RISKS & CHALLENGES TO WATER RESOURCES

and opportunities for sustainable management in the United Kingdom, Belgium and the Netherlands

August 2020 // www.pro-water.eu

Interreg 2 Seas Mers Zeeën PROWATER
European Regional Development Fund

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COLOFON

The PROWATER project has received funding from the Interreg 2 Seas programme 2014-2020 co-funded by the European Regional Development Fund under subsidy contract No 2S04-027. Interreg 2 Seas is a European territorial cooperation programme for the United Kingdom, France, the Netherlands and Belgium (Flanders).

Citation:
Stacey Freya, Bauer Katharina, Staes Jan, Van Kessel Bart, Neville Jo, Vande Velde Katherine, Broeckx Annelies, Wilkinson Debbie (2020). Risks and challenges to water resources and opportunities for sustainable management in the United Kingdom, Belgium and the Netherlands. Deliverable 3.1.1 of the PROWATER project, Interreg 2 Seas programme 2014-2020, EFRD No 2S04-027.

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ABSTRACT

The Interreg 2 Seas PROWATER project aims to provide leverage to the implementation of Ecosystem-based Adaptation (EbA) measures for sustainable water resources and landscapes resilient to droughts and flooding. Across Europe, the components of freshwater catchments that play a critical role in the quantity, quality and pattern of water availability - such as geology, land cover and soils, often termed natural capital – are in a degraded state due to over-abstraction, agricultural intensification and urban development, reducing their capacity to provide ecosystem services as well as their resilience to extreme events. Climate change is increasing the frequency of droughts and intense storms, as well as changing seasonal weather patterns. Population growth and the need to protect vulnerable ecosystems put further pressure on water resource managers to ensure a sustainable long-term water supply to protect environment and economy alike. This report summarises climate-and natural capital- related risks to water resources in four regions of Northern Europe and sets out how EbA measures such as soil management, wetland restoration and forest conversion can increase the resilience of catchments to climate change and increasing demand for water. While EbA measures are increasingly becoming mainstreamed to respond to water quality and flood risk pressures, their potential to increase the resilience of water resources in terms of quantity is only starting to be recognised outside of the environmental sector. These measures, combined with demand management and hard infrastructure, restore resilience of water supply by restoring the natural capital water resources depend on. Strategic investment in integrated catchment scale EbA implementation for water resources will benefit the water industry as well as provide a wide range of public goods such as flood risk reduction, healthy soils and climate change mitigation.

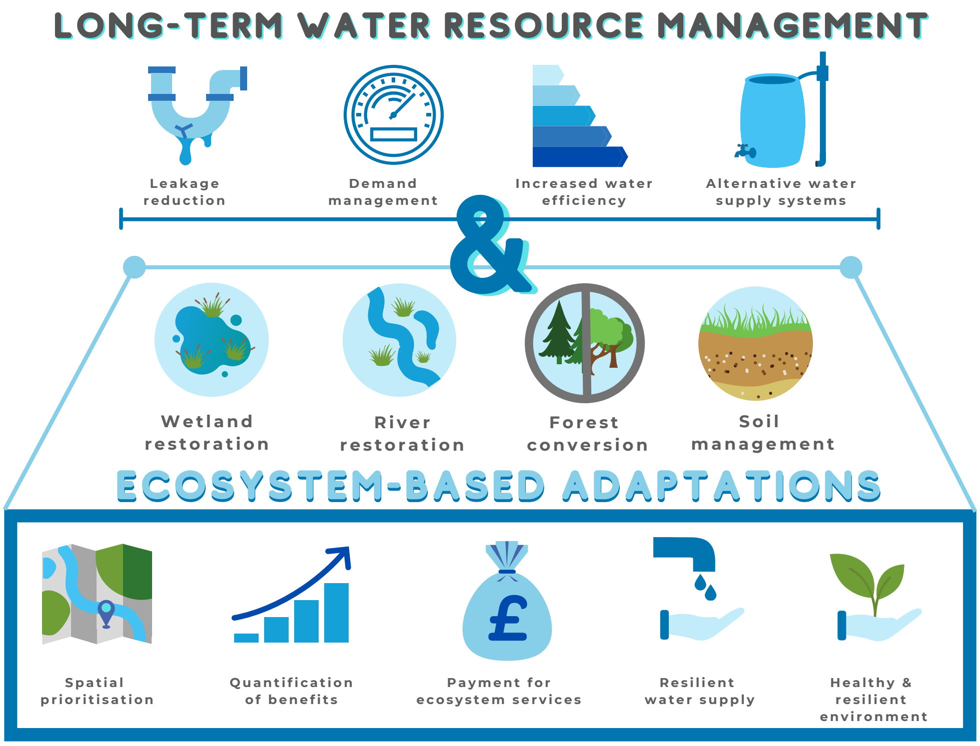


Figure 1. Long-term water resource management and the importance of Ecosystem-based Adaptation (EbA) measures for sustainable water resources and landscapes resilient to droughts and flooding. The Interreg 2 Seas PROWATER project focusses on EbA measures increasing the infiltration and water storage capacity of the landscape, including wetland restoration, river restoration, forest conversion and soil management.

GLOSSARY

Available renewable water: renewable water supply from ground- and surface water that includes the impact of upstream consumptive water users and large dams on downstream water availability.

Aquifer: an underground layer of rock or other substrate that can store water, from which groundwater can be abstracted.

Confined aquifer: an aquifer below the surface that is surrounded by impermeable layers above and below. They are mainly recharged by horizontal rather than vertical flow.

Drought: a period of time with below average precipitation. Drought is part of the natural climate variability and can be observed in all climate regimes. There is no universally accepted definition of drought. However, three types of drought are commonly distinguished:

- **Meteorological drought:** a deficit in precipitation over a defined period and region as compared to climatological average values.

- **Agricultural drought:** a lack of moisture to support crop growth, leading to a reduction of annual yields in the affected regions.

- **Hydrological drought:** a lack of precipitation leading to reduced stream-flows, lake, or reservoir levels. Time-series of these variables are used to analyse the occurrence, duration and severity of hydrological droughts.

Ecosystem-based Adaptation: the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change. EbA involves the conservation, sustainable management and restoration of ecosystems to reduce the harmful impacts of climate hazards. The concept of EbA has been promoted through international fora, including the processes of the United Nations Framework Convention on Climate Change (UNFCCC) and the Convention on Biological Diversity (CBD).

Ecosystem Services: the benefits and goods provided to people by healthy ecosystems, such as clean water, flow regulation, extreme weather mitigation or pollination of crops.

Effective rainfall: the amount of rainfall contributing to stream flow, subsurface flow or groundwater recharge, that is the rainfall that is not lost to evapo-transpiration, also referred to as precipitation surplus.

Groundwater abstraction: the process of taking or extracting water from aquifers.

Nature-based Solutions: the sustainable management and use of nature for tackling socio-environmental challenges, including through a wide range of ecosystem-based approaches. Solutions are intended to be cost effective and provide economic, social and environmental benefits and resilience.

Natural capital: the elements of nature that provide a flow of benefits and services to humans, for example forests, biodiversity, wetlands or soil.

Natural renewable water resources: the total annual amount of a country's water resources (internal and external resources), both surface water and groundwater, which is generated through the hydrological cycle.

Non-public water supply: the provision of water by additional sectors that do not receive water from the water companies providing public water supply. This can include farmers with their own boreholes, or hydropower plants with their own abstraction points, for example.

Public water supply: water provided for human use by licensed water companies.

Resilience: the ability of a system to face shocks and persistent structural changes a way that maintains function of the system and societal well-being.

Supply demand balance: the difference between the amount of water required by users and the amount of water provided by suppliers.

Surface water abstraction: the process of taking or extracting water from streams, lakes and reservoirs.

Unconfined aquifer: aquifers that are directly recharged by the land above the aquifer (as opposed to confined aquifers).

Water consumption: the portion of water use that is not returned to the original water source after being withdrawn. Consumption occurs when water is lost into the atmosphere through evaporation or incorporated into a product or plant (such as a corn stalk) and is no longer available for reuse.

Water scarcity: a lack of water to meet the standard demand. This can be due to physical shortage, due to the failure of institutions to ensure a regular supply or due to a lack of adequate infrastructure.

Water stress: the ratio of total (consumptive and non-consumptive) water withdrawals to available renewable surface and groundwater supplies.

Water use: the total amount of water withdrawn from its source to be used for consumptive and non-consumptive purposes.

INTRODUCTION

Climate change is causing seasonal weather patterns in Northern Europe to change, increasing temperatures and winter precipitation as well as making extreme events such as heatwaves, meteorological droughts and extreme rainfall events more likely. (Sari Kovats et al., 2014). These predictions will exacerbate existing seasonal variations in water availability, leading to erratic and uncertain water supplies often coinciding with peaks in demand for human and environmental needs. Between 1976 and 2006, droughts alone cost the EU economy for €100 billion (The Nature Conservancy, 2020). Population growth and increasing water consumption will put further pressure on water supplies. Globally, the gap between renewable water supply and water demand is predicted to reach 56% by 2030 and the cost of delivering sustainable water management has been estimated at $1037 billion (Strong et al., 2020). Many areas within the 2 Seas region are already under water stress (e.g. areas where historic overexploitation of groundwater resources was exacerbated by recent climate change impacts), and without action the situation will only get worse (WRI, 2020) Figure 1.

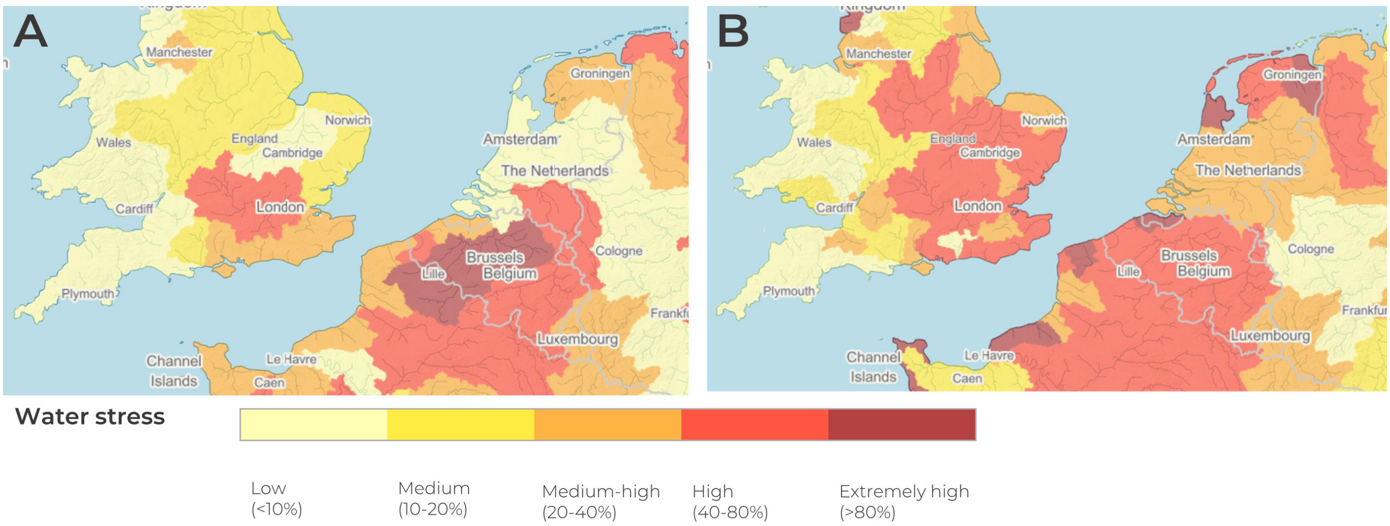


Figure 2. Maps showing the baseline (A) and future (B) water stress for the 2 Seas program area. Where the future scenario represents the situation in 2040 under a Business as Usual climate projections (SSP2 RCP8.5). SSP2 RCP8.5 represents a world with stable economic development and steadily rising global carbon emissions, with CO2 concentrations reaching ~1370 ppm by 2100 and global mean temperatures increasing by 2.6–4.8°C relative to 1986–2005. The water stress value measures the ratio of total water withdrawals to available renewable surface and groundwater supplies. Water withdrawals include domestic, industrial, irrigation, and livestock consumptive and non-consumptive uses. Available renewable water supplies include the impact of upstream consumptive water users and large dams on downstream water availability. Higher values indicate more competition among users. Source: WRI Aqueduct, accessed on 27/05/2020 aqueduct.wri.org

Indirectly, climate change impacts water resources by increasing agricultural water demand for irrigation, human use and environmental need in hotter summers and more frequent droughts. Water quality, already impacted by diffuse and point source pollution from intensive agriculture and urbanisation, is also vulnerable to changing rainfall patterns. Periods of low river flows reduce the ability to dilute pollution, while heavy rain can flush more pollutants into waterbodies. This poses a risk not only to aquatic ecosystems, but also to human water supply as treatment costs rise. Freshwater biodiversity is declining at twice the rate of marine and terrestrial systems (Acreman et al., 2020), with the dominant threats being overexploitation of water resources and agricultural activity. Bringing together different sectors to increase the resilience of river and groundwater catchments to these combined pressures in a united approach will provide multiple societal and environmental benefits.

Strategic water reservoirs and aquifers allow us to bridge droughts or periods of water scarcity. However, over time the replenishment of these strategic water reserves has become insufficient because landscapes have been subjected to land use changes, soil sealing, groundwater abstraction and drainage. These pressures have a major impact on the hydrological system and many hidden ecosystem services. Floods, water shortages, erosion, loss of biodiversity and eutrophication are signs that the hydrological cycle is seriously disturbed. In many cases we have become dependent upon expensive technical measures to replace those regulating functions, which will be further impacted by the changing climate.

The Interreg 2 Seas PROWATER project aims to provide leverage to the implementation of Ecosystem-based Adaptation (EbA) measures for sustainable water resources and landscapes resilient to droughts and flooding. These measures restore ecosystems to enhance water retention and infiltration at the landscape level, improving long term stability of groundwater levels and river base flows, and so increasing catchment resilience to droughts and floods with benefits to water quality and biodiversity Figure 2. This report describes risks and challenges for sustainable water resources in the Interreg 2 Seas region (Belgium, Netherlands, and the United Kingdom) and sets out opportunities where EbA can offer solutions to these challenges.

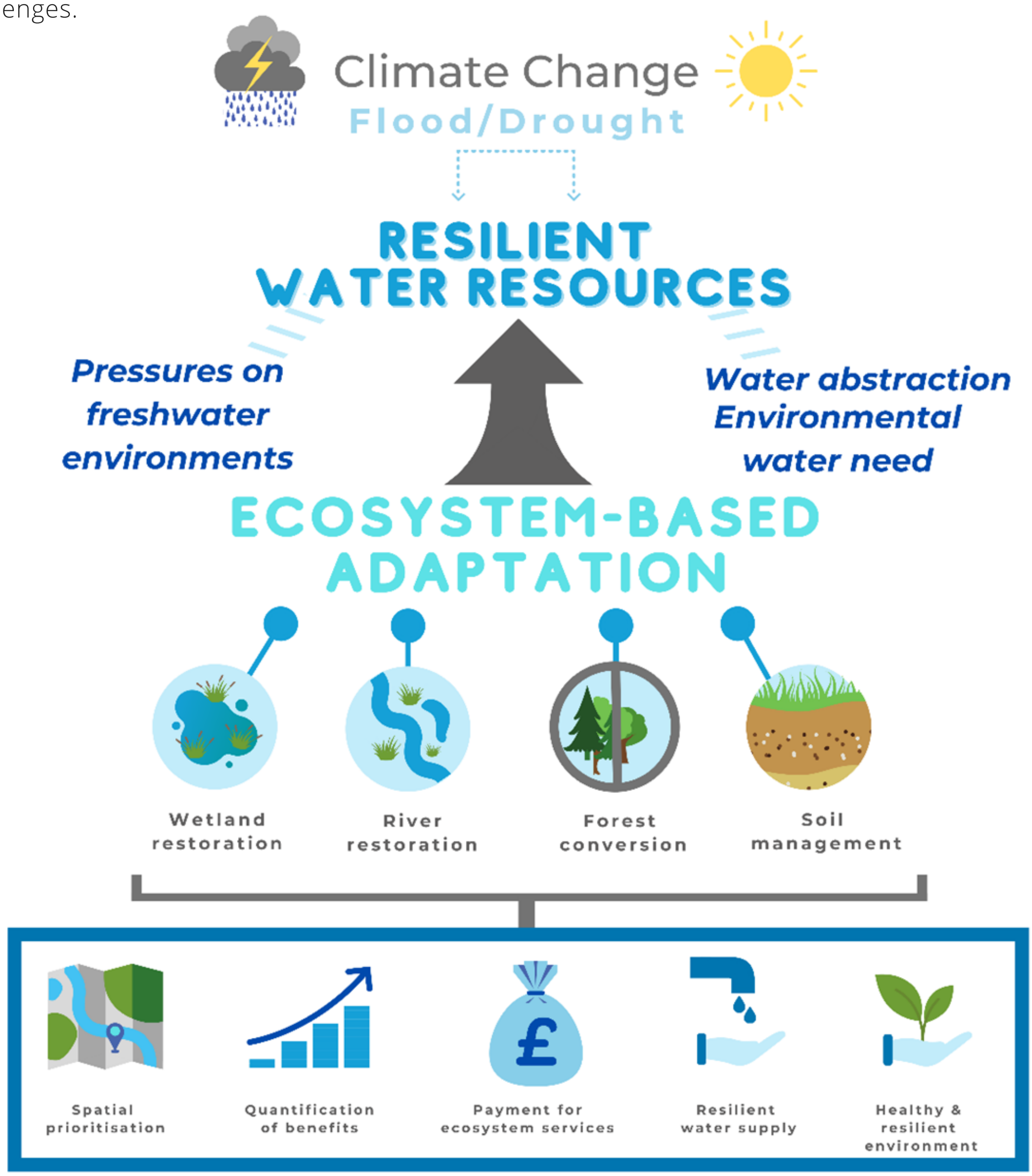


Figure 3. Synthesis of the PROWATER project. The cross-border project PROWATER stands for 'protecting and restoring raw water sources through actions at the landscape scale'. Through Ecosystem-based Adaptation (EbA) measures increasing the infiltration and water storage capacity of the landscape, PROWATER intends to increase the resilience of the 2 Seas area to drought effects. In addition to the EbA demonstration sites, PROWATER will develop spatial prioritisation tools, ecosystem service quantification tools, and long-term strategies for larger-scale implementation of these EbA measures (including an assessment for the potential of Payment for Ecosystem Service schemes) in the different regions of the 2 Seas area (PROWATER, 2020).

