. Elderly people, sick and recovering people, new born people in hospitals and kids in day care centres are considered vulnerable.

More research is needed on the impact of the UHIE for Flanders, for example on: other urban areas like Antwerp or Ghent, urban networks, smaller entities of built structures, nucleuses in rural areas, etc. What will be the effect in relation to the UHIE and the ongoing urbanization and suburbanization processes?

We conclude for the urban areas that the used materials, amount of hardened surfaces, urban morphology (design), urban green and water can influence to a certain extent the UHIE.

Heat can also influence constructions and building materials and need to be taken into account on the design table to assure the functioning (e.g. raising or expanding concrete)

Precipitation – can cause pluvial flooding in urbanized areas as a result of the high amount of hardened surfaces in combination with low retention and/or sewerage capacity. The risk of pollution is severe if the storage capacity is reached and the surplus water is discharged into rivers or streams.

Precipitation can also cause flash flooding when the area is situated next to a river or stream (e.g. extreme rain shower from 12 – 14 November led to a peak discharge on 15 and 16 November). It is widely known in Flanders, that due to the raising demand for land and the belief in technological solutions no space is left over for water. History has already shown that potential risks can increase because the technological implementations are not always fully adjusted to the changing conditions through time (e.g. population growth and urbanization, globalization and economic development, climate change, governance and privatization, risks on critical infrastructure). Due to these pressures, providing safe water supply, basic sanitation and maintaining the environment is likely to be more difficult in the future (Vairavamoorthy and van der Steen, 2009)

Evaporation – includes evapotranspiration (see Temperature). Urban water bodies, parks, gardens, trees can have mitigating effect on potential heat waves or UHIE by moisturizing the air.

Sea level Rise – Urban areas in the coastal region (e.g. Ostend) are sensitive for sea level rise, for the time being mostly in combination with stormy weather. Ground floors, basements, underground facilities (e.g. underground parkings), low-lying areas and infrastructure (e.g. roads, tram or train track, electricity cabins, etc.) are potential vulnerable. Similar to the streams in urbanized areas, the SHA at the coast are located in such way that there is no space left to the sea. The policy for the coastal defence that is formulated as the 'Hold-the-line’ principle, indicates this lack of space. What kind of developments will be possible when the sea level rise reaches a worst case of 2 meters and more taking into account the decisions taken in the present? These and other questions need to be investigated in the integrated case studies.

Storminess – Constructions and infrastructure are calculated for certain wind speeds. For example the term 'wind' in the equation to calculate constructions has more weight for open areas than for urbanized areas. Another aspect of urban areas is, that they are made up of buildings, constructions and infrastructure from different periods with different insights in construction logic. For this reason and for the reason that structures become antiquated there is always a possible threat for possible damage (e.g. think of buildings in urban areas in scaffolding with nets strung to avoid any falling debris)

Urban green can also be a threat under severe wind conditions, as the closure of city parks indicates under these circumstances.

Drought – As recent studies and models demonstrate drought may be one of the key challenges for the future. It may have impact as well on structures as on the functioning of systems. Structures on clay foundations with limited depth could potentially be affected if the water table drops due to drought. Drought can compromise the supply of consumption and production water, as well the functioning of the navigable rivers. Rivers are home to many economic activities, as a consequence of drought water-related business can be affected (De Schepper, 2010).

Inland flooding – this is partly discussed under the effect precipitation, reminding pluvial- and flash flooding. Another effect to take into account, but also briefly discussed in the case 'no room for the river', is the potential threat of the Scheldt as tidal river. The Sigma plan is developed to tackle this threat with the implementation of controlled floodplains.

The following effects are added to the list of 'primary effects', because they are also climate related and as the last decade (and before) has shown, they can have effect on the functioning. Frost and snow in winter and early springtime. Smog on windless days in combination with higher temperature and sunshine.

Frost – is mentioned separately from temperature. It can affect the construction and the functioning of buildings, infrastructure and transport of people and goods. (e.g. frost on the roads, on the overhead wire and rails, et cetera.). In Flanders/ Belgium the difference in temperature between winter and summer can easily reach 35 ° to 40 ° Celsius and more, expansion and extension of materials and volumes need to be taken into account.

Snow – Recent events clearly showed potential vulnerability of constructions for snow loads and the vulnerability of the Flemish mobility and the shortcoming capacity to deal with snow.

Smog - Smog is caused by a combination of climatic conditions and emissions as a result of human activities. There are two types: summer smog (brown) and winter smog (gray) and they both have an effect on human health. Slowing down traffic speed as an example has an effect on the functioning. It can have an effect on buildings or on the design of cities from an air quality point of view.

In conclusion we can say that the effects on the structures of human activity is not a one to one relationship, but that they interact. In view of adaptation and to exclude different kinds of externalities, this means that the various examinations, both for the components as the lenses through which one looks at each question should be integrated if we want to formulate intelligent answers.

5 EXPECTED EVOLUTION OF SOCIO-ECONOMIC VARIABLES

5.1 Importance of socio-economic scenarios

Future vulnerability cannot be predicted based only on the climate scenarios, changes in the socio-economic conditions also contributes to it (Ribeiro et al, 2008). As shown in Figure 48, for the socio-economic change in the future there is need to develop scenarios parallel to climate scenarios.