OVERVIEW OF REGIONS

The PROWATER project is an Interreg 2 Seas project and the challenges and solutions outlined are applicable across the entire 2 Seas region, and beyond. Pilot sites are being implemented by partners in Southern England, Flanders (Belgium) and the Netherlands. This report provides an overview of the UK pilot regions.

SOUTHERN ENGLAND

The UK experiences a wide range of climatic conditions with a distinct North-South and East-West divide, which has an impact on water resources. Although often regarded as a wet country with no concerns of water stress, the seasonal and geographical distribution of demand for water and its availability, high population density and industrial needs mean that some areas of the UK face a range of water resource challenges. In this report the UK has been divided into two focus regions, the South East and South West, as they face markedly different situations regarding water resources.

SOUTH WEST

The South West is home to around 4.7 million people and contributes more than £100 billion a year to the UK economy. The region is predominantly rural, and its main industries are agriculture, tourism, and mineral extraction Figure 4.

Figure 4. Impressions of the landscape diversity in South West UK

There are over 70 000 ha of Sites of Special Scientific Interest, 45 Special Areas of Conservation, 15 Special Protection Areas and 7 Designated Wetland sites (West Country Water Resources, 2020). Many of these sites have important water dependent habitats from estuaries to heathland and peatland mires. Within the region there are three distinct areas, the east with its chalk landscape and rolling downs, the west with its steep granite landscape and the flat peaty levels of Somerset between them. Even within the region the dominant water supplies contrast, with 85% from groundwater sources in the east, to 90% from surface water, via small rivers and reservoirs, in the west of the region. Despite an average annual rainfall of 1000 mm, one of the highest annual rainfall levels across England Figure 5, the likely increase in periods of extreme rainfall and drought still present significant challenges for water supply and the environment (West Country Water Resources, 2020).

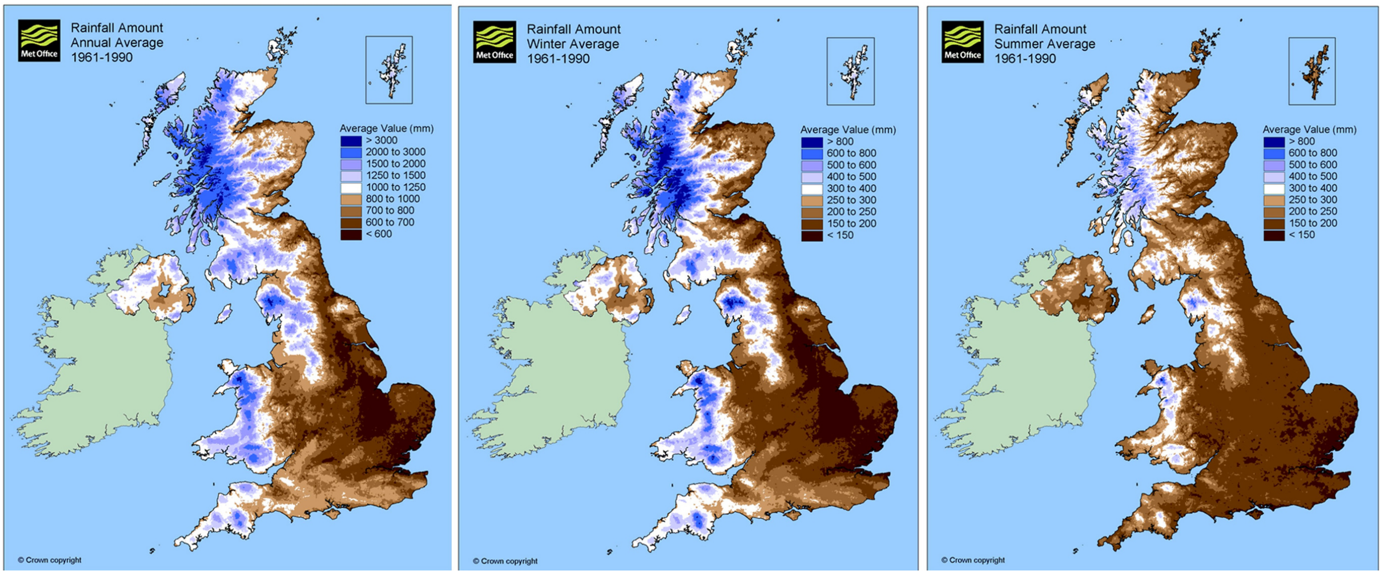


Figure 5. Rainfall distribution across the UK for annual, summer and winter rainfall for the period 1960 – 1990.The 30-year period 1961 to 1990 has been designated as the international standard reference period for climate averages by the World Meteorological Organization. Source: MET Office UK Climate averages Accessed: 10/06/2020 (Met Office Hadley Centre, 2018a) © Crown copyright

Credit: Unsplash Tata Sakharova

SOUTH EAST

The South East is one of the driest regions of the UK with an average annual rainfall of 800 mm. The region is characterised by a mix of agricultural and semi-natural land cover with some large urban areas Figure 6.. The region is home to a third of the UK's population (around 20 million people) and is already facing water supply challenges. It covers 26 400 km2 and contains 32 river catchments. Over 65 designated globally rare chalk streams (a quarter of all chalk streams found globally) can be found in these catchments. Chalk streams are fed by chalk aquifers and sensitive to (over) abstraction of groundwater. These groundwater bodies also supply more than half of public water supply (up to 100% in some areas). London and the South East are important economical regions and contribute 23% and 13% respectively to the UK GDP every year. The combined pressures of high population density and expected growth of urban areas, low rainfall levels and increasing extreme events make water resource management a pressing issue in the area that is tightly linked to the resilience of natural habitats and the wellbeing of its communities.

Figure 6. Impressions of the landscape diversity in South East UK

BELGIUM - FLANDERS

The region of Flanders is situated in the northern half of Belgium and covers 13 522 km². Bordering the North Sea, Flanders has a rather flat topography with parts reclaimed from the sea (polders) and large parts dominated by wide river valleys and a dense network of slow-running watercourses Figure 7.

Figure 7. Impressions of the landscape diversity in the Campine region; The sandy soils and topography generate a high diversity in abiotic conditions and land-use

The highest point only reaches 156 m above sea level. It has a maritime climate with an annual precipitation of 800 mm and mild winters and summers (average of 3°C in January and 21°C in July). The Flemish Region has a high population density (445 inhabitants/km²) and one of the densest traffic networks in the world (Lammar and Hens, 2005). It is already internationally labelled as a risk area for water scarcity and water shortages have already occurred in the summers of 2003, 2006, 2011, 2015, 2017, 2018, 2019 and 2020. Each of these drought episodes has had serious economic and ecological impacts. Because surface water flow regimes are very sensitive to droughts, there is increasing pressure on groundwater. Water supply from abstracted groundwater is currently at its limits, with most of the aquifers facing systematic low water levels.

In the PROWATER project, we focus on the Campine ecoregion. Groundwater in the Campine Region is Flanders' most important buffer to overcome water shortages. A thick unconfined aquifer holds an enormous volume of groundwater, but a structural imbalance between recharge and abstraction directly impacts streams and wetlands.

THE NETHERLANDS - NOORD BRABANT

Noord-Brabant is the second largest province of the Netherlands covering 5 082 km² and has a high population density (519 inhabitants/km²). It has a maritime climate with mild winters and summers. The average annual precipitation is 750-850 mm and annual evaporation of 570-600 mm with irregular precipitation patterns. The river area in the north and west of the province consists of a mixture of river clay (upper layers) and marine clay (lower layers as remains of the former tidal delta area).

The regional water authority Brabantse Delta (waterschap Brabantse Delta) manages the water systems in the southwestern part of the Noord-Brabant province and borders the Dutch provinces Gelderland, Zuid-Holland, (north) Zeeland (west), Limburg (east) and the Belgian provinces of Antwerpen and Limburg (south). The Noord-Brabant province is relatively flat and consists mostly of Pleistocene sands which are intersected by brook valleys Figure 8.

Figure 8. Impressions of the landscape diversity in the Noord-Brabant region, Netherlands region.

The last two droughts of 2018 and 2019 had serious economic and ecologic impacts. The situation is not yet alarming on a national scale. But the effects on more elevated parts in the South, which have predominantly sandy soils, are clearly visible. These areas are characterised by surface water systems that are dependent on rainfall and groundwater and because the e systems are very sensitive to droughts, the pressure on groundwater is increasing. In the 1970s and 1980s, the hydrological system was modified substantially ('get rid of surplus precipitation as fast as possible') to support more intensive land use patterns. The challenges posed by drought and water quality will increase with climate change. The Province of Noord-Brabant has set the ambition for this region in the south of the Netherlands to be climate proof and water robust, i.e., able to cope with extreme weather events and water shortage. Additionally, the water quality and ecological objectives of the Water Framework Directive have to be met before the end of 2027. A more integrated land- and water management approach is needed to tackle both issues of drought and water quality. Such an approach, including more Ecosystem-based Adaptations, will also contribute to sustainable restoration of biodiversity.

KEY MESSAGES

- Climate change increases the challenge to cope with (prolonged) dry periods and to improve the ecological quality of both surface waters and groundwater dependent terrestrial nature areas.

- Human modifications of the hydrological system in the landscape have impacted on water provisioning.

SOUTHERN ENGLAND

- Climate in the UK is very variable, and the South East and South West face markedly different situations with regards to water resources, economic status, population density and environment.

- The UK is perceived as a water-rich country, but this perception does not account for the high demand from a growing population, and the seasonal and spatial distribution of available water resources.

- Water Resources are already under pressure in parts of the country.

BELGIUM - FLANDERS

- Flanders is a water scarce region due to the high population pressure on a small surface area.

- Flanders is internationally labelled as a risk area for water scarcity and water shortages have already occurred.

THE NETHERLANDS – NOORD-BRABANT

- In the 20th Century, the hydrological system and related land use patterns have been developed to get rid of excess water in the landscape. Consequently, the capacity to store surface water and infiltrate water in the landscape has been reduced substantially.

- Noord-Brabant is a water scarce region due to the development of intensive agriculture and urban areas in the past century.

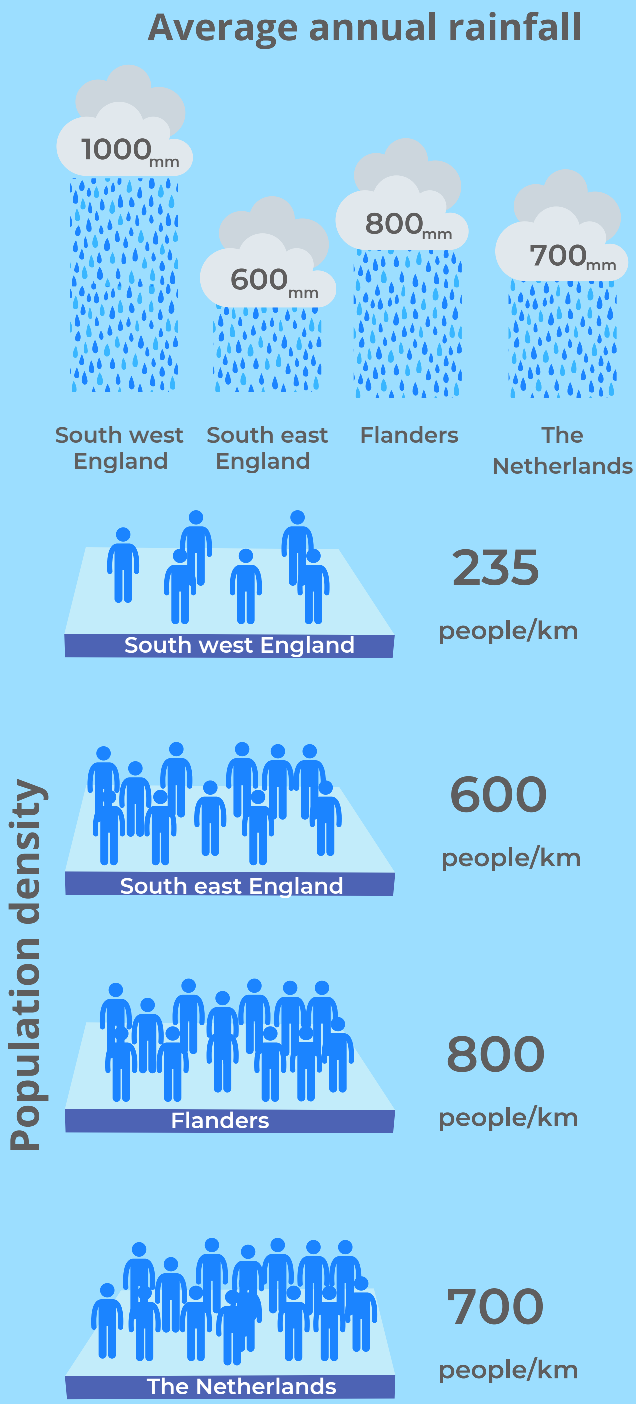


Figure 9. Average annual precipitation (top) and population density (bottom) for South West England, South East England, Flanders and the Netherlands.

CONNECTING NATURAL CAPITAL AND WATER RESOURCES

River and groundwater catchments and the habitats within them are the natural capital that provides water resources. The type, condition and location of the natural capital present exerts influence over when, how, and where water moves. This, in turn, influences the quantity and quality of water available to humans as a resource. Often, the ability of landscapes to deliver essential functions such as storing, cleaning, and regulating water flows, is reduced as modifications to deliver specific benefits, such as food production, have impacted their capacity to provide many hidden but no less vital functions (Grizetti et al 2019). Pressures from development, climate change and population growth are increasing, further reducing the diversity, condition, and connectivity of natural capital and with it the landscape's resilience. To protect and restore water resources, as well as the many other regulating and supporting ecosystem services, it is necessary to restore and protect the natural capital that provides them.

The potential of EbA measures for restoring and protecting sustainable water resources is influenced by catchment hydrology. By identifying how water moves through a landscape, the amount available for sustainable use and the key factors that influence quantity and quality of water can be identified. Geology, soil type, topography and land use are all key factors alongside climatic conditions which determine hydrological behavior (i.e., runoff, interflow and baseflow) of water within the catchment Figure 10 (Vandecasteele et al 2018). To manage water resources sustainably we need to make better use of periods with (extreme) precipitation surplus by reducing direct runoff and shifting towards more stable interflow and baseflow.

SURFACE RUNOFF
is the very fast and direct component draining into rivers, often loaded with sediments and pollutants.

INTERFLOW
is the gradual release of surface water to rivers, stored in ditches, ponds, small landscape depressions, wetlands and soil.

BASEFLOW
is more stable and is supported by seepage of groundwater (via springs) to the riverbed and riparian wetlands.

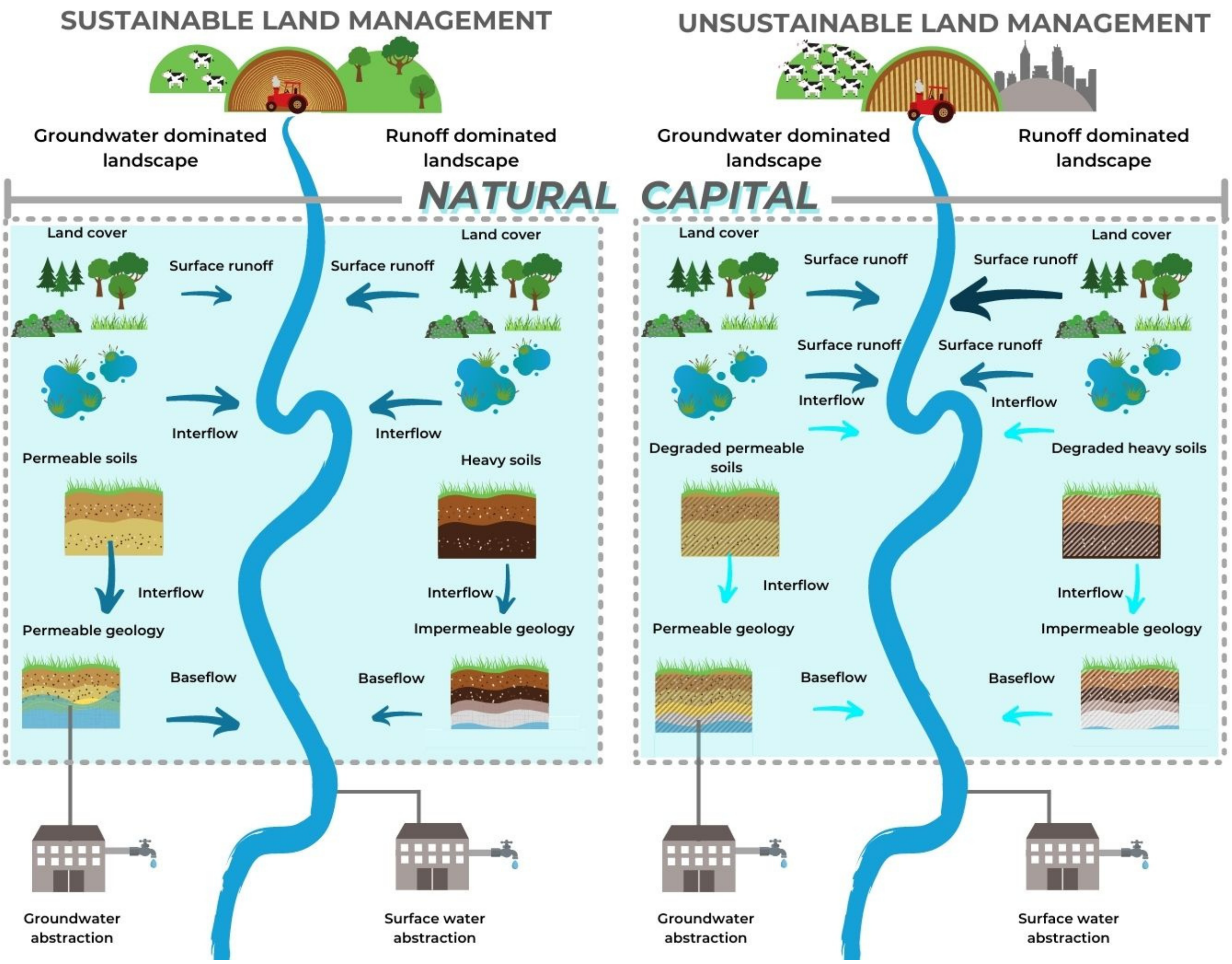


Figure 10. This diagram demonstrates how unsustainable land management affects the hydrological function of different soil types. On permeable soils urbanisation, poor soil management and land use change reduce the amount of water reaching underground aquifers via interflow. As a result, less water is available for abstraction and to supply rivers via base flow, while surface runoff increases, raising the risk of flooding and reducing the amount of time that water is held in the landscape. Impermeable soils do not support aquifer recharge under normal conditions, so the main effect of these changes is a greater increase in the amount of surface run off, causing 'flashy' catchments that rapidly respond to rainfall. These rivers have a greater probability of flooding and are vulnerable to extended periods of low rainfall.

The pathway of water through a landscape depends on the types of surface and subsurface soil types and superficial and bedrock geology present. As these features are not uniformly distributed through catchments there will be multiple processes present, but catchments can usually be described as either runoff or groundwater dominated.

In unmodified or sustainably managed groundwater dominated catchments there is little runoff following precipitation as water predominately infiltrates through permeable substrates and moves either laterally or vertically below the surface. However, modification such as surface sealing, soil compaction and land drainage reduce the ability of water to infiltrate and therefore result in greater levels of runoff. Groundwater replenishment depends on the hydrological connectivity to the surface. When connectivity is interrupted by these modifications the resilience of this water supply is reduced.

In unmodified or sustainably managed runoff dominated catchments, water predominantly moves above the surface but interflow and baseflow are still present. As above, when the landscape is modified, surface runoff dramatically increases and interflow and baseflow are further reduced. This leads to an increase in frequency and severity of low river flows during dry periods and an increased risk of flooding following periods of extreme rainfall.

RUNOFF DOMINATED VS. GROUNDWATER DOMINATED CATCHMENTS

Runoff dominated catchments are more vulnerable to shorter droughts as the river flow often closely mirrors the amount of recent rainfall. Groundwater levels typically show smoother trends with a lag in the response to rainfall patterns as the response is dictated by the time it takes water to infiltrate through the soil, but are more vulnerable to winter droughts, especially over multiple seasons. Groundwater dominated catchment are therefore more resilient to droughts if infiltration is not impeded through anthropogenic effects such as surface sealing, excessive and fast drainage and soil compaction. When the surface of the land is altered in a way that affects the natural movement of water down to groundwater these catchments can be very vulnerable to droughts. In the 2 Seas region many areas rely on groundwater sources to supply water for human consumption and industrial processes. As weather patterns are predicted to become increasingly unpredictable it is crucial that our hydrological catchments are resilient, ensuring that there is enough water for people and nature to thrive. One way to achieve this resilience is to protect and restore the natural infiltration capacity of catchment landscapes.

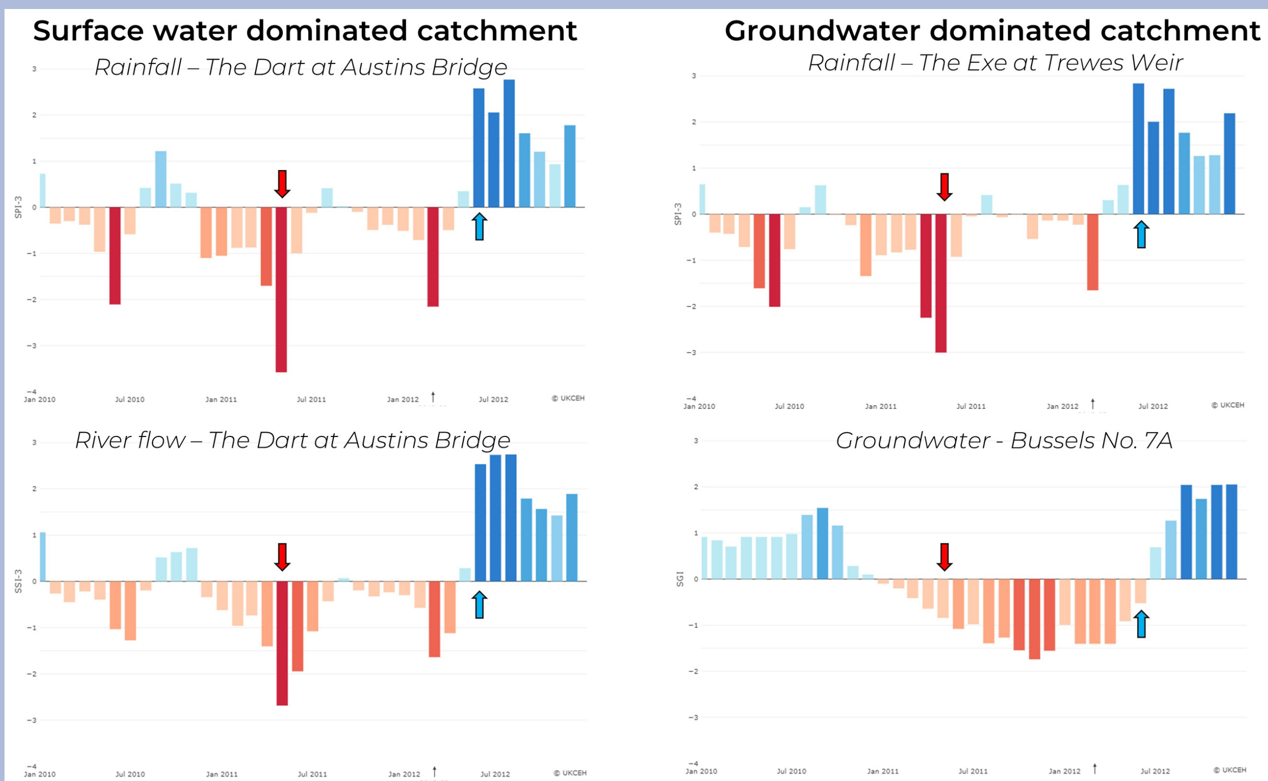


Figure 11. Rainfall and river flow in Runoff dominated catchment (i.e. surface water dominated) vs. rainfall and groundwater in groundwater dominated catchment.

SOUTHERN ENGLAND

Across England, groundwater contributes 30% (6 064 000m3) to public water supply (BGS, 2019). Certain types of bedrock, limestone and sandstone, have a high capacity to store water - these are principal aquifers. They are found across wide parts of South East England, while South West England has a higher proportion of less productive aquifers Figure 12. Surface flows contribute around 70% of public water supply, i.e., from reservoirs, lakes and rivers (Water UK).

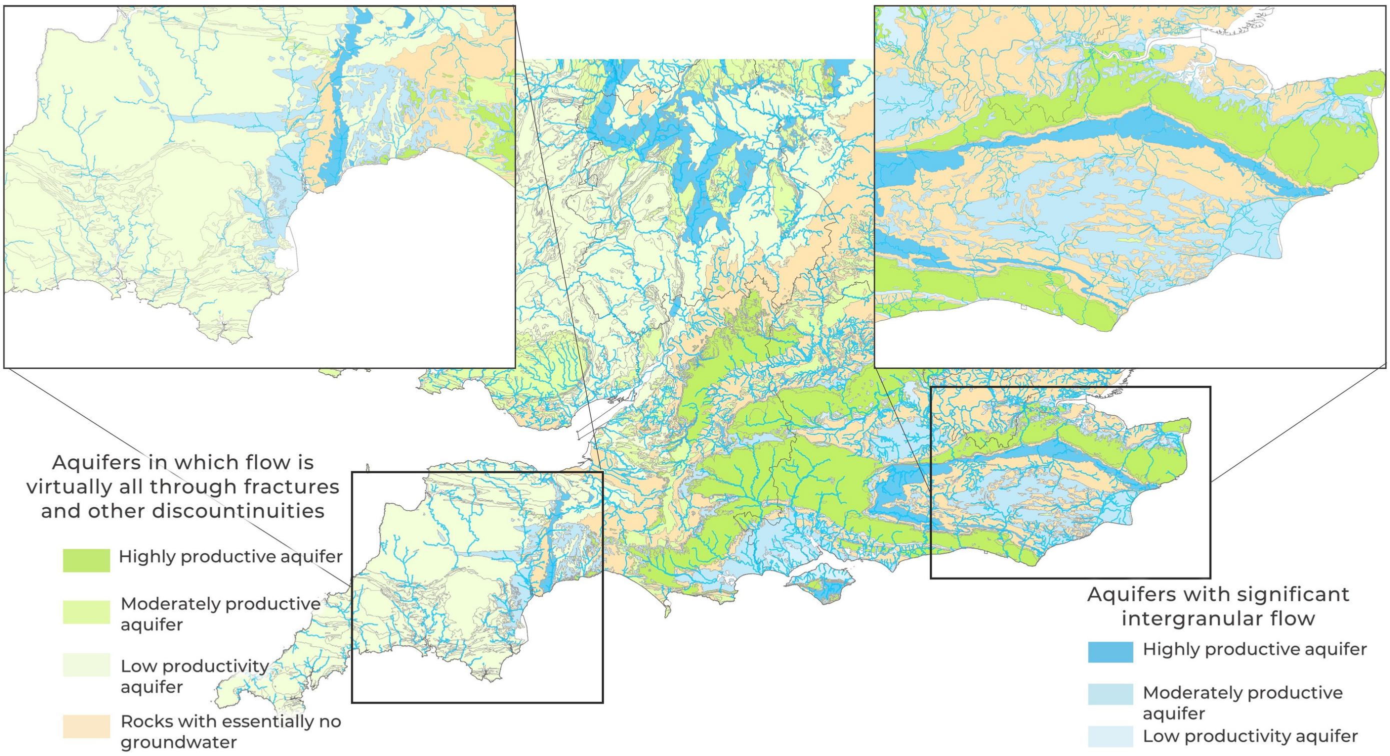


Figure 12. Hydrogeology of the South West and South East showing low productivity aquifers (very pale green) and highly productive aquifers (strong blue and green). Adapted from UK Water Resources Portal.

Soil degradation is widespread and puts pressure on water resources by reducing the capacity of the landscape to infiltrate and retain water. Almost half of all arable land in England is at risk of erosion, it is estimated to have already lost up to 80% of its organic carbon (i.e., organic matter), and 35% (3.9 million hectares) is at risk of compaction (Environment Agency, 2019a). The estimated total cost of compaction is £472 million per year. The importance of functional soil is increasingly recognised, for example in the 25 Year Environment Plan as well as the Agriculture Bill for the UK.

The chalk aquifers of the southern England support some of the rarest habitats present in the UK– chalk streams, many of which are impacted by over-abstraction as groundwater levels recede to such a degree that springs stop flowing. While migration of stream heads is a natural behavior of chalk streams (resulting in winterbournes), over-abstraction lowers levels beyond sustainable limits. Many rivers in the South East have experienced this and continue to be affected by low flows, including the Darent, Hogsmill and Lea in the Thames catchment.

SOUTH WEST

The South West landscape consists of groundwater dominated catchments in the rolling chalk downs in the east, to the steep runoff dominated granite landscapes with flashy rivers in the west and the flat peaty levels of Somerset in between them. The region lies beyond the extent of the ice-sheets that dominated the evolution of the British landscape over the past 2 to 3 million years. Most of the region has few to no recent surface deposits. In the east of the region there are flinty gravels overlying chalk bedrock, otherwise deposits are limited to some areas of sand and gravel deposits alongside the larger river systems. The higher parts of the region, such as Dartmoor and Exmoor, contain blankets of peat many metres deep. The east has a sedimentary bedrock whereas much of the rest are basement rocks with periodic granite intrusions.

The largest cities are Bristol, Bath and Exeter and the major industries in the region are tourism and agriculture. Around 80% of the region is rural with dairy farming being the most common land use. The small dairy fields, areas of high moorland and a legacy of mineral abstraction dominate the character of this landscape (West Country Water Resources, 2020).


Credit: FlickrCC Richard Szwejkowski

SOUTH EAST

A complex geology consisting of chalk, sandstone and clay gives rise to a wide variety of soil types and landscapes with a mix of runoff and groundwater dominant freshwater systems. South East England's landscapes include rare groundwater fed chalk streams reliant on winter rainfall and intrinsically connected to the most important source of drinking water, as well as surface water fed clay rivers heavily impacted by summer droughts and often important for local abstraction.

The region is characterised by a mix of agricultural and semi-natural land cover (including England's most wooded county, Surrey), with some large urban areas including London Figure 13. 40% of England's woodlands are located in the region (Bannister, 2007) as well as a significant proportion of the UK's chalk grassland, a species rich, nutrient poor habitat. 47% of the South East's farmed land are farmed for cereals, while 20% are grazed by livestock, with an average farm size of 87 ha (compared to the English average of 86 ha). The region contributes about half of England's top fruit and small fruit production (Department for Environment Food and Rural Affairs, 2020). Soil erosion due to poor agricultural practices caused a series of muddy floods in the South Downs at the end of the last century, emphasising the impact of poor management even on permeable soils (Boardman, Evans and Ford, 2003). 18% of the waterbodies across the area are impacted by changes to their natural flows, often due to over-abstraction.

Credit: FlickrCC Neil Howard

The value of different habitats for water resources is increasingly recognised, for example in regional Natural Capital Investment Strategies. Freshwater habitat restoration and creation, woodland and soil management as well as improved agricultural practices are targeted areas for investment to protect water supply. The draft Kent Biodiversity Strategy, for example, aims to restore 10 ha of wet woodland (Kent Nature Partnership, 2020). Additionally, there is increasing interest in understanding the value of habitats such as grasslands for groundwater replenishment. In the South West there are many projects working to restore the rare Culm Grassland habitat found in north Devon and Cornwall on heavy clay soil. This mix of purple moor-grass and rush pasture can hold up to five times as much water as intensive grassland in extreme weather events and is widely being recognised as an important Natural Flood Management feature (Devon Wildlife Trust).

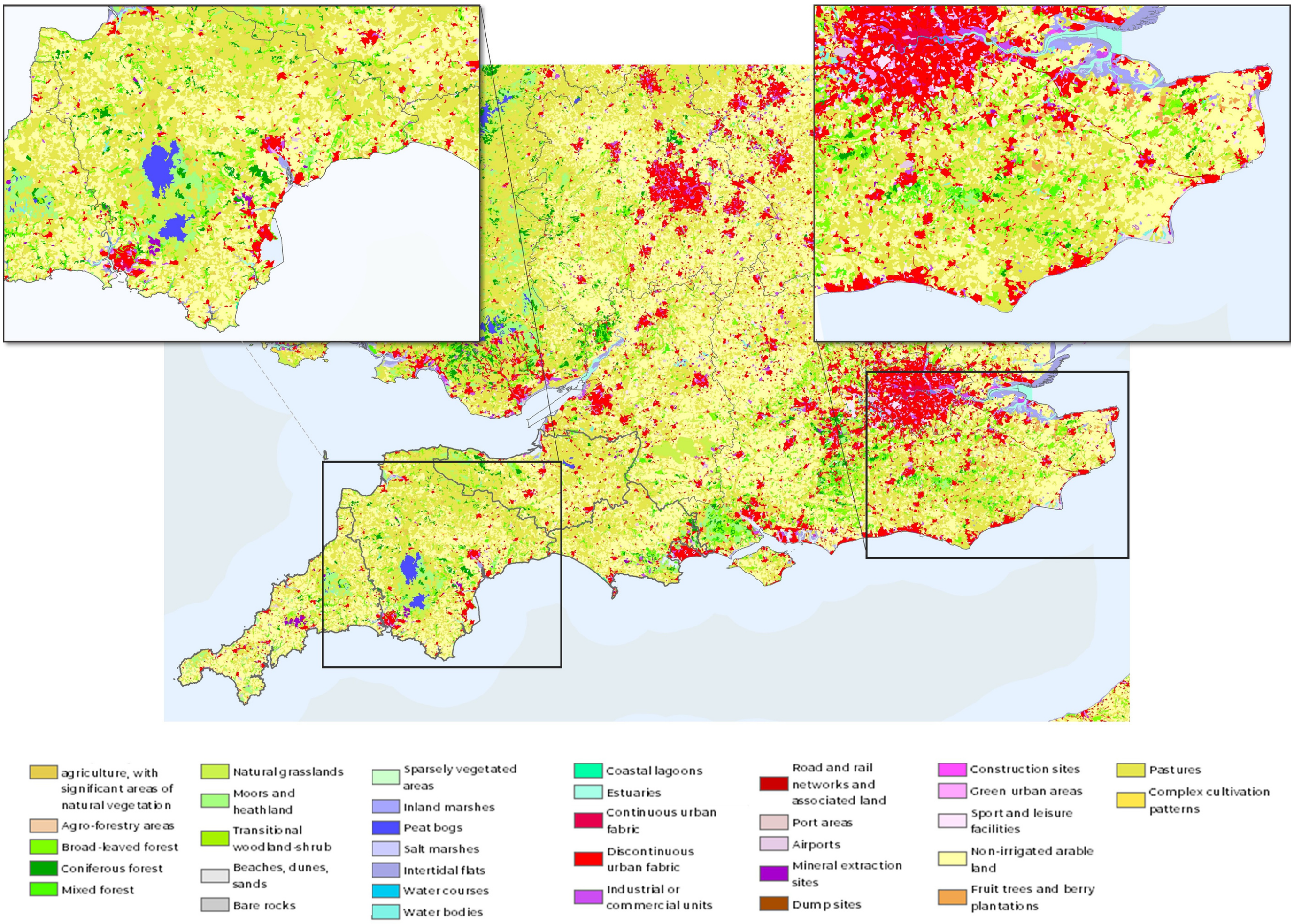


Figure 13. Map showing the dominates land cover types for the south of England. Data source: CORINE Land cover 2018 data (Copernicus Land Monitoring Service, 2018) © European Union.

PRESSURE FROM CONVERSION OF LAND TO AGRICULTURE AND URBANISATION HAS REDUCED THE CAPACITY OF THE LANDSCAPE TO PROVIDE CLEAN AND PLENTIFUL WATER.

Pressures on natural capital

Natural wetlands and connected terrestrial habitats are important components of the hydrological landscape, storing water and buffering river flows through continual steady interflow, but are often degraded. In the UK, 90% of unimproved grassland have been lost since the 1930s (Kent Nature Partnership, 2020), 40% of wet grasslands since 1970 (Natural England, 2009), and 90% of lowland ponds were lost in the 20th century, with land use and land cover change such as agricultural land drainage and urban development as the main drivers (Hayhow DB et al., 2019). This results in a compromised water system which is less resilient to the pressures of increasing water demand and extreme weather from climate change. The pressure on our landscape is therefore pressure on our water resources.

Land drainage has reduced wetland areas since Roman times but was accelerated rapidly by government-funded agricultural drainage schemes in the last 200 years. Headwater streams and wetlands, such as mires and flushes, are often lost to intensified land management draining these areas Figure 14. One study has estimated that as much as 80-90% of floodplain wetlands in the upper Tamar catchment (Devon, South West England) have been lost since 1990 (WERG 2000). Woodland (a third of which is coniferous) covers just 10% of England compared to the European average of 37%, wet woodlands and riparian woodlands in particular have been lost through land use changes (Woodland Trust, 2011).