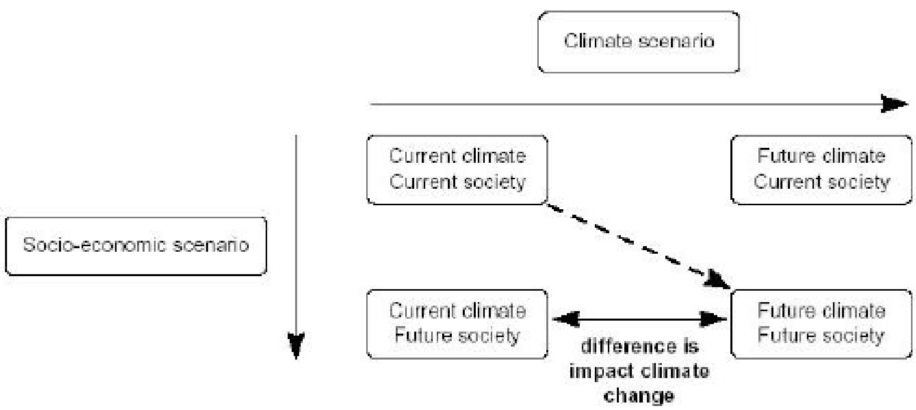


Figure 48 Socio-economic scenarios versus climate scenarios (used in De Sutter, 2010)

The prediction of socio-economic scenario's is not easy as it is a result of very complex set of drivers. The recent financial crisis have once again demonstrated that such unexpected events with huge impact on the socio-economic world situation may occur and are difficult to predict.

The SRES-world images provide little concrete guidance to impact assessment (Van Drunen, 2009). Available socio-economic forecasts refer to a much shorter time scale than climate change scenarios. Most of the available projections extend up to 2030 and in rare cases up to 2050 and 2060. There are no socio-economic projections for the year 2100 on the scale Flanders.

Two circumstances can be considered while making the predictions, one to observe the average or most likely scenario based on the most reasonable evolution of the relevant socio-economic indicators. Another would be the worst case scenario i.e. the evolution of the socio-economic society with the most devastating effects for a given policy field, which is certainly relevant to policy exercises in the longer time scale.

5.2 What are socio-economic scenarios ?

Scenarios are a common tool in order to illuminate possible futures. As we cannot know the future for certain, this tool may help to show what changes from the present are possible in the future. Whilst already used in the environmental sciences in the 1970's, the current interest in environment-related scenarios dates back from the early 1990's (Berkhout en Van Drunen, 2007). An often-quoted definition of a scenario comes from the Millennium Ecosystem Assessment (2005), which states the following:

"Scenarios are plausible, challenging and relevant sets of stories about how the future might unfold. They are generally developed to help decision-makers understand the wide range of possible futures, confront uncertainties and understand how decisions made now may play out in the future".

Scenarios come in many forms. Berkhout and Van Drunen (2007) differentiate global and domain scenarios. Global scenarios provide an integrated view of future developments, including many different dimensions within a single scenario (e.g. a storyline of the future, to which many attributes may be attached). These global scenarios are often used to frame assessments of, for instance, environmental issues (e.g. climate change). They use different driving forces and make statements about several parameters and the general state of the system as a whole. Domain scenarios, on the other hand, generally involve a single issue (e.g. a forecast). They can (and often do) involve multiple driving forces, but they aim to make projections about a single parameter (e.g. the amount of accessible fossil fuel).

When it comes to creating scenarios, there are four qualities that are often mentioned (see Berkhout and Van Drunen, 2007). First, scenarios should be *relevant*. In other words, they should be tailor-made for the objective of the study and not be an end themselves. This is especially related to domain scenarios and less for global scenarios as the latter ones are supposed to provide a frame for follow-up studies. For the CCASPAR project, this means that the scenarios would need to provide information and parameters that are relevant for describing or estimating impacts on the spatial environment, including urban areas, agriculture and nature.. Second, scenarios should be *consistent*, meaning that relations between different driving forces and parameters within a scenario should be accounted for in order to avoid implausible combinations and get a coherent projection. Third, scenarios should be *plausible*. While scenarios are useful to highlight the unexpected, they should be possible at the same time. Fourth, scenarios should be *transparent*, meaning that they should clearly expose assumptions and relations in order for the users to adequately interpret and use the scenarios.

When it comes to global (or national) socio-economic scenarios, a number of main dimensions of change are usually distinguished (see Berkhout and Van Drunen, 2007). The first is economic development, usually including the rate of development (e.g. GDP growth) and the nature of the economy in terms of trade flows and government regulation and provision of services (e.g. globalised vs. regional economy, open vs. regulated). The second dimension is the nature of governance. This is generally related to the relative influence of national governments vs. international organizations (e.g. UN, EU) and possibly private businesses (multinationals). The third dimension relates to technological change. Whilst widely regarded as a fundamental driver at the global level, it is often used as a second order issue in scenarios. The focus is generally on substitutions (e.g. of fuel type) or a general direction and rate of change (away or towards innovative technologies). The fourth and fifth dimensions are more related to the ‘demand’ side instead of the ‘supply’ side. Demographic change, i.e. size and composition of the population, is often well understood and quantified. Social change, on the other hand, is dealt with less consistently. For some domains, like energy, transport and the built environment, this is better represented.