Historic wetland loss in England to 2008

Extent of wetlands in 2008

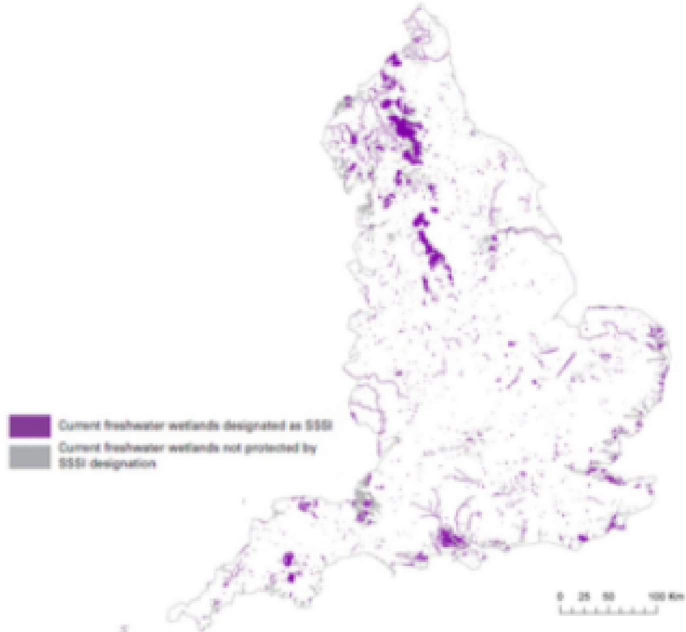
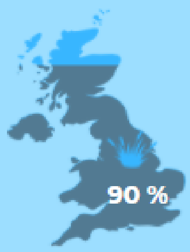


Figure 14. Loss of wetland habitats in the UK. Source: (Wetland Vision, 2008) © Wetland Vision.

WETLANDS ARE AMONG THE MOST PRODUCTIVE ECOSYSTEMS IN THE WORLD, COMPARABLE TO RAIN FORESTS AND CORAL REEFS.



of UK wetlands have been lost since 1970

The Water Framework Directive is widely regarded as one of the most ambitious pieces of European environmental legislation, combining an integrated approach focused on the water environment and its health rather than isolated components potentially impacting it. Established in 2000, it set out to achieve 'Good status' for water bodies across the EU by 2015 and prevent any further deterioration, based on an extensive monitoring network and understanding of cause-effect relationships impacting water body health.

A recent review of the WFD found that less than 50% of all water bodies have so far reached this target. However, this was found to be due to insufficient implementation, integration, and funding, rather than due to the legislation itself, and to variations across the nations. The WFD is seen as a key pillar of environmental improvement across the EU, including to tackle biodiversity loss.

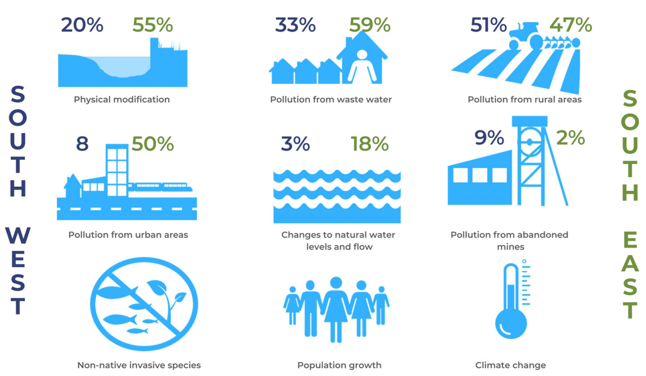


Figure 14. The main reasons for not achieving good status under the Water Framework Directive in the South East & South West. Source: (Environment Agency, 2020a) © Environment Agency 2020).

The historic degradation and loss of these habitats have altered the retention and flow of water though the landscape, and often increased pollution pressure, making freshwater ecosystems less resilient to climate change and less able to support sustainable abstractions. This is visible in the state of the freshwater environment today: 51% of waterbodies in the South West suffer from diffuse agricultural pollution and 18% of waterbodies in the South East are impacted by changes to their flows, often due to abstraction. The 2019 WFD status showed that only 14% of UK rivers are in good ecological condition and none reached good chemical status. Surveys of invertebrates show a loss of between 37 and 58% of species that indicate healthy water bodies since 1998 (Chalk Streams in Crisis, 2019). Nearly a quarter of rivers in England are at risk from too much water being abstracted and not enough left for wildlife (WWF).

By 2050, the Environment Agency estimates that at least 538 000 m3/d of abstraction needs to be reduced in Southern England to meet sustainable abstraction targets that prevent a negative impact on river ecosystems ('Meeting our future water needs : a national framework for water resources', 2020). Unsustainable abstraction levels, such as those in the South East and Eastern England where 22% of freshwater is abstracted, can affect wildlife in many ways (Kowalski et al., 2011). Low flows affect a river's shape and habitat, the transport of nutrients, oxygen levels and the quality of water as there is less dilution of pollution.

Reducing abstraction to sustainable levels through managing demand, leakage in the network and water use efficiencies will all contribute to solving this issue, but it is also necessary to increase the resilience of the catchments providing water. Without restoring the capacity of the catchment to retain and regulate water, water resource managers are not making use of opportunities for cost effective investments into resilient water supplies that can also benefit habitats, wildlife, and agricultural production.

BELGIUM - FLANDERS

Climatic conditions vary slightly across the Flemish Region with the coastal region being cooler due to the influence of the North Sea, and micro-climatic differences due to soil, topography, and geology. The Campine Region (in yellow in Figure 15) has sandy soils with a low water holding capacity. The topsoil drains relatively quickly, leaving less water in soil pores to evaporate. This part of the country has more extreme temperature fluctuations (2°C warmer and colder) than the rest of the Flemish Region. The Campine ecoregion has a deep unconfined aquifer, which is very important for surface hydrology. The southern part of the Flemish region has more heavy, loamy soils (in light green in Figure 15) and a lot of intensive agriculture. These soils dry out much slower and stay cooler. As they have a limited infiltration rate, they are at risk of erosion during heavy rainfall events. The river flow in the loam area is mostly determined by precipitation, but in the deeper valleys springs feed the river system. The sand-loam belt (in dark green) has intermediate properties and is also crossed by several larger rivers (Scheldt, Lys, Upper Scheldt) and canals. The polder and dune area have been shaped by land-sea interactions and display a lot of local variation in soil and hydrology. The polders rely on precipitation and are yet hard to drain due to their topography. When they are drained, they face problems of salinisation during dry summers. When they are not drained, they face inundation risk during wet periods. The dune ecoregion has several freshwater aquifers, which are extremely important for water resources.

Credit: FlickrCC VISITFLANDERS

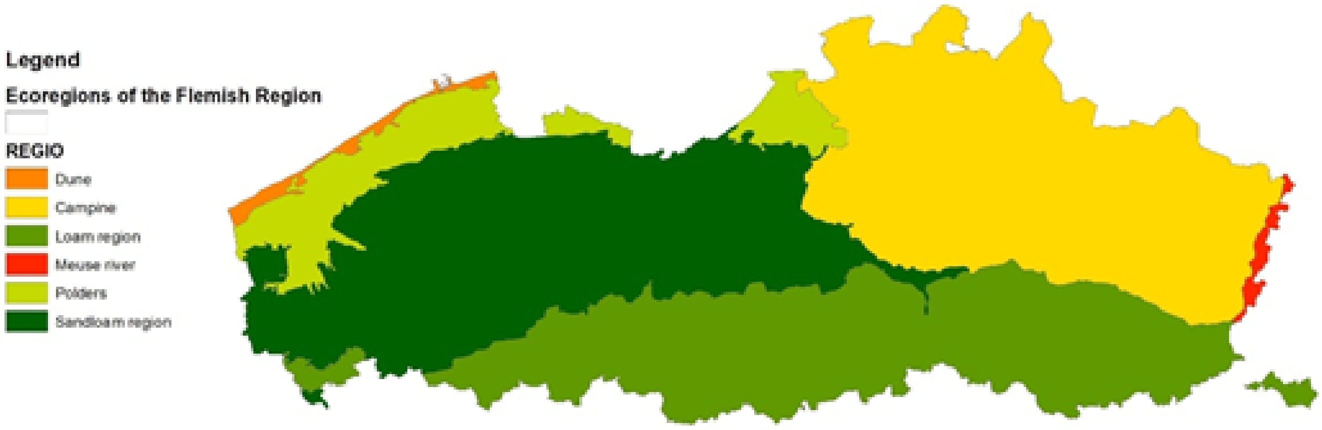


Figure 15. Map of Flanders with indication of different ecoregions: dune area, polder area, sand-loam region, Campine region and loamy region.

Water supply from abstracted groundwater is currently at its limit in Flanders. Of the 42 groundwater bodies, eight have too low water levels. Flanders did implement several measures for groundwater restoration at the request of Europe, but it was calculated that these measures have many shortcomings (Rekenhof, 2014).

Groundwater in the Campine Ecoregion is Flanders' most important buffer to overcome water shortages. Because of the sandy soils and the large area of forest and natural habitats, the groundwater reservoir is large and of good quality. Yet the replenishment of these groundwater reserves is insufficient due to landscape change. Infiltration losses occur due to soil sealing, canopy interception and soil compaction. In addition, a lot of water is lost due to excessive drainage Figure 16. This includes the draining of marshlands for agriculture, straightening and canalisation of rivers for navigation and flood control and large-scale embankments of former flood zones. Besides economic benefits, these changes impact on many of the hidden ecosystem services. Floods, water shortages, erosion, loss of biodiversity and eutrophication are signs that the regulation of hydrological extremes is seriously disturbed. In many cases, Flanders has become dependent upon expensive technical measures to replace those regulating functions. Nonetheless, there are many opportunities to increase recharge, especially in those regions that have high groundwater abstraction pressure Figure 17, Figure 18.

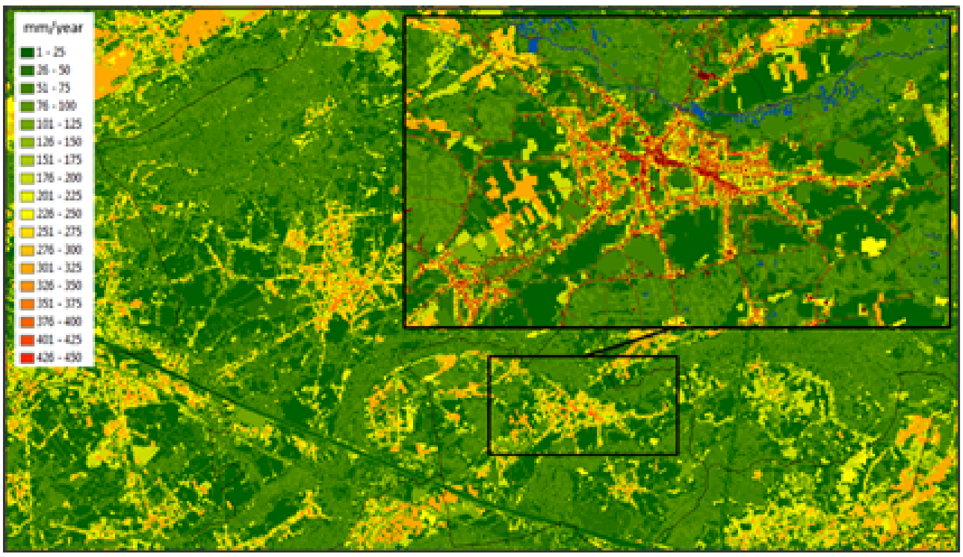


Figure 16 Impact of soil sealing and canopy interception on infiltration (net losses, compared to the potential infiltration) (Staes and Meire, 2013).

About 80% of all Habitat Directive areas (nature protection areas) in Flanders are in the Campine Ecoregion and many of them are groundwater dependent ecosystems (Louette et al., 2011). A conflict between water provisioning and biodiversity conservation is looming. After all, many water production centers are located in or near protected nature sites and recent re-licensing of abstractions is already accompanied by lawsuits against the water companies.

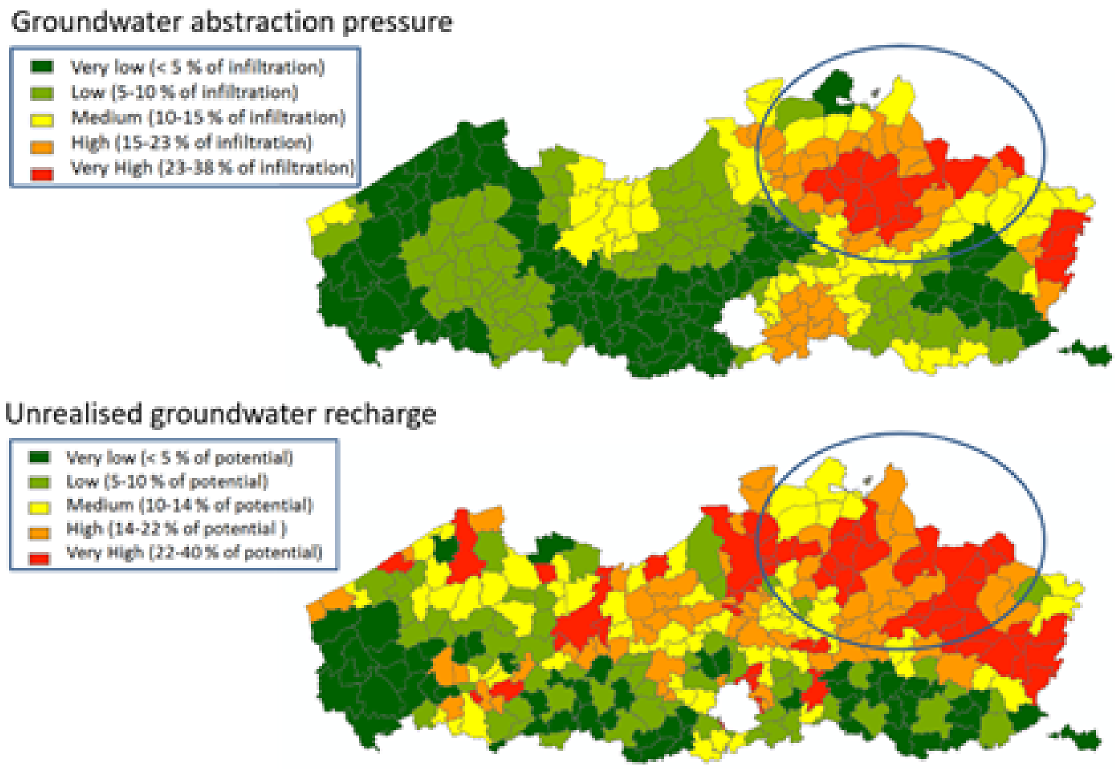


Figure 17. Groundwater abstraction pressure and unrealised groundwater recharge in Flanders (Vrebos et al., 2017).

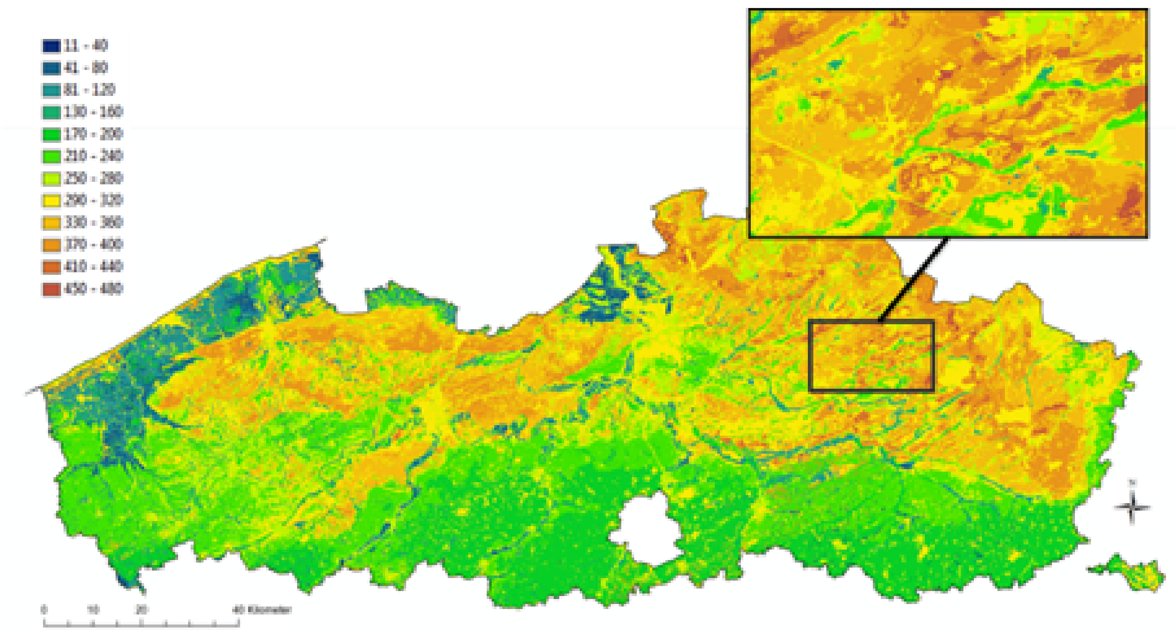


Figure 18. Potential infiltration for the Flemish Region, taking into account soil texture and soil hydrology (Staes and Meire, 2013).

Pressures on natural capital

Belgium is the country with the highest proportion of soil sealing in Europe. The Flemish Region has been suffering from huge urban sprawl and land-use fragmentation in general. The dominant land use is agriculture (46%), but this rural matrix is under pressure and heavily fragmented by transport infrastructure, urbanisation, and industry (Van Steertegem, 2009). The most detailed land cover map shows a net soil sealing of 7.4%, while built-up area amounts to 28% of the territory (MIRA, 2018). About 25% of the urban area is effectively sealed and the remaining area are verges, gardens, and fallow land. The rate of soil sealing has been and continues to be high, with a doubling of urbanised area every 25 years since 1976 (Poelmans et al., 2010). Despite recent policy intentions, this trend is hard to counter because the spatial destination plans of the 1970s designated a lot of land for urban expansion (Poelmans et al., 2010).

In the last 50 years, almost 75% of the wetlands in the Flemish region have disappeared Figure 19 (Decleer et al., 2016). 37 000 ha (15%) have been urbanised; the rest was mainly lost because of intensification of agriculture and to a lesser extent also due to an increase in forest production which has an increased water loss through evapotranspiration. Headwater wetlands have disappeared to the extent that they no longer fulfil the function they once had. Temporary wetlands, which play an important role in the regulation of water flows and aquifer recharge, have declined by 75% (133 000 ha).