When working with scenarios, especially in the social sciences, there are some important problems to overcome (Berkhout and Van Drunen, 2007). For instance, there are general assumptions of continuity and universality, meaning that processes and trends in the future will be behave similar to observations in the past. Where in the natural sciences this is often (up to a point) accepted by researchers, this is not the case for social systems, which can change significantly over time. Unlike some natural systems, social systems cannot be predicted at all. Generally, this is tackled by looking at a range of possible future socio-economic conditions instead of one, generating a range of possible outcomes. Another issue with scenarios is that they should be viewed within a frame themselves. As everything where mankind is involved, scientific knowledge is inherently subjective, influences by discourses, assumptions and interests of the researchers involved. Whilst it is not possible to overcome this completely, it is argued that underlying assumptions should be made as transparent as possible and uncertainties should be acknowledged explicitly. Overall, the whole process of working with scenarios can be regarded as a joint learning process between creators and users. This can encourage new ways of looking at an issue by, for instance, changing the starting point (i.e. look at some economic or social condition and how climate change may affect it rather than looking at how climate changes first).

Scenarios are often used as a way to deal with uncertainty. In such a case not a single scenario of the future is considered, but multiple scenarios are explored which together envelop a wide range of possible futures (Van Drunen and Berkhout, 2009). A common methodology to derive at a set of scenarios is the so-called scenario axis technique (e.g. Van ‘t Klooster and van Asselt, 2006). Using such a technique two key uncertainties are identified that fundamentally differentiate future storylines. When these two key uncertainties are visualized as two axes in a graph, four quarters are formed, each of which represents a different scenario. The Dutch WLO study (CPB et al., 2006) uses this approach to frame their four storylines (see 4.4).

When multiple scenarios are explored, it’s important to keep in mind that there is usually no probability associated with it. They are just multiple views that are in principle equally likely. Actually, the scenarios used describe only a limited amount of an infinite set of possible futures, that are all different from the ones described. The probability of a specific scenario exactly developing in the real world is therefore close to zero. Still they provide useful handles to explore how the future could (roughly) develop. This also leads to the point that scenarios are not *predictions* (as no probabilities can be given), but they are rather *projections* of possible futures, based on a number of assumptions.

Another important notion is that scenarios are often based on the extrapolation of current trends. The extrapolation implies that any discontinuities (unexpected events or changes much more rapid than at present) are not considered. Such unexpected events (e.g. natural disasters, financial breakdown, etc.) can have a major influence on society and the direction it takes, and are often more important drivers of change. In flood disaster management it is well known that many large protection projects (e.g. storm surge barriers) are built in the aftermath of large flood disasters. Alternatively, one can design scenarios that describe rather sudden events that test the limits of current management policies (e.g. Olsthoorn et al., 2008).

5.3 Projection for Flanders until 2030

Recently, the Environmental Outlook 2030 (Van Steertegem ed., 2009), the Nature Outlook 2030 (Dumortier ed., 2009) and underlying studies at the Federal Planning Bureau (Hertveldt, 2009) developed projections for a number of social, economic and environmental indicators for year 2030 (and partly until 2060). Some conclusions from these documents are listed below.

An interesting source of comparison would be the Dutch-WLO scenarios on a regional geographical scale for year 2040 (WLO, 2006).

5.3.1 Demographic trends

The following data, provided by the Belgian Federal Planning Bureau, should be interpreted as the "most probable scenario", an "average scenario". The population in Flanders will grow by about 12% by 2030, primarily the result of immigration and a temporarily increase in birth rate. The largest increase occurs in 2015, after a relapse occurs. Table 9 shows the "prediction" of the main demographic data. Data are available by district, age and gender.

Table 9 Demographic projections (Hertveldt, 2009)

Indicator	2005	2030	2005-2030 (% increase)
Growth in number of people	33.9	12.4	0.46% per year on average, 12.3% or 6.785 million in total
Share in total population (in%) 0-17 years 18-59 years 60+ years Total	 20,0 57,3 22,8 100	 19,0 50,1 30,8 100	7,2 -1,7 51,9 12,3
Status (in%) Students Working Inactives Total	 21,6 43,7 34,7 100	 19,9 43,1 37,0 100	(absolute change) +45.000 +283.000 +413.000 +741.000
Family Type (%) Single people without children Single person with children couples without children couples with children others Total	 11 8 24 50 7 100	 15 8 27 42 8 100	

5.3.2 Economic forecasts

The following data, provided by the Belgian Federal Planning Bureau, should be interpreted as the "most probable scenario", an "average scenario". The average annual GDP growth is around 2%. The importance of the service sector continues to grow at the expense of the agricultural and industrial sectors. Employment growth rate is stagnated, resulting in a growth of approximately 15% above the level of 2005 in 2030. Table 10 shows a summary of some key information on economic development. These data do not yet consider the impact of the financial crisis.