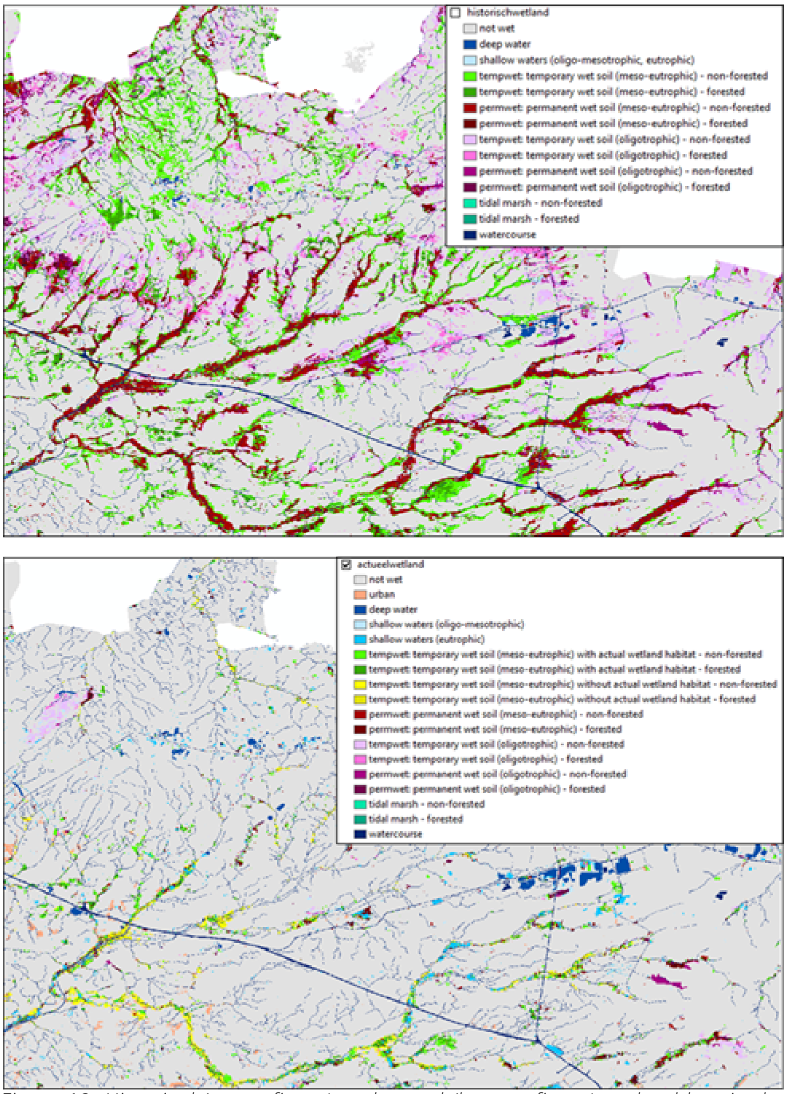


Figure 19. Historical (upper figure) and actual (bottom figure) wetland loss in the Campine region (Decleer et al., 2016).

The Flemish region had a total licensed abstraction of 377 million m3 per year at the end of 2018 (VMM, 2019). About 282 million m^3 are licensed for abstractions from unconfined layers and it is estimated that 60% thereof is effectively abstracted, along with a number of unquantified abstractions. These are shallow, small abstractions (< 500 m^3/y) that are exempt from permits. In addition, there are likely also many illegal abstractions that would require a license.

Due to these land cover and land use changes degrading Flander's natural capital, the hydrological regime of many rivers has become more extreme, with increased peak flows (and associated runoff), increased flood risks as well as more extreme low surface water levels. Due to extensive drainage, the spring groundwater table declines very early in the growing season and a great amount of the natural retention capacity is lost. A key problem is that the degraded landscapes in Flanders discharge shallow groundwater prematurely as a result of soil sealing and extensive drainage, so that it does not have the opportunity to infiltrate into the subsoil.

THE NETHERLANDS - NOORD BRABANT

The Netherlands is often regarded as a "water rich land", situated below sea level for about 60% of its territory. It may seem odd that in the Netherlands water scarcity can arise during parts of the year, as this country is situated in the delta of the rivers Rhine and Meuse and has a mild, humid climate. However, large parts in the south and east of the Netherlands are over one metre above mean sea level and cannot be supplied with fresh water from the river Rhine and Meuse due to gravity forces. These higher sandy hills are mainly dependent on precipitation and groundwater for the supply of fresh water. Noord-Brabant is one of the regions feeling increased pressure on its water supply. The water management system in this region has been considerably adapted in the past century, especially to drain and discharge excess water to allow more intensive agriculture, by digging and re-dimensioning ditches and by installing drainage pipes, weirs, and pumps. As a result, groundwater levels dropped substantially between 1950 and 2010, while crop production increased Figure 20.

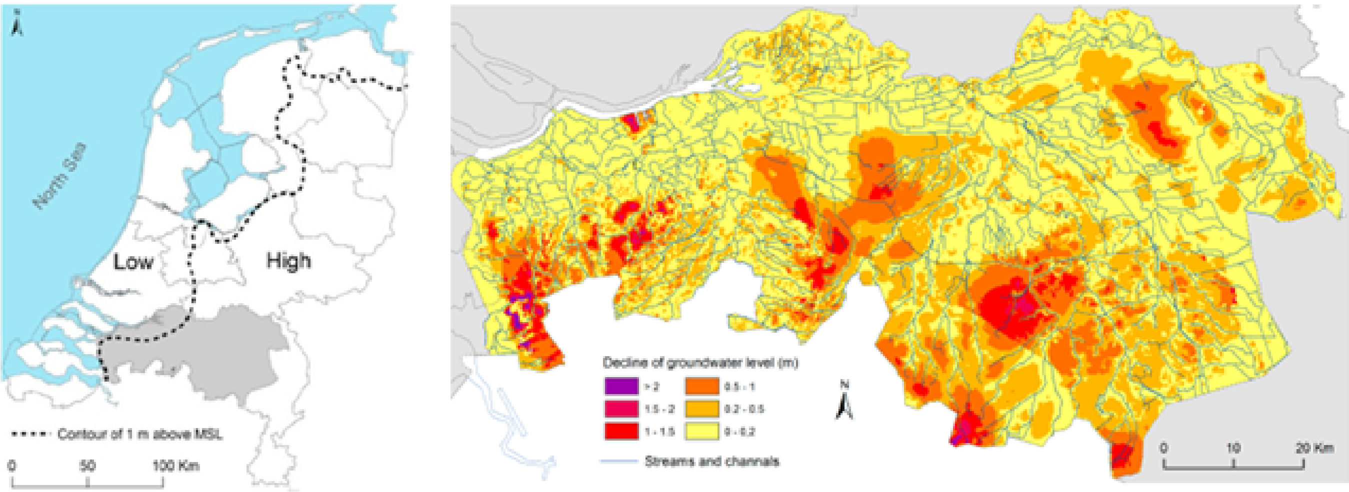


Figure 20. Left: Division of the country in high and low part (Noord-Brabant: grey). Right: Simulated decline in groundwater level due to change in land use between 1950 and 2010.

The average precipitation in Noord-Brabant is 800 mm per year. From this 800 mm about 600 mm evaporates on average. Resulting in 200 mm of fresh water per year that is either available for storage in surface- or groundwater, or drains through drainage pipes and ditches into the larger rivers. About 1700 million m3 of rainwater falls on the surface area of Noord-Brabant per year. Due to this strong developed water management system, about 80% of the rainfall flows away through ditches and sewers and only 12% (of the precipitation surplus) infiltrates to the deeper groundwater. The average annual total groundwater recharge is 260 million m3.

DUE TO INTENSIVE LAND USE AND WATER ABSTRACTIONS, GROUNDWATER LEVELS IN THE SANDY SOILS IN THE NOORD-BRABANT PROVINCE DROPPED DRAMATICALLY BETWEEN 1950 AND 2010.

Pressures on natural capital

In the Netherlands , 97% of the historic wetland (fen peat, raised bog, salt marshes and mud flats, river deposits and dunes beaches) has been lost (van Eerden et al., 2010, Warmer et al., 2018). Wetlands remained undisturbed for a long period, but they have become seriously affected since the late Middle Ages; the construction of dikes, embankments and drainage have caused the area of wetlands to shrink dramatically. This led to the disappearance of many freshwater lakes and the almost complete loss of the area of brackish water, the natural link between sea water and freshwater Figure 21.

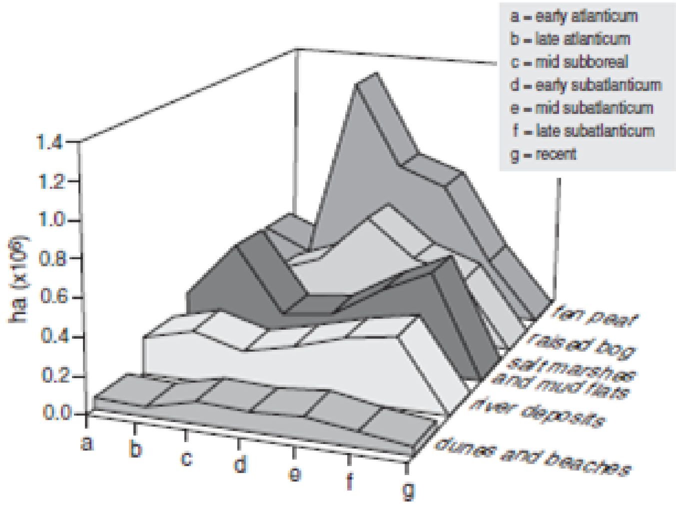


Figure 21. Changes in surface area of wetland ecotypes in the Netherlands for seven periods up till 2010. Ref: van Eerden et al., 2010.

The effects of decreased precipitation surplus, increased drainage and increased water abstraction are already being felt in Noord-Brabant. Groundwater levels have been dropping since the 1950s as the demand for drinking water, agriculture and industry from groundwater sources has increased rapidly. The conversion to intensive agriculture, urban areas, water level controlled and freely drained areas (Figure 21, Figure 22) has led to a decline of groundwater levels in natural habitats adjacent to farmland, resulting in serious loss of conservation value (Witte et al., 2019). Since the 1990s, these problems have been recognised by the Dutch government and several projects have tried to restore groundwater levels. Any further increases in demand of groundwater will put further pressure on these protected nature sites. To reverse the downward trend in groundwater levels in the sandy soils (Figure 20), more substantial modifications in water and land use are required.

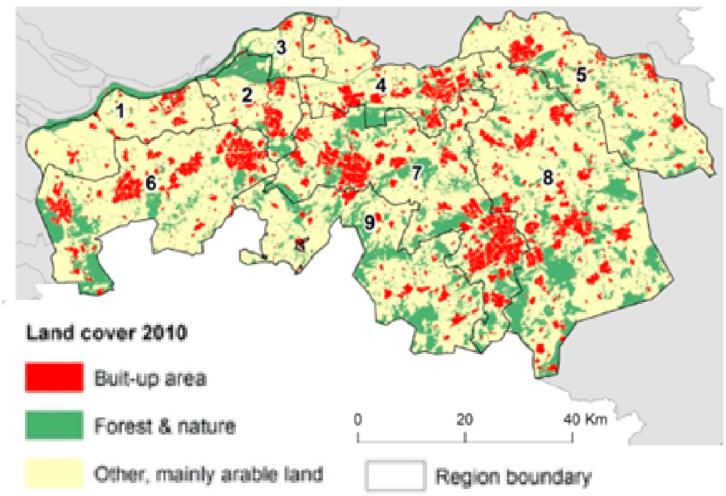


Figure 22. Main land use in Noord-Brabant. Source: CBS, 2010.

CLIMATE RESILIENT INTEGRATED LAND AND WATER MANAGEMENT REQUIRES GREATER LEVELS OF INFILTRATION AND RETENTION IN THE LANDSCAPE AND A SUBSTANTIAL DECREASE IN PEAK FLOWS FOLLOWING RAINFALL.

The increasing water demand and its pressure on the groundwater levels became especially clear in the year 2018, when the Netherlands suffered one of the driest summers on record with a precipitation deficit of over 300 mm during the summer months from the 1st of April to 30th September. This led to an extensive depletion of the groundwater resources during the summer quarters. During these summer months, about 170 million m3 was abstracted from the groundwater. Drinking water abstractions were 27% higher than the average of the past 10 years and irrigation water for agriculture during these four months was 1.5 times higher than groundwater abstraction for drinking water. It is expected that due to climate change, groundwater demand by agriculture could double from 35 million m3 per year to 70 million m3 per year. As large parts of the rainwater that falls during winter still flows away through drainage pipes and ditches (60-95%), groundwater recharge will still be limited during the winter period. This 'surplus' discharge flow is a critical key factor for new land-water management approach in which Nature-based solutions play a major role.

The Dutch Government has asked the province to investigate the possibilities of increasing the drinking water supply by 30% in 2040 to ensure that demand for drinking water can be met. This puts great pressures on the groundwater system. At the start of the revision of the groundwater abstraction policy in Noord-Brabant, it was thought that there would be capacity for extra groundwater abstractions. However, recent warm summers with increasing water demands and studies revealing that groundwater abstractions already have reached the groundwater replenishment volumes, reveal that adaptation of the groundwater policy and landscape management will be crucial in order to adapt to the current and future challenges. Without revision of the policy, further desiccation of nature reserves and increasing pressure on Natura 2000 areas that are dependent on seepage will occur and eventually even the drinking water production will be at risk of not meeting demand.

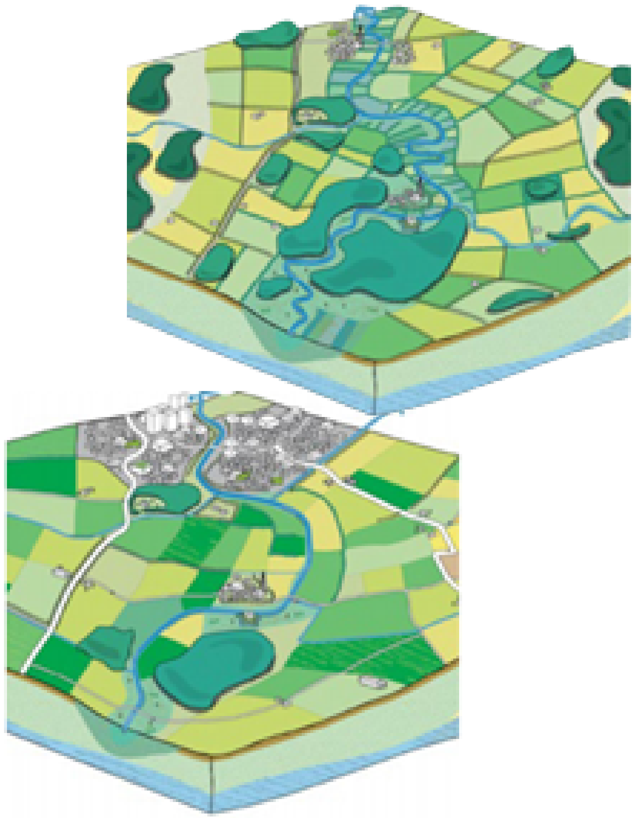


Figure 23. The province of Noord-Brabant is strongly altered in last century to improve the drainage of the land. Top: historic landscape. Bottom: current landscape.

Relation between sustainable water resources and healthy natural water systems

The detailed water catchment analyses for the Water Framework Directive (WFD), as conducted by the Brabantse Delta water management authority between 1995 and 2020, showed that hydrological pressures are critical for reaching the good status of the brook systems in the sandy hills. In addition to critical chemical and morphological pressures, especially reduced baseflows and widening and deepening of the water systems for the sake of rapid (precipitation) discharge flows in wet periods, hinder full compliance with the WFD's objectives. Between 2016 and 2020, the percentage of good status for all measured biological elements the 25 water bodies in the Brabantse Delta 'management territory' fluctuated between 16 and 20%. In order to increase this percentage, interrelations between groundwater and surface water bodies deserve more attention. Nature-based solutions, such as more infiltration and water retention in the landscape and 'hydro-morphological re-shaping' of the brook systems, are essential for meeting the good status.

KEY MESSAGES

- Catchments and the wetlands and terrestrial habitats within them are natural capital. They play a key role in the regulation of the quantity and quality of water that is available to humans and the natural environment. Therefore, natural capital and economic capital cannot be detached from one another.

- Protecting, restoring, and connecting wetlands and terrestrial habitats and restoring linked hydrological processes on a catchment scale allows the mitigation of extreme weather events and increases the resilience of wetlands and terrestrial habitats to additional pressures such as abstraction and pollution.

- The hydrological functioning of catchments determines the approach to Ecosystem-based Adaptation that would improve their resilience of water resources. EbA measures should reflect the processes that would occur naturally in the landscape, taking account of geology, climate and ecosystems.

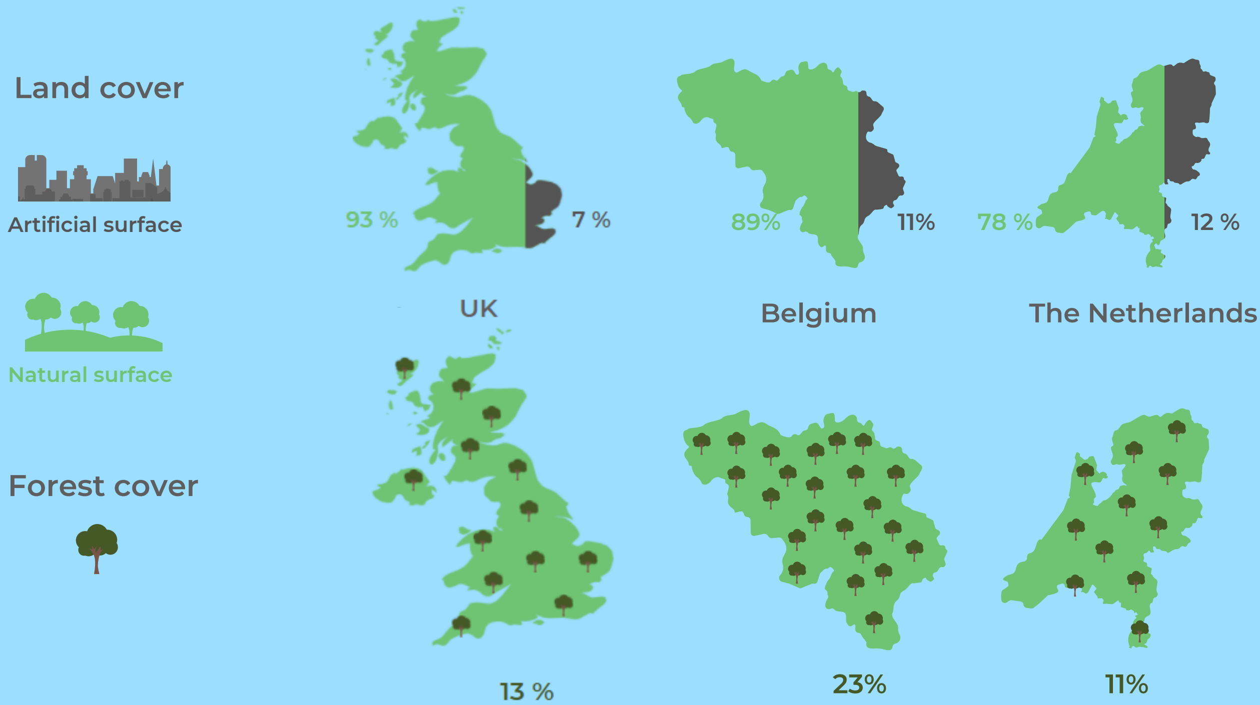


Figure 24. Land cover (top), forest cover (bottom) for the United King, Flanders and the Netherlands.