Table 10 Economic forecasts (Hertveldt, 2009)

Indicator	2005	2030
Share of industries in gross value added (%),		
agriculture,	1,2	1,0
energy,	2,9	2,5
manufacturing, construction,	17,	15,2
trade and catering,	5,0	6,1
transport and communications,	13,5	10,9
financial services,	8,1	9,1
healthcare and social,	6,4	7,6
services,	6,6	7,4
other market services,	25,4	28,0
non-tradable services,	13,3	12,4
Total	100	100
Share of industries in employment (%),		
agriculture,	2,0	1,1
energy,	0,7	0,4
manufacturing, construction,	14,2	8,7
trade and catering,	5,7	5,8
transport and communications,	17,8	17,0
financial services,	6,9	6,8
healthcare and social,	3,3	2,9
services,	11,0	14,3
other market services,	19,0	25,5
non-tradable services,	19,4	17,5
Total	100	100

5.3.3 Future spatial evolution

In the framework of the nature and environmental scenarios for 2030 a number of policy exercises have been carried out for the future spatial evolution in Flanders by 2030. The main conclusions from this exercise are listed below; as summarized from (Dumortier ed., 2010; Van Steertegem ed. 2010) in (De Sutter, 2010):

- The growth of population and economy implies a larger need for residential and commercial buildings. One expects an increase in paved area in between 13 and 17%. In the studies a distinction is made between a number of environmental scenarios (independent of adaptation policy), a scenario based on current policy and a scenario where EU environmental obligations are met.
- This results in an increase in the area for residential & commercial use (increase of 4-5% to a value of 24 and 25% in 2030) and industrial use (between 2 and 4% increase), and a decrease in space occupied by agriculture (a decline of 5-6% to a value around 48% in 2030). This means that around 85% of the currently planned residential expansion areas would be already occupied as early as 2015.
- The area of nature & forest remains in 2030 at about the same level as in 2005 (approximately 17%).
- There are secondary indicators derived as the "seal rate" (the ratio of surface-sealed soil to the total area within a land use category), the density (share of "hard" land use classes within a radius of 1500 m), the fragmentation ....
- Information is available at the level of an administrative district.

Table 11 Observed and modeled land cover proportions (%) in Flanders, basic scenario (Dumortier, 2010)

Land use (ha)	2010	2030
Bos met natuurbeheer	15856	20968
Bos met bosbeheer	121442	126036
Grasland met natuurbeheer	9389	16632
Heide met natuurbeheer	6291	7992
Kustduin met natuurbeheer	1424	2158
Moeras met natuurbeheer	6156	12537
Slik en schorre	2849	4145
Akker met milieudoelen	13946	15185
Akker met natuurdoelen	513	992
Akker	387218	363740
Productiegrasland met milieu- en natuurdoelen	8883	8998
Productiegrasland	214875	205589

In (Poelmans, 2010) an alternative scenario for built-up area is formulated. A relationship between GDP and built-up area per capitafor the period 1995-2000 is extrapolated until 2025. Based on the existing scenarios for GDP (yearly growth of 2,3 % until 2025 (Federaal Planbureau, 2010) and population (Federaal Planbureau, 2008), a scenario for total built-up area is formulated. This method was then compared with 3 types of extrapolations until 2050 of the observed trend of urban expansion. The high scenario based on extrapolation of observed trends corresponds well with the alternative method. Information on the 3 scenario's based on the observed trends are given in Table 12.

Table 12 Observed and modeled land cover proportions (%) in the Flemish-Brussels Region (data from Poelmans, 2010)

%	2000	2025			2050		
		Low	Middle	High	Low	Middle	High
Built-up land	18,3	22,5	29,9	35,3	29,1	41,5	51,5
Arable land	35,3	33,4	30,7	28,6	31	25,7	20,9
Grassland	32	30,1	27,1	24,7	27,5	21,9	17,7
Forest	13	12,6	10,9	10	11	9,5	8,5
Water bodies	1,4	1,4	1,4	1,4	1,4	1,4	1,4

The result is a high range of possible scenarios, in between about 400.000 and 700.000 ha of total built-up area in the Flanders-Brussels region by 2050.

The use of these extrapolation methods at a longer scale is doubtful. For instance, percentages of built-up land above 50 % by 2050 seem extremely high. Using these scenarios for a time scale of 2100 would results in even extremer % of built-up area in Flanders.

5.4 Socio-economic projections for the Netherlands

In the Netherlands the most widely used socio-economic scenarios are known as the WLO (*Welvaart en Leefomgeving*) scenarios (CPB et al., 2006). These scenarios have been developed by three planning agencies in the Netherlands (*Centraal planbureau*, *Milieu- en natuurplanbureau* and the *Ruimtelijk planbureau*), of which the latter two have merged recently into a single planning agency (*Planbureau voor de Leefomgeving*).

5.4.1 Scenarios

The WLO study consists of four scenarios, created using the scenario axes method as shown in Figure 49. The two key dimensions used to create these four scenarios are i) the extent of international cooperation (national vs. international), and ii) the way the collective sector is shaped with respect to the private sector (public vs. private).

Figure 49 The scenario axis technique used to frame four scenarios for the Dutch WLO scenarios (after CPB et al. 2006).

The WLO scenarios aim to describe changes in the physical environment under different autonomous developments (the two key uncertainties). National policy is an important factor when it comes to shaping the physical environment. In order not to disturb the signal of the external drivers, national policy (with respect to the physical environment) has been kept as equal as possible between the different scenarios, with differences between national policy in the scenarios being the result of the exogenous (from outside the Netherlands) drivers underpinning the separate scenarios. The results of the WLO scenarios can then act as a reference to compare different national policy options in such a future world. The narratives of the four scenarios are quickly described below.

Global Economy

The Global Economy world is one of free international trade. The EU expands eastwards and the WTO is successful in linking trade between different countries. There is, however, no political integration and international cooperation on various global issues fails. Welfare increases strongly with economic growth and population grows strongly due to immigration. This growth in economy and population is the highest among the four scenarios.

Strong Europe

In the Strong Europe scenario there is a focus on international cooperation and the EU gets an influential role in global economy and politics. The international cooperation successfully addresses various global (environmental) issues. Social-economic policy aims at solidarity and there are high investments in research and education. There is considerable economic growth and some population growth due to immigration.

Translantic Market

In the Transatlantic Market scenario the EU does not become a political success as member states hold on strongly to their sovereignty. Trade between the EU and US does grow a lot though, resulting in a new merged market. Individual responsibility is stressed by the national government, resulting in limited social security systems and public facilities. Innovation, competition, productivity and the economy grows strongly (more than SE, less than GE) while population increase is limited. International environmental issues are not being resolved and inequity in income grows.

Regional communities

In Regional Communities the international political and economic cooperation fail. The world splits into seperate trade blocks and international environmental issues are not resolved. Still the pressure on the environment is the lowest here since growth in economy and population is rather low in this scenario. Social safety nets stay in place and solidarity takes an important place in the political landscape. There are limited incentives for innovation or high productivity resulting in relatively high unemployment rates. Economic growth is the lowest from all four scenarios.

5.4.2 Methodology

The Netherlands is divided into three zones for the WLO study: i) Randstad (metropolitan centre of the Netherlands), ii) the periphery and iii) the rest of the Netherlands. For each scenario and zone eight different themes are considered which together form a comprehensive projection. These themes (or sectors) are housing, employment, mobility, agriculture, energy, environment, nature, and water.

There are several drivers considered in the WLO scenarios. These are:

- Demography (immigration being a key variable)
- International economic and political developments (functioning of EU and WTO)
- Technological developments (speed of innovation)
- Developments in economic production structure (demand for space; pollution)
- Social-cultural developments (degree and rate of individualism)
- Economic growth
- Climate change (flood defenses based on differentiated safety or equity)

To assess the impacts of these drivers on the different themes recognized in the WLO study use is made of a large variety of models, including models of the international and national economy, the demography, on mobility, energy, emissions and air quality, et cetera. In total around 40 different models are used and linked to derive at the parameters for each scenario. As the main focus of WLO is on the physical environment, results for given themes are often calculated in the amount of houses, area covered by specific land uses, amount of cattle, etc.

5.4.3 Projections

Projections for a variety of indicators for the Netherlands under the four different scenarios are summarized in Table 13 . The table shows clearly that the two private oriented scenarios yield the highest economic growth, where the highest population growth is expected in the international oriented world. With respect to the changes projected for 2040 it is important to mention that for many issues the largest changes are projected before 2020. This is mainly the result of a decrease in population growth (or even a decline) that is project to occur after 2020, but also due to changes in the structure of the economy (e.g. increasingly more services oriented). Because of these developments the pressure on the physical environment will decrease. This is the case, for instance, for the area needed for business areas, industrial complexes, roads, etc.; but also congestion in traffic will not increase in three of the four scenarios relatively to the present. The Global Economy is the only scenario where pressure on the physical environment continues to grow rapidly.

In terms of land use, most scenarios show a decrease in agricultural area (except for intensive horticulture) and an increase in natural area and industrial area. This increase in natural area also occurs mostly before 2020, as it is for a large part the result of the establishment of main ecological network

(Ecologische Hoofdstructuur; EHS) areas in the Netherlands, which should be completed by 2018, according to current policy.

Table 13 Summary of the main results for the four WLO scenarios. Taken from the website of the WLO study (www.welvaartenleefomgeving.nl).

	Global Economy	Strong Europe	Transatlantic Market	Regional Communities	unit
	level in 2040				
Demography and economy					
Inhabitants	19.7	18.9	17.1	15.8	million
Number of households	10.1	8.6	8.5	7.0	million
BBP per capita	221	156	195	133	index 2001=100
Ageing (population above 65)	23	23	25	25	%
	Global Economy	**Strong Europe**	**Transatlantic Market**	**Regional Communities**	**unit**
	mutations compared to 2002				
Home					
Single-family dwelling	+ 1.9	+1.1	+1.0	+0.3	million
Multiple-family dwelling	+1.2	+0.6	+0.5	+0.1	million
Industrial areas					
Industrial plants	+43	+18	+23	-3	%
Offices	+34	+19	+16	+1	%
Informal work locations	+46	+27	+25	+7	%
Mobility					
Passenger transport	+40	+30	+20	+5	%
Transportation of goods in ton km	+120	+40	+65	-5	%
Congestion hours	+70	+0	-10	-70	%
Agriculture					
Agricutlure area	-15	-15	-15	-10	%
Glasshouses	+60	-15	+5	-45	%
Number of dairy cows	+25	-5	-5	-15	%
Number of pigs	-5	-55	-5	-55	%
Energy					
Use of energy	+55	+10	+40	-5	%
Use of coal	+195	+40	+155	+35	%
Stock of natural gas	-95	-85	-85	-75	%
Share renewable energy (electricity)	1	34	2	24	%
Environment					
CO_2 emission	+65	-20	+30	-10	%
Chronic illness due to particulate matter (PM10)	+22	+5	+26	+1	%
Waste (total)	+100	+44	+53	+11	%
Nature and recreation					
Nature areas (reserves)	+20	+25	+18	+22	%
Sport and recreation areas	+75	+48	+33	+18	%
Areas with low nitrogen deposition	+0	+53	+3	+51	% point