SOUTHERN ENGLAND

- Pressure from the development of land for agriculture and urbanisation has reduced the capacity of the UK's landscape to provide water-related ecosystem services (water quantity and quality).

- Southern England has a varied geology which results in a mixture of hydrological systems. This means that each catchment may require a different set of EbA measures to improve resilience of water resources, depending on the natural capital present.

- In the UK, there is increasing recognition of the importance of investing in EbA measures to increase resilience of catchments and communities against flooding, drought, and other pressures.

- Pathways for investment in EbA and systems to ensure outcomes are not yet mainstreamed, and demonstration projects are needed to enable further uptake.

KEY MESSAGES

BELGIUM - FLANDERS

- Land cover and land use changes have impacted the hydrological systems within Flemish catchments, affecting water availability and quality.
- Due to Flanders's degraded natural capital and the impact of climate change, the hydrological regime of many rivers has become more extreme with consequently increased peak flows (and associated runoff), increased flood risks as well as more extreme low flows and water levels.
- In the last 50 years, almost 75% of all wetlands have disappeared in Flanders, mainly due to urbanisation and intensification of agriculture. Upstream temporary wetlands have also disappeared at an alarming rate despite their importance for water flow regulation and aquifer recharge.

THE NETHERLANDS – NOORD-BRABANT

- Due to intensive land use and water abstractions, groundwater levels in the sandy soils in the Noord-Brabant province dropped dramatically between 1950 and 2010. Consequently, biodiversity is under pressure due to desiccation of nature reserves and decreased baseflows of surface water bodies.
- The effects of climate change and the expected increase in the demand for drinking water exacerbate the challenges of both freshwater demand and supply management in relation to biodiversity and good status of groundwater and surface water bodies.
- Climate resilient integrated land and water management requires greater levels of infiltration and retention in the landscape and a substantial decrease in peak flows following rainfall. This requires substantial modifications in the land and water use.

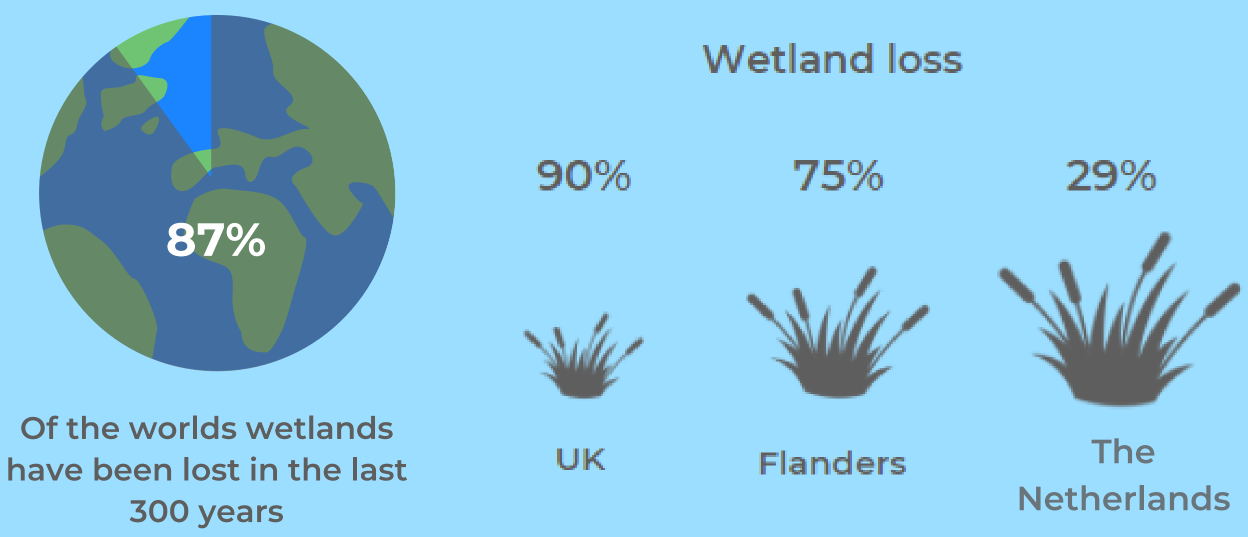


Figure 24. Wetland loss for the United King, Flanders and the Netherlands.

WATER RESOURCES

Water is essential for life and an indispensable resource for the economy. Although renewable water is abundant in Europe, renewable water resources per person across Europe have shown a decreasing trend between 1960 and 2017. Annual renewable freshwater resources are estimated at 4 560 m³ per person when their total volume is averaged over the total European population for the period 1990-2017 (EEA, 2020). Groundwater resources and rivers continue to be affected by overexploitation in many parts of Europe, especially in the western and eastern European basins (EEA, 2020). This section describes the current and projected water resources situation in the focus regions.

Demand for water is driven by the household use of private users, irrigation needs in agriculture, industrial processes (such as manufacturing or power generation) and navigation. This demand usually has distinct spatial and temporal patterns – for example, demand is highest in large urban areas (high population density), and increases during hot, dry periods in the summer. Demand usually does not correspond well to when and where water resources are available. As both the population and economy are expected to grow and use more water, this mismatch is increasing.

Understanding when and where demand for water is highest it is important to make better informed decisions about water resource management. There are many ways to manage water resources such as demand management, network upgrades to reduce leakage, increasing water use efficiency, and alternate water supply systems (such as rainwater harvesting and water re-use systems). All of these methods are crucial to sustainable water resource management and need to be implemented alongside EbA measures that increase the resilience of water sources in the environment.


Credit: Unsplash Manki KIm

SOUTHERN ENGLAND

The UK water industry was privatised in 1989. Today, 32 companies supply water, sanitation, and drainage services. Water utilities in England and Wales have a monopoly on water (i.e. public water supply) and sewerage services for household customers for specific regions. As part of this structure, each utility is subject to economic, environmental, and drinking water quality regulations. Ofwat is the economic regulator, the Environment Agency and Natural Resources Wales are the environmental regulator for England and Wales, respectively; and the Drinking Water Inspectorate is the drinking water quality regulator.

0.14 m3 (140 litres) per person is the average daily water demand across the UK (National Audit Office, 2020), Even higher demand levels are found across South East England. A national target to reduce demand to 0.11 m3 (110 litres) per person per day by 2050 was set by all water companies in 2020 (Environment Agency, 2020a), although some are putting more ambitious targets in place to reduce the gap between demand and supply (e.g. Southern Water's 'Target 100'). The most cost-effective approach to demand management proposed by the Environment Agency could contribute up to 86% of projected demand for 2050 (with a reduction to 0.08 m3 per person per day) – but these savings may not always be made at the time and in the location most affected. Non-household demand (demand for offices, schools and similar businesses supplied through public water supply) –accounts for 20% of water supplied and is regulated separately from household supply. Leakage from infrastructure accounts for 20% of water use nationally but varies strongly between water companies. By 2025, water companies have committed to reducing leakage by 16 %, and 50 % by 2050, although some are aiming for higher targets (Environment Agency, 2020a).

Non-public water supply, i.e. the water abstracted and used by anyone other than public water companies, is used for hydropower, industrial processes, agriculture, or navigation. In the past not all abstractions required licences, there were many exceptions such as trickle irrigation. Sometimes even large abstractions were exempt, but now abstractions above 20m3 require a licence unless exempt under Water Abstraction and Impounding (Exemptions) Regulations 2017.

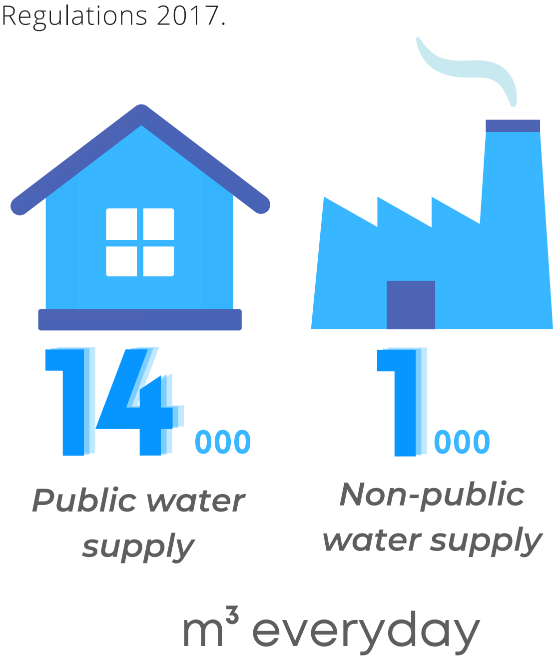


Figure 25. Public (left) and non-public (right) water supply (m3 per day) in Southern England.

SOUTH WEST

Every day, Wessex Water, South West Water and Bristol Water supply 1.4 million m3 of public water in this region (511 million m3/year) (West Country Water Resources, 2020). Public water supply makes up 85% of total water demand in the South West, with the next biggest consumers being mineral workings and agriculture. Non-public water demand is the third highest of all the regions in England at approximately 180 000 m3/d (65.7 million m3/year). The pressure on the water supply in South West England is relatively modest in contrast to other regions in the UK, such as South East England. Analysis of water risk by the World Resource Institute identifies a 10% baseline water stress for the Southwest River Basin District (i.e., proportion of total available blue water abstracted based on 1960-2014 data), putting the region into a low-risk category (Figure 2).

The region has not experienced any severe restrictions that limit water availability since the 1976 drought. However, modelling undertaken as part of the development of the National Framework ('Meeting our future water needs : a national framework for water resources', 2020) estimated that if the region was to experience severe restrictions to the availability of water, the impact on the economy would be in excess of a loss of £2bn a month. These restrictions on the availability of water are expected in the form of two major drivers of increased water use by 2050, one being population growth and the other increasingly common drought spells due to climate change. Both require us to build a more resilient public water supply, using a sustainable approach that also ensures a resilient environment.

Currently, most management catchments of the South West have a demand that does not outweigh the available resource during average low flow periods. The abstraction demand ranges from 0.1 – 100% with the exception of the Bristol Avon and North Somerset streams which see a demand of 100-125% of available resource (HR Wallingford, 2015). At the operational catchment level, the variation in available resources show there are some areas where additional water supply is available < 30% of the time Figure 26. These shortfalls can be overcome by transfers of water throughout the region from areas of surplus. This highlights that there is already a need to increase the resilience of small catchments even though currently, the overall water resources position is secure.

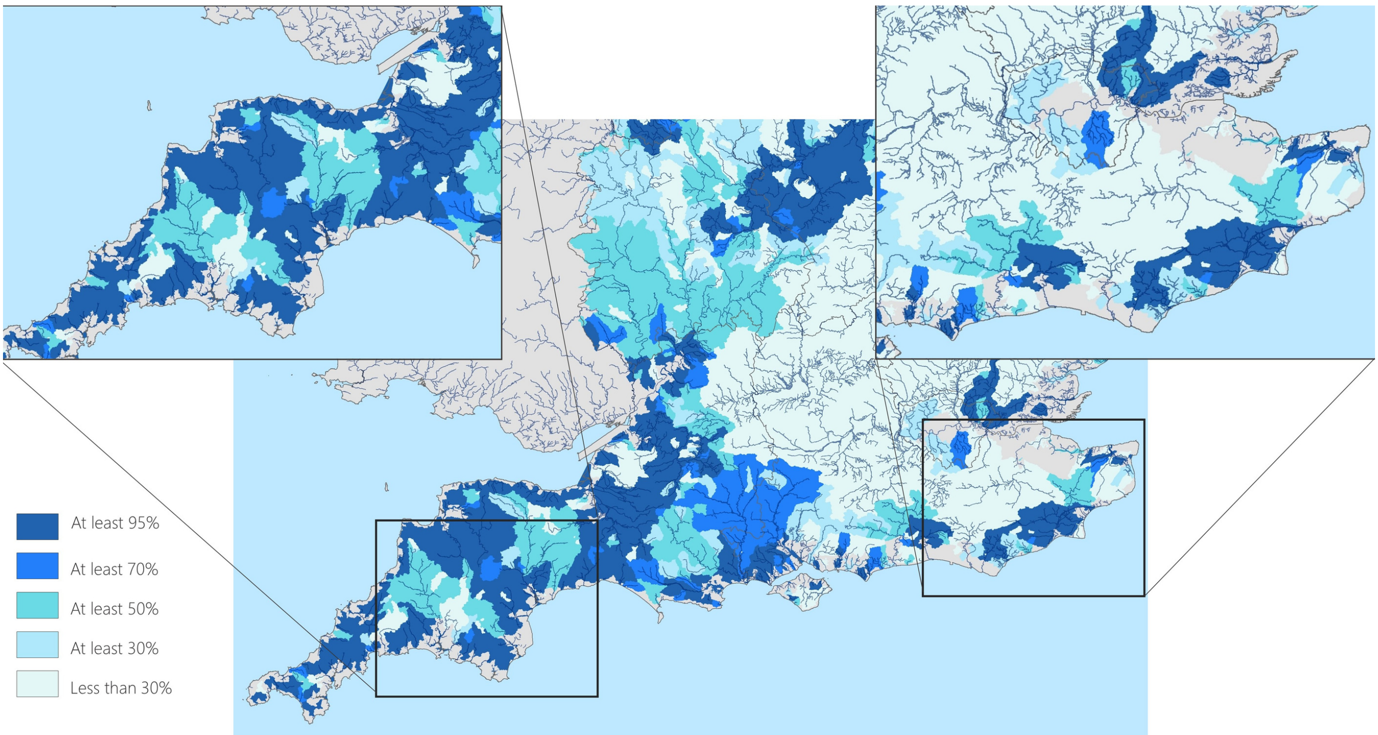


Figure 26. This figure shows how reliable (i.e. the proportion of time that it could be used) a new abstraction license might be based on how much water is available at different flows. The percentages relate to the amount of time that additional water may be withdrawn without harming the environment. Management Strategy (CAMS) 2020).

CAMS, the Environment Agency's Catchment Abstraction Management Strategy, is the process with which the EA assess the availability and reliability of water for abstraction for each management catchment. Based on this process, abstraction licenses can be granted. This process sets out by calculating a water balance, including environmental requirements (using an Environmental Flow Indicator), and assess where and how often additional water might be available to be abstracted. This results in 2 sets of indicators: one showing the resource available at different flows (low to high), and one showing how reliable (i.e. the proportion of time that it could be used) a new abstraction license might be based on how much water is available at different flows. Through the abstraction licensing process as well as monitoring of rainfall and flows, the EA should monitor how much water is used by licensed abstractions and how much is available in the environment. Up to June 2020, abstractions below 20m3/d did not require a license. This process is currently changing.

In the South West it is predicted that the total water available will remain greater than the forecasted demand, at least up to 2050. The dominant need for water will remain with the public water supply and despite an increase in population growth (15% by 2050), planned water savings through leakage reduction and personal use mean public water supply should remain in surplus by 6-17% under the Westcountry Water Resources Group forecasts. These forecasts rely on significant reductions in both infrastructure leakage and per capita use. It is not yet clear how achievable they are. Even if successful, these water savings alone will not provide surplus water uniformly across the region. Moreover, these forecasts do not explicitly consider the changing demand for water from the environment. As the South West is expected to be in a strong position with regard to water resources, there is additional pressure to increase efficiencies to enable regional transfers of surplus supply to neighbouring regions such as the South East (Environment Agency, 2020a).

A 5% increase in non-public water supply demand by 2050 (mainly from the agricultural sector) is predicted. If the current water availability is assumed to remain the same, there will be a need for additional water transfer to meet this demand (West Country Water Resources, 2020). The Westcountry Water Resources group is currently developing the Regional Plan which will reveal how the need for water may change at a local level and implications for non-public users. These situations may be where EbA measures resulting in additional water input could be included as increased demands are often very localised. With such a high proportion of this region's non-public water demand in the agricultural sector, the majority of which is made up of livestock farming, the effects of a warming climate on agricultural management patterns and the need for water for livestock will be an important strategic issue that EbA can have a role in.

SOUTH EAST

In total, 5 million m3/d are supplied on average by six water companies in the South East – Affinity Water, Portsmouth Water, Sutton and East Surrey Water, South East Water, Southern Water and Thames Water), rising by 1 million m3/d in hot periods (Water Resources South East, 2020). Most water companies in the South East have a higher demand per person (up to 0.16 m3 or 160 litres per person, per day) than the UK average (0.14 m3 per person, per day or 140 litres). In addition, 153 000 m3/d is currently used by non-public users such as agriculture and industry, which in the South East consists mainly of paper and pulp, agricultural irrigation, and power generation. Many farms, especially smaller ones, also rely on public water supply for livestock in dry periods. Other sectors, like horticulture, are expanding and their abstractions are only being monitored now. There is therefore a lot of uncertainty associated with non-public water supply demand, which can be crucial especially during dry periods as need is highest and supply lowest.

Groundwater is the main source of water, especially where the chalk aquifer provides clean, reliable storage and permeable soils allow groundwater recharge. Between 35% (Thames Water) and 85% (SES water) of public water supply is abstracted from groundwater. Where landscapes are less permeable (clay soils), surface water abstractions are often used to supply water and stored in reservoirs, such as Bewl Water reservoir in Kent. The groundwater resource can be impacted heavily by historic and current nutrient pollution from agriculture and waste water treatment.

Currently, 52% of the precipitation surplus (i.e., water that is not lost to evapotranspiration) is abstracted in the Thames River Basin District, and 35% in the South East – indicating high levels of water stress as a large proportion of the available resource is used. This is confirmed by the Environment Agency's classification of the area as seriously water stressed. Because of this, water companies can install water meters in every household and on average 60% of households in the region have a water meter. Water companies have committed to supporting consumers in reducing their water demand further, but this is a challenging task.

Many catchments in the South East are at the maximum of their ability to provide water during low flows, and groundwater levels have been declining (Jackson, Bloomfield and Mackay, 2015). At low flows, most catchments of the South East could not allow any additional abstraction or even already have significantly more demand placed on them than they can sustain (for example a demand of 150-200% of available resource in the Medway, and 100-125% of the available resource in the Stour) (HR Wallingford, 2015).

Waste water discharges can make up a high proportion of flows, especially during dry periods. If these discharges into the river are considered, the available resource rises to 51 000 - 100 000 m3/d in each catchment named above. This shows the importance of accounting for treated effluent volumes in water resource management, and the impact of these inputs on many freshwater systems that rely in part on their ability to dilute pollution.