5.5 Long-term socio-economic projections

5.5.1 General

Socio-economic scenarios generally use output of a variety of models to estimate future variables (e.g. demography, GDP, sectoral development, technological development). Such models are calibrated using historic data and as a result, the time horizon of such estimates are limited (Van Drunen and Berkhout, 2009). The validity of the corresponding scenarios is therefore limited on the long term (more than a couple of decades) as well.

Nevertheless, there is a need for a long-term (in this context more than a view decades) view of socio-economic variables. This is especially the case in climate change impact assessments as climate change effects will likely be limited in the coming decades, but will start to become more pronounced in the second half of the 21st century. Moreover, the difference between climate change scenarios is also limited for the coming decades (partly because a third of the warming by mid-century will be due to already committed climate change). The difference between climate change scenarios will be much more substantial at the end of the century (IPCC, 2007).

5.5.2 Attempts in the Netherlands

There have therefore been various attempts to set up socio-economic scenarios for such long time scales as well. Two examples from the Netherlands include a study by Jonkhoff et al. (2008) and Van der Hoeven et al. (2008). Both studies attempt to project conditions for 2100 in order to support climate change assessments by extrapolating certain parameters from the WLO scenarios (which go up to 2040). Jonkhoff (2008) looks at specifically at future economic effects of climate change with respect to flooding and salinization. To estimate these economic effects in 2100 Jonkhoff et al. (2008) extrapolated growth figures for four sectors (agrictulture, industry, commercial and non-commercial services) up to 2100. By doing so the sectoral composition of the Netherlands, as well as the total GDP was estimated for four different scenarios as shown in Table 14.

Table 14 Sectoral composition of the Netherlands in 2002 and projections for 2100 for four scenarios

Sectoraandeel 2100	2002	Regional Communities	Strong Europe	Transatlantic Market	Global Economy
Landbouw	2,3%	1,5%	0,6%	0,6%	0,6%
Industrie	24,1%	11,1%	10,3%	8,5%	4,7%
Commerciële diensten	49,8%	62,6%	66,7%	77,0%	85,4%
Niet-commerciële diensten	23,8%	24,8%	22,3%	13,8%	9,3%
Totaal	*100,0%*	*100,0%*	*100,0%*	*100,0%*	*100,0%*

Bron: TNO, o.b.v. CPB

Van der Hoeven et al. (2008) also extrapolated the WLO scenarios, but took two of the four scenarios that would give the largest range in terms of flood exposure. Two parameters are quantitatively extrapolated: population and economy (GDP); based on studies on these individual parameters. The aim of Van der Hoeven et al. (2008) was to create spatial land-use maps of how the Netherlands may look like under the extrapolated scenarios. While the size of the population and economy are important parameters to project land-use, many more assumptions need to be made concerning, amongst others, technology, governance and behaviour. In order to approach this in a consistent way the (SRES) storylines underlying the two different scenarios were consulted and assumed to continue up to the end of the 21st century.

It is clear that the range of possible outcomes increases with the time horizon that is considered. Especially if socio-economic scenarios go beyond a couple of decades the assumption of continuity and universality begins to pose problems. For some parameters, most notably GDP and population, reasonable estimates can be made for longer time scales. Based on these estimates it is possible to conjure up long-term scenarios, but a couple of key points need to be kept in mind when doing so. Firstly, such long-term scenarios only look at gradual developments. Discontinuities, like wars, large natural disasters, financial crises, etc. are not accounted for. While this also holds for shorter socio-economic scenarios this is even more important on long time scales. Secondly, the storyline (with qualitative information on governance, technology, etc.) underpinning the scenarios is also kept constant. This means that any dynamics in politics and innovation (i.e. the theory of Kondratieff on cyclicity in sectoral growth) are disregarded. The end result of a long-term socio-economic scenario should therefore be viewed as a 'if such and such conditions prevail until 2100, it will result in this and that' situation. Given these constrains, long-term scenarios are therefore probably best used to illustrate the (wide) bandwidth of possible futures, and not so much to explore individual scenarios.

5.5.3 Information for Flanders

The Federal Planning Bureau carried out a long-term projection of demographic parameters to the year 2060, as part of a study on aging issues (Federaal Planbureau, 2008).