The drinking water resource is further impacted by current and historic pollution issues such as nitrogen, pesticides, and pathogens in surface and groundwater bodies Figure 27. In some cases, sources can become so compromised by pollution that they cannot be used any further, as treatment becomes uneconomical until new treatment methods may become available or cost reduces.

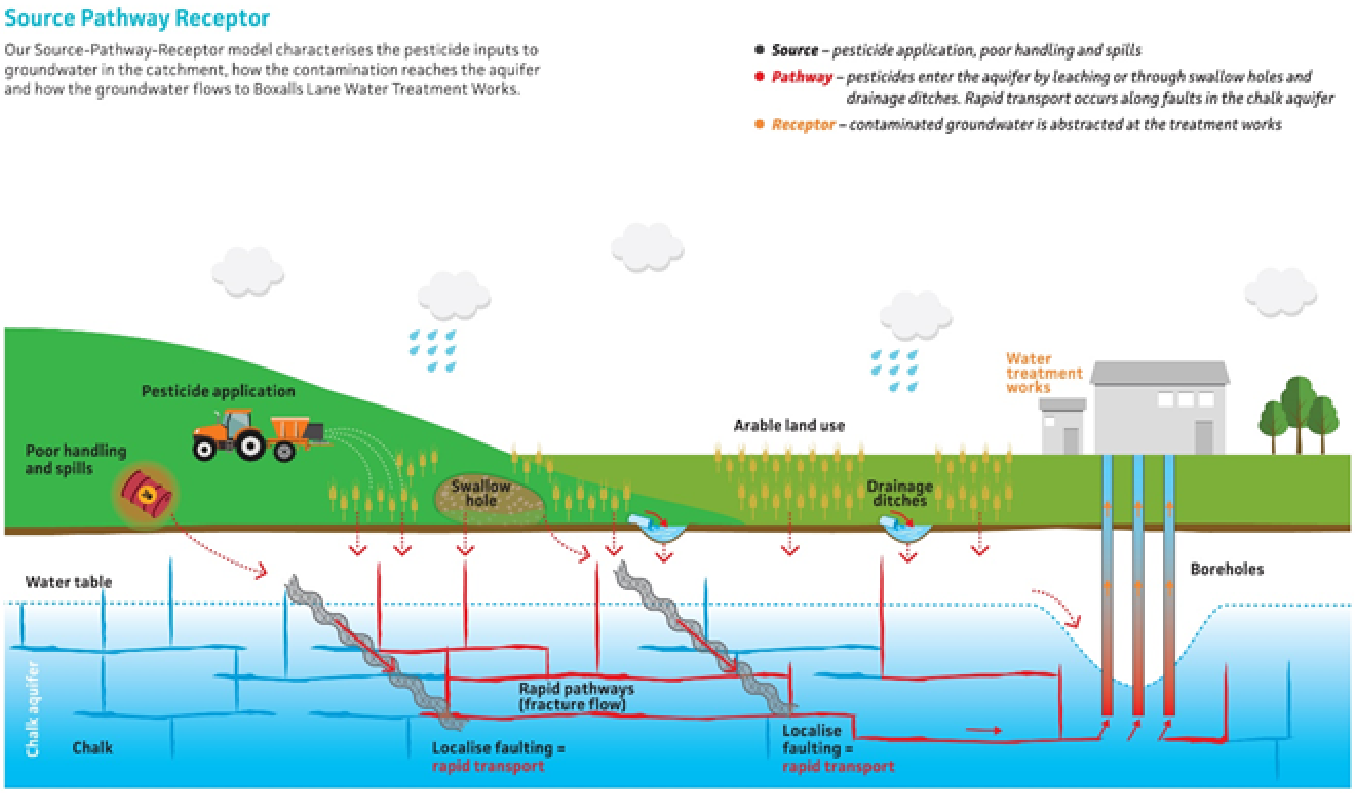


Figure 27. Groundwater resources – as well as surface water – are significantly impacted by historic pollution due to intensive fertilizer use, as well as pesticide and pathogen input from land management and sewage treatment. In some cases, the level of pollution leads to the water source becoming untreatable. Image Source: South East Water.

By 2030, demand for water will exceed the resources available in the South East by at least 86 600 m3/d (Water Resources South East, 2020). Climate change, population growth, and the need to increase resilience to extreme events all add up to a higher water demand across the region. Growing agricultural demands due to the growth of some sectors, especially horticulture, adds further local stress. The South East has also experienced more droughts than other UK regions, which all adds to the complexity of balancing the water resource demands within the region.

Biggest users of non-public water supply by 2050

BELGIUM - FLANDERS

With 860 – 1 466 m³ annually renewable freshwater resources per inhabitant, Flanders is at the very bottom of the water availability index of the European countries (with 4 560 m³ per inhabitant per year being the average of the water availability index) (EEA, 2020). Compared to many other countries, the inflow of water from large international rivers is relatively low. Flanders has an intensive use of space and land on a small surface area. With an average water demand of 700-800 million m³ per year, there is a huge dependency on the rainwater that falls on this limited surface area, of which 60-70% evaporates on average every year. This leaves an average precipitation surplus of 3 - 4 billion m³ per year. Flanders uses as much water as Portugal on a surface area that is almost 7 times smaller and with a water availability index that is about 7 times less.

Flanders' supply of drinking water is highly dependent on groundwater, which is annually replenished by a precipitation surplus. Approximately 49% of the 350 million m³ water used for drinking water production is abstracted from groundwater (170 million m³). Most of those groundwater volumes are abstracted within the Flemish Region (95%) and the remaining 5% are abstracted in the Walloon region. The 183 million m³ abstraction from surface water in Belgium is mainly carried out by water companies Water-link (80%) and De Watergroep (20%). Water-link uses water supplied by the Meuse river that feeds the entire canal system of the Campine region. The abstractions are buffered by two large reservoirs and take place along the Albert Canal in Broechem (6 million m³) and the Netekanaal in Lier (2.4 million m³). Water-link produces 145 million m³ of piped water, of which a large proportion is used by the industry in the port of Antwerp. The water availability is thus buffered by reservoirs, but directly related to the Meuse discharge treaty and the management of the Albert Canal by the Vlaamse Waterweg. The reservoirs can supply water for about 30-40 days without new intake from the canal system. During extreme droughts, the available flow from the Meuse river is needed to operate the canal system and to avoid saltwater intrusion at the sea-sluice. The water company Pidpa also captures a small volume of canal water, to locally replenish groundwater levels. The flows of the Meuse, Scheldt and Lys that enter the Flemish Region are sensitive to the precipitation surplus. More importantly, a lot of the water transfers have been arranged by international conventions.


Credit: Unsplash Macau Photo Agency

Deep groundwater has the advantage of being of better and more consistent quality, so treatment is easier than that of surface water. Groundwater abstractions are not tied to a specific location (unlike surface water abstractions) and can therefore be installed and exploited more widely throughout the catchment landscape. In the past, there was no stringent policy on groundwater abstraction and (too) many permits were issued. Approximately 23 000 licensed groundwater abstractions are assumed to have a total abstraction volume of about 350-450 million m³/year (including those for drinking water production). Shallow groundwater is less desirable for high-end applications due to diffuse pollution, for example nitrates and pesticides, but can be used for irrigation and other low-end applications.

Most of the groundwater abstractions are situated in the deep unconfined aquifer of the Campine region (Antwerp/Limburg). For the Campine Ecoregion, about 13% of the long-term annual precipitation surplus (1340 million m³) is abstracted annually (175 million m³). Although this seems quite a reasonable figure, the abstraction/recharge ratio can rise significantly when a series of dry years occur. There is also a strong spatial variation in abstraction pressure Figure 28. Furthermore, these numbers do not account for illegal abstractions and losses due to drainage. In general, we observe lower superficial groundwater levels and decreased baseflow, especially during summer.

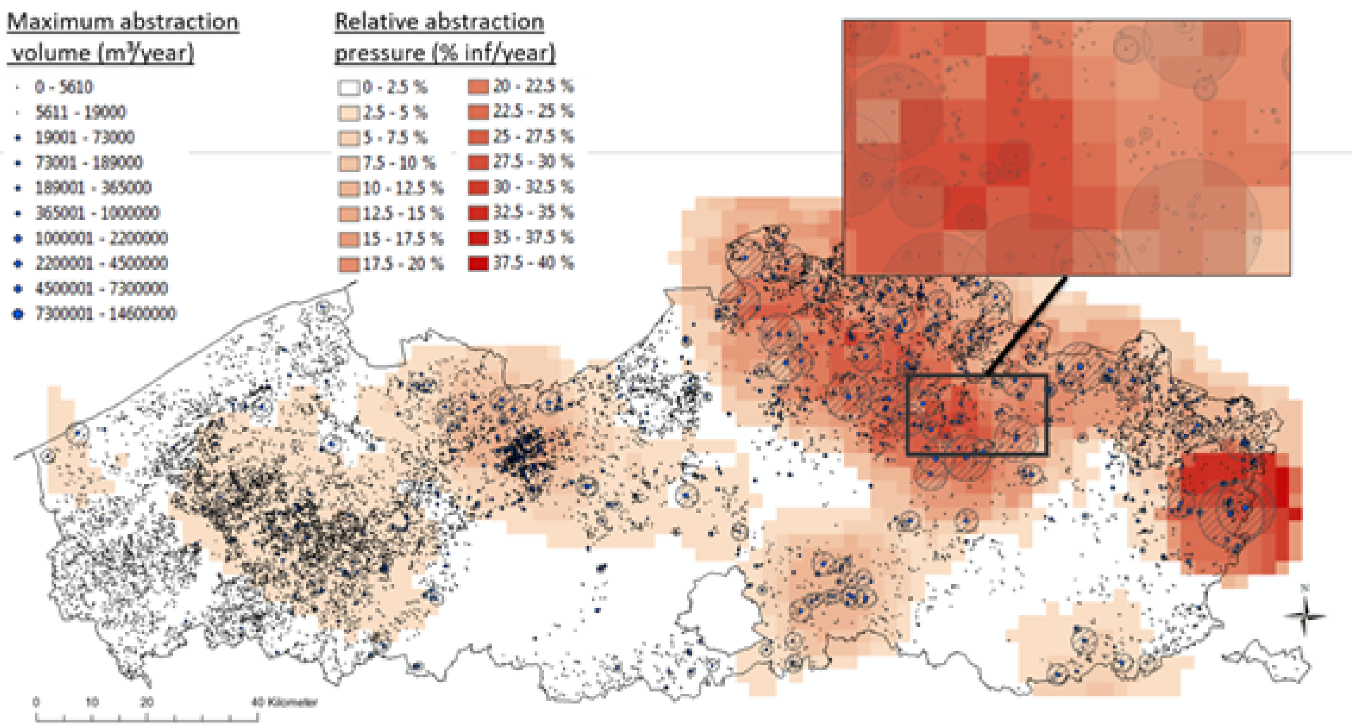


Figure 28. Relative abstraction ratio (percentage of annual recharge abstracted), groundwater abstraction wells (unconfined) and virtual buffers of needed recharge area (8 m³ of recharge area for each m³ annually abstracted) (Staes and Meire, 2013).

In the western part of Flanders, unconfined abstractions are very shallow and limited due to the geological structure of the subsurface. Confined aquifers (e.g. Sokkel, Landeniaan) are deep aquifers, confined or overlain by impermeable material, which have been overexploited for many decades (mainly for industrial applications) and have not recovered. Flanders still has unsustainable abstraction from these confined aquifers (average of 161 million m³ per year). The recharge of these confined aquifers is very slow and can even take several centuries. At 2 mm per year, only 1 % of annual precipitation reaches these confined layers. With an abstraction greater than the recharge, the levels of these groundwater bodies still drop by an average of 2 cm per year.

Precipitation surplus and groundwater replenishment

The average annual precipitation in Belgium is 925 mm and 853 mm for Flanders. For Flanders, with a surface area of 13 522 km², this amounts to about 11.5 billion m³ of water, nearly 5 million Olympic swimming pools. For an average year, there seems to be no water shortage. Taking 2017 as a reference, there were roughly 10 285 million m³ of precipitation (795 mm/y) and roughly 9 926 million m³ of inflow through rivers and canals. Evaporation losses were calculated at 6 859 million m³ (67% of total precipitation and 34% of total available water). This means that there is a precipitation surplus of only 253 mm in the Flemish territory. Due to changes to the landscape, there is no optimal use of effective rainfall as a large proportion is lost through runoff (17% of surplus lost within days) and superficial drainage (20% of surplus lost within weeks). The remaining (63% of surplus) will contribute to deep recharge (of non-confined aquifers) (2 777 million m³ for 2017), but abstractions (6%) and deep drainage (of non-confined aquifers) (4%) mean that only 52% of the effective rainfall remains to support baseflow to rivers Table 1.

Table 1. The Flemish water balance for 2017. About 60% of the effective rainfall reaches the groundwater system while 40% is lost through drainage and overland runoff. Groundwater replenishment is thus much lower than geophysical potential. About 52% of the effective rainfall enters the rivers as base flow, while 6% is abstracted and 4% is lost through unintentional drainage by leaky sewer pipes. A large proportion of abstracted water and parasitic water in sewer infrastructure will return to the rivers as effluent from treatment facilities. Reference: rapport reactief afwegingskader + webpage historische grondwaterindicator (VMM, 2020b).

Situation for 2017 (795 mm total rainfall, 253 mm effective rainfall)	Mm³	M³/s	%
Runoff drainage through stormwater infrastructure	390	12.36682	9 %
Overland runoff to the river network	343	10.87646	8 %
Superficial drainage by ditches	856	27.14358	20 %
Base flow to streams and rivers	2227	70.61771	52 %
Groundwater abstraction	256	8.117707	6 %
Parasitic water in sewer infrastructure (drainage by leaky sewers)	190	6.02486	4 %
Total	4262	135.1471	100 %

But the above numbers and proportions show an annual average for the whole Flemish region and for a rather normal year. In contrast, during a dry summer month, these numbers look very different. During dry spells, there is no runoff in the system, most of the superficial soil water has been drained and increasingly more groundwater is being abstracted to meet the rising demand for water. The groundwater is therefore an important storage reservoir to overcome periods of low precipitation. But recent years with consecutive droughts show a fast decline of groundwater levels in response to drought and a slow and incomplete recovery during winter. This also means that the groundwater base flow to rivers is much reduced.

Groundwater replenishment accounts on average for some 3 000 million m³ of water (2 777 million m³ for 2017). But compared to the population density, this is quite limited. During years with below average rainfall, recharge is also significantly lower. The past 10 years, the trend of a slightly increasing annual rainfall did not continue, while mean annual temperatures have risen consistently above the long-term average. This means that evapotranspiration must have increased, and that effective rainfall has been reduced by at least 50 mm (20% lower) in the past 10 years.

Table 1 also illustrates that there is a huge potential to increase deep recharge. An additional 400 million m³ of groundwater recharge could be achieved with a 25% increase in infiltration from sealed surfaces, a 25% reduction in surface runoff and a 25% reduction of superficial drainage. This corresponds to an average annual river flow of 12.5 m³/s. The groundwater abstraction pressure will be reduced, groundwater levels will increase, and rivers will have more stable base flow during droughts. This will in turn alleviate the pressure on the groundwater system because this would allow more irrigation from surface water.

Current water demand

Households, industry, energy and agriculture consume significant amounts of water. The use of water for human activities puts considerable pressure on ground-- and surface water resources and can lead to a decline in water resources and the quality of water available to humans and nature.

Table 2. Water use in million m3 in Flanders for the period 2000-2018 (MIRA, 2020).

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Total (excl. Cooling water)	750	741	740	734	745	740	760	753	722	679	715	729	706	728	744	758	741	746	749
Piped water	377	367	366	365	372	354	373	370	358	352	357	365	364	353	350	352	348	349	353
Surface water	168	172	176	177	177	190	181	172	165	135	160	164	142	169	190	205	191	178	178
Groundwater	151	149	143	140	138	137	135	135	128	122	120	118	117	113	108	107	107	106	103
Rainwater harvest	40	41	41	39	42	41	42	44	43	44	44	44	47	47	47	48	49	49	48
Other	15	11	14	13	15	18	28	32	28	28	33	38	36	47	49	46	46	64	66
Cooling water	3488	3194	3199	3347	3114	3151	3104	3132	2906	2962	2923	2585	2411	2142	2315	1682	2023	2107	1720

The total water demand (excl. cooling water) showed little or no change in the period 2000-2006. Following a clear decrease between 2006 to 2009, the years leading to 2015 showed a slight upward trend. The increase since 2012 can mainly be attributed to a new liquid gas installation in Zeebrugge (i.e. where gas is liquified) and impacts surface water. Since 2015, there has been no marked change Table 2.

In the period 2000-2018, groundwater use decreased by 31%. In 2017, mains water use was 8% lower than in 2000, but there was a slight increase in 2018. The dry and warm summer of 2018 may have played a role in this. The highest daily mains water demand in the period 2018-2019 amounts to around 1.35 million m³. Nevertheless, it seems that government policy is having an effect. Through measures such as permits, levies and awareness-raising, the government is trying to limit the use of mains water and groundwater. Total mains water demand falls back to 1.1 million m³ per day when the weather is cold/wet (winter months) (VMM, 2020a).

The use of cooling water has also decreased. The use of 'other water' shows a striking increase. Other water comes from the product, ice, waste water from another company or (drinking) water that is traded between companies. The use of rainwater also seems to be slowly increasing, an evolution that can be linked to the obligation to have rainwater tanks for new or renovated buildings since 2004 Table 3.

Households have the largest share in the demand for mains water and rainwater. Annual mains water demand of households is around 220 million m³/year. This is on average 600 000 m³/day, which is approximately half of the total mains water demand. Mains water demand by industry may be less weather sensitive. 75% of the variation in mains water demand due to varying weather conditions (summer-winter) can be attributed to households and 25% to agriculture. Industry has the largest share in the of demand for surface water and other water, the energy sector is the largest consumer of cooling water and agriculture is the largest consumer of groundwater.

Table 3. Proportion of water use in million m3 by several sectors in Flanders for 2018 (MIRA, 2020).

	Piped water	Groundwater	Surface water	Rainwater harvest	Other water	Total	Cooling water
Trade and services	8.70	3.70	1.50	5.92	1.46	5.48	0.16
Agriculture	1.99	53.19	3.17	10.32	1.36	9.82	0.00
Energy	3.01	0.01	35.19	3.08	5.53	10.46	66.56
Industry	23.42	40.18	60.15	21.83	91.66	40.38	33.28
Households	62.88	2.92	0.00	58.85	0.00	33.85	0.00

Water imports under pressure

Flanders imports roughly 10 000-15 000 million m³ from neighbouring regions (data for 2017). This almost equals total precipitation of the Flemish territory. Evidently, there are large interannual variations and the bulk of the water is transferred during wet periods. Most water enters Flanders through the Scheldt, Lys and Meuse river, but there are also a lot of smaller streams entering from Wallonia and some interregional transfers of piped water.