Table 15 Demographic prognosis 2000-2060 (Federaal Planbureau, 2008)

	2000	2006	2010	2020	2030	2040	2050	2060
Bevolking op 1 januari	10 239 085	10 511 382	10 807 396	11 538 332	11 982 074	12 227 315	12 439 135	12 662 761
Natuurlijk saldo	9 980	19 795	22 629	20 602	12 084	2 246	-4 801	-3 683
Geboorten	114 883	121 382	127 123	130 195	125 811	127 827	129 621	129 745
Sterfgevallen	104 903	101 587	104 494	109 593	113 727	125 581	134 422	133 428
Saldo interne migraties	0	0	0	0	0	0	0	0
Interne immigraties	442 564	505 216	513 202	539 174	544 388	554 636	564 064	571 318
Externe emigraties	442 564	505 216	513 202	539 174	544 388	554 636	564 064	571 318
Saldo externe migraties	13 732	49 536	55 991	39 119	17 407	19 473	26 176	28 707
Externe immigraties	70 194	108 774	123 369	117 626	92 255	89 925	97 026	101 228
Externe emigraties	56 462	59 238	67 378	78 507	74 848	70 452	70 850	72 521
Aangroei van de bevolking	23 712	69 331	78 620	59 721	29 491	21 719	21 375	25 024
Statistische aanpassing	617	3 821	16	13	-4	-13	-7	-1
Bevolking op 31 december	10 263 414	10 584 534	10 886 032	11 598 066	12 011 561	12 249 021	12 460 503	12 687 784

Bron: Waarnemingen 2000-2006: RR - AD SEI, Berekeningen FPB; Bevolkingsvooruitzichten 2007-2060, FPB - AD SEI

Figures are available per province, for male/female, per age class (5 in total). Population is clearly ageing (in 2040, 1 out of 4 persons would be older than 65 years).

5.6 Socio-economic projections and applications for climatic change impact studies

Many climate change impact studies focused on the effect of climate change on certain sectors, often without taking other future developments into account. Increasingly more studies however recognize that for a comprehensive picture of future impacts of climate change, changes in socio-economy have to be taken into account as well (see e.g. UKCIP, 2000). Inclusion of socio-economic changes in future impact studies is becoming more and more common as a result. This integration of socio-economic change and climate change in impact studies is becoming increasingly important in flood risk studies, but also in other sectors the combined effects have been assessed. In the next paragraphs some global and national assessments will be discussed shortly to show the potential of combined studies.

One of the major attempts to combine socio-economic and climate change scenarios at a global scale was performed in preparation to the fourth IPCC assessment report. Arnell. et al. (2004) downscaled the SRES storylines from regional to national level and quantified some important indicators affecting potential impacts of climate change (e.g. GDP and population growth). Furthermore, various sectoral studies were performed to assess the combined impact of socio-economic and climate change on food security (Parry et al., 2004), water resources (Arnell, 2004), coastal flood risk (Nicholls, 2004), malaria exposure (Van Lieshout et al., 2004) and the environment (Levy et al., 2004). These studies set the scene for further global and regional studies which were used for the fourth IPCC assessment report.

The study on coastal flood risk was extended by Nichols et al (2008), estimating the exposure to future flood risk by combining sea-level rise (global and regional) with land subsidence or uplift (natural and anthropogenic), the intensity of storm surges and population and economic growth. They show that there are already a considerable amount of people and assets exposed to global flooding, equally split between the developed and developing world. By 2070, the total exposed population may have increased threefold and the exposure of assets may even be ten times that of 2005. Furthermore, the focus of most exposed cities will have shifted to Asia. The drivers behind this increase in population and asset exposure differs between cities, but on a global scale climate change and land subsidence contribute to about one-third of the increase and socio-economic change is responsible for the other two-thirds (Nichols et al., 2008).

At a national level, studies combining both types of scenarios have been performed in various countries including the UK and Netherlands. In the UK a comprehensive study for East Anglia and North West England has been performed within the RegIS project. This study performed a multi-sectoral integrated assessment of future impacts incorporating both socio-economic and climatic change (Holman et al., 2005a,b). They showed that future impacts include severe flood impacts and agricultural abandonment. The latter one is mostly driven by socio-economic change though as cropping was found to be relatively insensitive to climate. A study on coastal flood risk in the whole of England and Wales has been performed by Hall et al. (2006) in the context of the large Foresight project (Evans et al., 2004). By combining socio-economic and climate change scenarios they estimated annual expected flood damages to increase roughly 2 to 25 times by the 2080s, depending on the scenario's chosen. Their analysis specifically did not include adaptation measures but costs and benefits of adaptation measures were compared to see if they would be financially viable.

In the Netherlands a combined study has been performed by Aerts et al. (2008). In this study a land-use model was used to project land use for 2040 and 2100 under two socio-economic scenarios. These were combined with several scenarios for sea-level rise and river discharge in a damage model to estimate future flood damages and casualties (Maaskant et al., 2009). Similar to the study of Hall et al. (2006) in the UK calculations were performed assuming no adaptation measures. They found that estimated potential damages could increase four to twenty-five times by 2040 depending on the scenario combination.

6 SCENARIOS IN CCASPAR

This chapter describes the choice of scenarios – either literature scenarios or developed within Ccaspar that will be used within the different work packages.

It is important to note that there is no such thing as "a good scenario". It is also not exact to conclude that the "scenario in the middle" is more likely to occur and hence a better choice than a "minimum or maximum" scenario. It is important to ask which effects you want to study : for instance if you are more interested in drought problems, it is more interesting to consider scenario's with more extreme perturbation values on temperature rise, increase in evapotranspiration, ….

An important element of the Ccaspar project however, is that we not limit ourselves to "generally accepted or likely" scenarios. General scenarios should also to be translated to some rather extreme storylines for application in e.g. sensitivity maps and vulnerability maps, in order to determine how to achieve sustainable desirable state (s). The extremity of the scenarios forces to more sustainable structural solutions. The time horizon determines the feasibility of such sustainable solutions.

If you want to compare or integrate research results, it is quite obvious that you should start from the same basic assumptions, hence the same scenarios for each indicator.

6.1 General scenarios for Flanders

6.1.1 Temperature

We will use the unique set of scenarios available for the average monthly temperature (Baguis et al., 2009).

Table 16 Values for the 3 scenario's of monthly average temperature at Ukkel for CCI-HYDR climate scenarios, reference period 1961-1990 and scenario period 2071-2100 (Baguis et al., 2009)

Low	Mean	High
1.508	3.175	4.233
0.726	2.337	3.939
1.072	2.198	4.255
1.467	2.586	5.182
1.517	2.864	4.97
1.629	3.371	5.4
2.546	4.435	7.288
2.81	5.246	8.892
3.062	4.745	6.124
2.431	3.84	5.251
2.047	3.253	4.426
1.504	3.082	4.768

6.1.2 Precipitation

We will use the results for the RCM runs, as these scenarios seem internally more consistent and also for potential evapotranspiration, RCM runs are used.

Table 17 Perturbation factor for monthly rainfall in Ukkel for the CCI 3-hydr climate scenarios, reference period 1961-1990 to the scenario period 2071-2100, output for the RCM runs (Baguis et al. 2009)

	Monthly precipitation (regional climate model runs)		
	Low	Mean	High
1	0.98	1.21	1.64
2	0.89	1.25	1.68
3	0.86	1.19	1.49
4	0.76	0.99	1.34
5	0.66	0.88	1.08
6	0.47	0.74	0.95
7	0.29	0.61	0.92
8	0.24	0.57	0.92
9	0.54	0.76	1.03
10	0.72	0.93	1.33
11	0.76	0.99	1.34
12	0.9	1.15	1.57

6.1.3 Potential evapotranspiration

There is a choice between 4 methods (Baguis et al., 2009). We will choose the Monteith 24 h variant which produces the highest perturbation factor (maximum evapotranspiration is more" interesting" when studying drought issues).

Table 18 Perturbation factor for potential evapotranspiration in Ukkel for the CCI 3-hydr climate scenarios, reference period 1961-1990 to the scenario period 2071-2100, output for the Monteith method (Baguis et al. 2009)

	Monteith 24h		
Month	Low	Mean	High
1	1.137	1.337	1.826
2	0.973	1.133	1.324
3	0.868	1.026	1.279
4	0.959	1.105	1.412
5	0.977	1.148	1.379
6	1.018	1.152	1.412
7	1.079	1.209	1.474
8	1.143	1.315	1.734
9	1.13	1.31	1.692
10	1.017	1.265	1.497
11	0.949	1.328	1.578
12	1.118	1.388	1.865

6.1.4 Socio-economic indicators

6.1.4.1 Demography

One scenario of demographic evolution is available until 2060 (Federaal Planningbureau, 2008). Figures are given in chapter 4.5.3.

6.1.4.2 Economic growth

Economic growth figures are available until 2030 (Hertveldt, 2009). Figures are given in chapter 4.3.2.

6.1.4.3 Spatial evolution

Three scenario's for land cover change are available, based on extrapolation of existing trends of urban growth (Poelmans, 2010). The high range and the use of these scenarios at longer time scale remains a point of discussion. This aspect will be discussed in detail in the 2nd valorization product.

Table 19 Observed and modeled land cover proportions (%) in the Flemish-Brussels Region (data from Poelmans, 2010)

%	2000	2025			2050		
		Low	Middle	High	Low	Middle	High
Built-up land	18,3	22,5	29,9	35,3	29,1	41,5	51,5
Arable land	35,3	33,4	30,7	28,6	31	25,7	20,9
Grassland	32	30,1	27,1	24,7	27,5	21,9	17,7
Forest	13	12,6	10,9	10	11	9,5	8,5
Water bodies	1,4	1,4	1,4	1,4	1,4	1,4	1,4

6.2 Scenarios for the Campine Region and for the Coast

6.2.1 Use of the perturbation tool

A perturbation algorithm was developed within the CCI-HYDR project so that impact analysts in Belgium can assess the hydrological impacts of climate change. The algorithm imparts a perturbation to an observed series to generate future time series. The CCI-HYDR Perturbation Tool involves scenarios for rainfall, evapotranspiration, temperature and wind speed (Ntegeka, 2009).

The output series is the perturbed input series for a given time horizon in the future. Target years of 2020, 2030, 2040, 2050, 2060, 2070, 2080, 2090, and 2100 can be selected. Each target year is in the centre of a 30 year block.

6.2.2 The Campine Region

Due to delay in data delivery by a 3rd party, results for the use of this perturbation tool will be reported in another valorization product.

6.2.3 The Coast

Due to delay in data delivery by a 3rd party, results for the use of this perturbation tool will be reported in another valorization product.

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