Most of this water is not effectively used, but rather passes through on its way to the sea. There is little buffering capacity, although a small part of the passing water recharges groundwater reserves when canals pass though headwater catchments. There are also a few reservoirs that are replenished with canal water. But their capacity may be insufficient when droughts become even worse than the 2018 drought. In years with normal precipitation patterns, there are already issues in meeting the demand for ecology, navigation, industry and drinking water production. There are complex arrangements to distribute the water between the regions.

FLANDERS IS HIGHLY DEPENDENT ON THE INFLOW OF WATER FROM NEIGHBORING REGIONS TO OPERATE THE CANAL SYSTEMS. FOR BOTH MEUSE AND SCHELDT, THE COMMITMENTS MADE IN THE INTERNATIONAL CONVENTIONS COULD NOT BE MET DURING PAST DROUGHTS.

CASE 1: THE SCHELDT RIVER

The water supply from France/Wallonia on the Upper Scheldt and the Lys has to be distributed around Ghent to meet three different demands. The Ghent-Ostend canal and polders, the Ghent-Terneuzen canal to the Netherlands and the Upper Sea-Scheldt. For the Ghent-Ostend canal, the minimum water requirement to prevent salinification in the northern polders has been estimated at 2.3 m3/s. With additional water demand for other applications, this amounts to 4 m3/s.

There is also an international treaty with the Netherlands along the Ghent-Terneuzen canal. This stipulates that an average of 13 m³/s must be supplied for the canal for 2 months (61 days). This flow is needed to compensate for the fence loss with freshwater to prevent salinification. In 2011, it was not possible to reach that flow rate for almost eight months (242 days). For a 43-year period analysed, there were 37 periods with a flow rate below 13 m³/s averaged over two months. The average duration of these periods is 48 days. During the 1976 drought, the minimum flow was not achieved for 212 days. The 1976 drought has a return period of 86 years but is likely to occur every 20 years by 2050.

This means that the total water demand of 13 m³/s for the Ghent-Terneuzen canal, 4 m³/s for the Ghent-Ostend canal and 10 m3/s for the Zeeschelde (see below) cannot be met if the supply flow is less than 27 m3/s (850 million m³). The water entering the sea-sluices is inevitably lost. In 2018 and 2019, sea sluices were shut down during low tide to limit water losses from the canal. Evidently, this has economic consequences. During these droughts, saltwater intrusion occurred. Flushing the canal system with freshwater during periods of high flows can remediate salinisation in the canal system. But the infiltrated canal water also causes groundwater salinisation, which is more difficult to remediate.

The ecologically important Sea Scheldt only receives the remaining water. This means that the downstream Scheldt River frequently has flows too low to avoid ecological consequences. Especially since the channelisation of the Scheldt for larger ships to reach the port of Antwerp, higher flows are needed to avoid high concentrations of suspended solids. Strong primary production is the driving force behind the Scheldt ecosystem. To ensure this, the concentration of suspended matter (SPM) should not become too high and thus the flow rate should not become too low. Since 2009, the Upper-Sea Scheldt has regularly been confronted with very high SPM concentrations in summer. These high SPM values are strongly dependent on the flow rate: low flow rates lead to high SPM. Therefore, the relationship between suspended matter and flow rate is used to derive an ecological minimum flow rate. In 2011, the flow rate was below this predetermined level for 174 days. The demand for the Scheldt River and its canal system cannot be met and this will worsen over time.

CASE 2: THE MEUSE RIVER

The Meuse rises in France and flows into Belgium in the Province of Namur. In periods of insufficient water supply, the Meuse Discharge Convention enters into force. This treaty of 17 January 1995 between Flanders and the Netherlands lays down which fractions of the available flow in Monsin may be used for Flemish (Albert Canal and Kempen Canal) and Dutch (Zuid-Willemsvaart and Juliana Canal) use. During high flow, both Dutch and Flemish use is limited to 25 m³/s and the remainder is left for the river Meuse. When flow drops below 60 m³/s, a minimum flow rate of 10 m³/s must be guaranteed for the Meuse River. On average, this occurs 32 days a year. When there is a critical low flow (less than 30 m³/s), water should be divided equally between the three.

The Albert canal flows to the port of Antwerp and is also used to supply piped water for the city of Antwerp and the port (144 million m³), which corresponds to an average flow requirement of 4.5 m³/s. Flow variations are buffered in a 4.5 million m³ buffer basin. A minimum flow of 3 m³/s would be necessary to prevent salt intrusion from the Strasbourg dock. When the flow of the Meuse drops below 30 m³/s for longer periods, the demand cannot be met. This has occurred in 2018 and 2019 and future projections indicate that this will become even more problematic. A lot of measures have been taken to reduce the water demand: sluice-gate operation water losses are minimized by pumping upward, the drinking water buffer reservoirs will be expanded and there are plans to desalinize brackish canal water in the port of Antwerp.

Future demand

There is still about 160 million m³ of groundwater abstraction from confined aquifers in the western part of the Flemish Region. This method of abstraction is irrevocably finite and the Flemish policy now focuses on alternative water resources. Hence, an increasing demand on renewable water resources to replace these non-renewable water resources may be expected. Alongside advanced treatment for re-use and the development of storage reservoirs for drinking water production, increasing pressure on unconfined abstraction is also likely. The groundwater bodies where this unconfined abstraction is possible and also carried out in Flanders are located in the sandy soils of the Campine region and the Pleistocene river valleys. Due to the high infiltration capacity of the sandy soil, a lot of rainwater can easily infiltrate here. These soils can be compared to sponges that can hold and store a lot of water.

Since 2010, however, this unconfined groundwater supply has been increasingly dehydrated. Every summer the unconfined groundwater bodies are critically low, with the summers of 2017, 2018, 2019 and (possibly) 2020 as the climax. The supply on which Flanders is so dependent becomes dramatically insufficient to provide the region with sufficient water. But where does all the infiltrated water go to if we only pump 10% of all infiltrated water? Most of it never reaches deep groundwater layers, 50 to 70% flows into rivers. If water still flows after a long period of drought, it is because groundwater feeds the rivers. It is estimated that 10% to 30% disappears quite fast via small streams to drain (agricultural) land. Drainage causes at least as much water to drain away as is pumped for use. If groundwater recharge could be increased by just one percent, it will be enormous volumes that become available (also see the water balance for 2017 – Table 2).

Agriculture is evidently a very drought vulnerable sector and will use more water during drought episodes. The average long-term groundwater use by agriculture since 2000 is estimated at 55 million m³, or 75 % of the total water demand of agriculture. The recent droughts give a glimpse of a potential rising trend in agricultural water use. After the drought impact of 2017-2020, an increasing number of farmers have been investing in irrigation infrastructure and applied for groundwater abstraction permits. Especially because of the many bans on surface water abstraction, they will revert to the only available stable resource, which is groundwater. A more recent water balance study for the year 2017 calculated water use from groundwater by agriculture at 83 million m³. There is still high uncertainty about the water use by agriculture and often conservative figures are used.

The effects of decreased precipitation surplus, increased soil sealing, increased drainage and increased water abstraction are already being felt. The depletion of the groundwater resources during the summer months was so extensive that the water companies triggered an alert phase for drought during the summer of 2018 throughout Flanders. The result was a ban on the use of mains water to wash cars, water gardens and fill swimming pools, otherwise there would not be enough drinking water left to serve the country. Offenders received penalties ranging from fines to even prison sentences.

In addition to the lack of drinking water and thus the quality of life that is compromised, the forms of land use that depend on soil moisture under this summer desiccation are also groaning. Especially in the sandy areas, agriculture suffers enormous losses due to crop failures. In the cities (e.g. in Antwerp in 2018), one in ten trees died and many private gardens also suffered massive plant and tree deaths.

However, this crisis is only the beginning, but could result in a real disaster scenario for Flanders. In business as usual, the main water tap will be closed because there is simply not enough water to serve the entire country. The Flemish Government is currently developing a plan for priority water use during droughts that will come into effect in 2020. This is, of course, a very sensitive issue. After all, who will be given priority? Families, industry or agriculture and how do they relate to each other? As a result of the drought disaster, not only the quality of life but also the regional economy is at risk.

THE NETHERLAND - NOORD BRABANT

Precipitation surplus and groundwater replenishment

The average annual precipitation in Noord-Brabant is around 825-875 mm and the average annual evaporation is estimated around 570-590 mm Figure 29. Therefore, there is an average annual precipitation surplus of approximately 250 mm. Yearly this means that 1 700 million m3 rainfall reaches the surface and could infiltrate into the soil.

Due to drainage and discharge of excess water (which is a result of urbanisation and intensive agriculture) about 80 % of the precipitation surplus of 1 700 million m3 is lost as runoff in ditches and creeks and ends up in the river Meuse and the Delta area of the Meuse and Scheldt rivers. On a yearly basis about 200 million m3 rainwater (12 %) is able to infiltrate the soil towards the deeper groundwater Table 4.

From surrounding areas bordering on the province, about 60 million m3 of groundwater are provided yearly through horizontal groundwater flows. Total groundwater replenishment is estimated to be 260 million m3 per year (Verhagen et al., 2017).

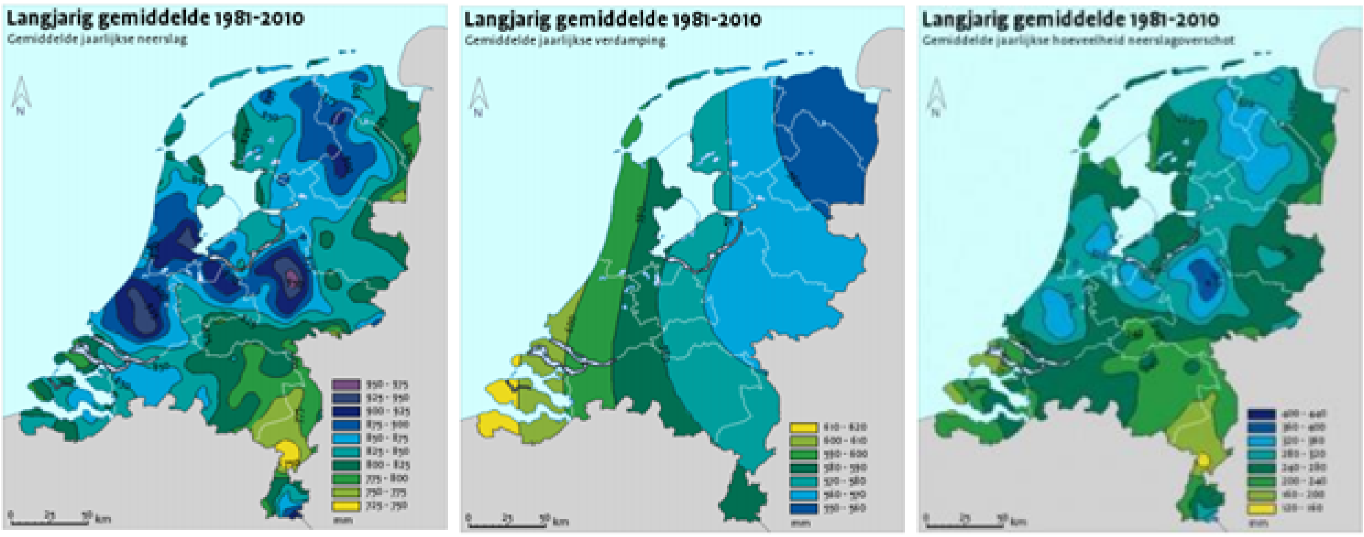


Figure 29. Average Yearly (1981-2010) precipitation (left), evaporation (middle) and precipitation surplus for the Netherlands (Klimaateffectatlas, 2020)

Table 4. Groundwater recharge, discharge and flux of the province of Noord-Brabant

Area	Groundwater recharge (million m³/year)	Discharge (million m³/year)	Flux (million m³/year)	Percentage recharge (%)
West Brabant	277	184	93	34 %
Peilgestuurd	509	614	-37	-7 %
Kempisch Plateau	167	131	36	22 %
Centrale Slenk	534	468	92	17 %
Peelhorst	199	197	13	7 %
Total	1686	1594	197	12 %

Table 4. Groundwater recharge, discharge and flux of the province of Noord-Brabant

Area	Horizontal recharge (million m³/year)	Horizontal discharge (million m³/year)	Net recharge (million m³/year)
West Brabant	53	78	-25
Peilgestuurd	108	30	78
Kempisch Plateau	62	75	-13
Centrale Slenk	66	42	24
Peelhorst	12	16	-4
Total	301	241	60

Current water demand

Groundwater abstractions for drinking water, industry and agricultural irrigation are recorded yearly. The exact location and depth of the abstraction and the variation in time are not always available.

The annual abstractions for drinking water in the province of Noord-Brabant by the water companies Brabant Water (+/- 95%) and Evides (+/- 5%) is about 200 million m3 per year. Yearly abstractions for industry in Noord-Brabant have significantly decreased in the past 40 years, from an annual abstraction of 100 million m3 in the 1980s to about 21.5 million m3 per year in 2017. The amount of groundwater that is used by agriculture for irrigation during the growth season can vary considerably per year. The average abstraction is about 35 million m3 per year (Brabant Water, 2018).

Besides licensed abstractions, there is an estimated number of more than 16 000 small non-licensed abstractions in Noord-Brabant, with a capacity of less than 10 m3 per hour. The total volume of these abstractions is unknown but estimated at 25-50 million m3 per year.

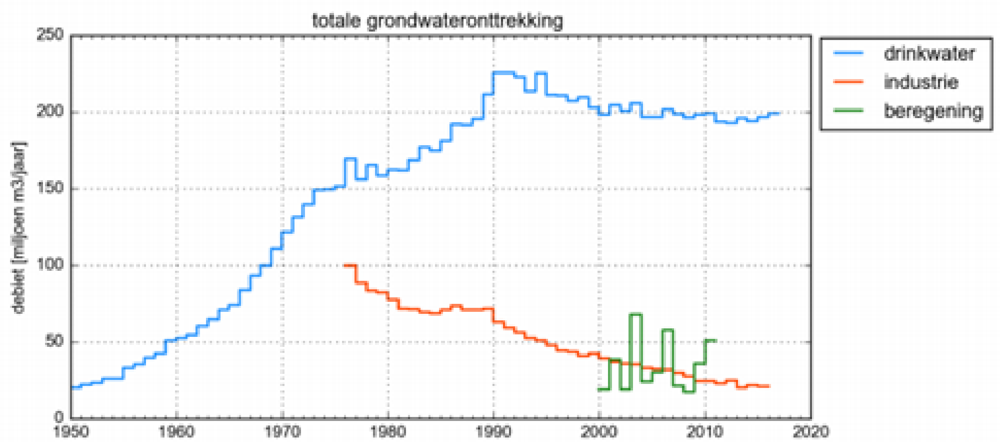


Figure 30. Total groundwater abstraction levels for the province of Noord-Brabant from 1950 till 2017. Blue: Drinking water, orange: Industry and green: Agricultural irrigation

The average total yearly abstraction of groundwater in Noord-Brabant is 275-300 million m3 per year. The current water demand is thereby exceeding the current policy with an abstraction limit of 250 million m3 per year and exceeds the estimated groundwater replenishment of 260 million m3 per year (Verhagen et al., 2017).

Future demand

The total volume abstracted from the groundwater in Noord-Brabant has been declining in the past 20 years, due to a strong decline in the abstractions of groundwater for industrial use. However, current demand is still unsustainable and could rise again due to different pressures.

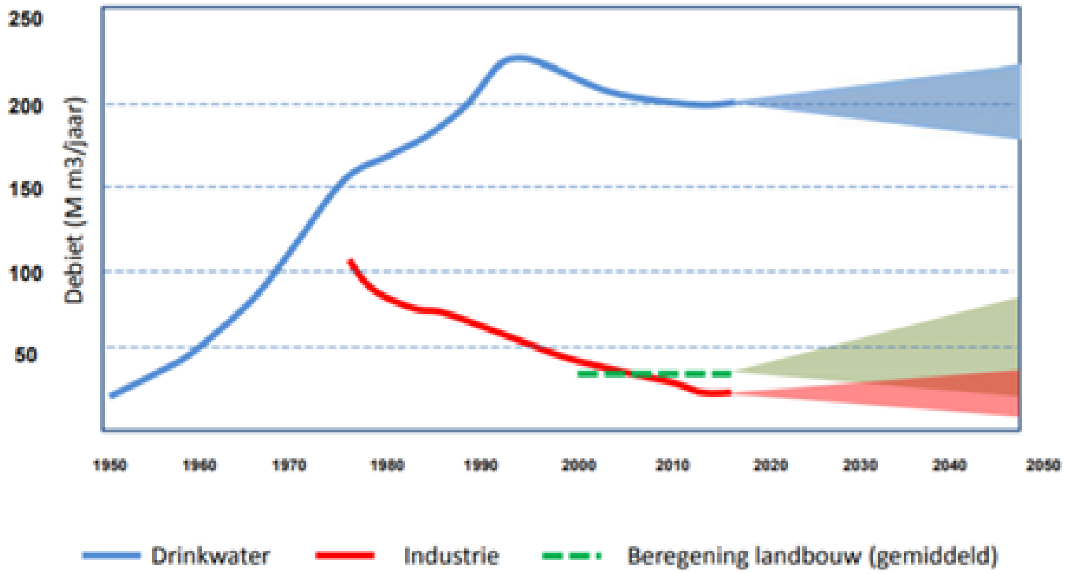


Figure 31. Yearly registered abstractions of groundwater from 1950 till 2017 (in million m3 per year) and expected trend till 2050.

The increase in water demand for industry and drinking water is likely to increase with economic growth. The maximum estimated increase for industry and drinking water is 32 million m3 (12+20 million m3 respectively). The demand in the agricultural sector is strongly related to climatic conditions. The average water demand is currently 35 million m3 per year but exceeded 100 million m3 during the drought year of 2018.

Although future water demand is difficult to estimate and is affected by different parameters, the national government has asked the province to investigate the possibilities to facilitate an increase of 30 % in drinking water demand by 2040. This is an increase of 60 million m3 per year. This is a significant increase, especially since the deep groundwater levels are already under pressure.

KEY MESSAGES

- Renewable water resources per person across Europe have shown a decreasing trend between 1960 and 2017.

- Demand for water is driven by the household use of private users, irrigation needs in agriculture, industrial processes (such as manufacturing or power generation) and navigation. Peaks in demand do not correspond well to when and where water resources are currently available.

- A growing need for water in agriculture presents an opportunity to drive efficiency and use of EbA approaches to ensure environmental as well as business resilience.

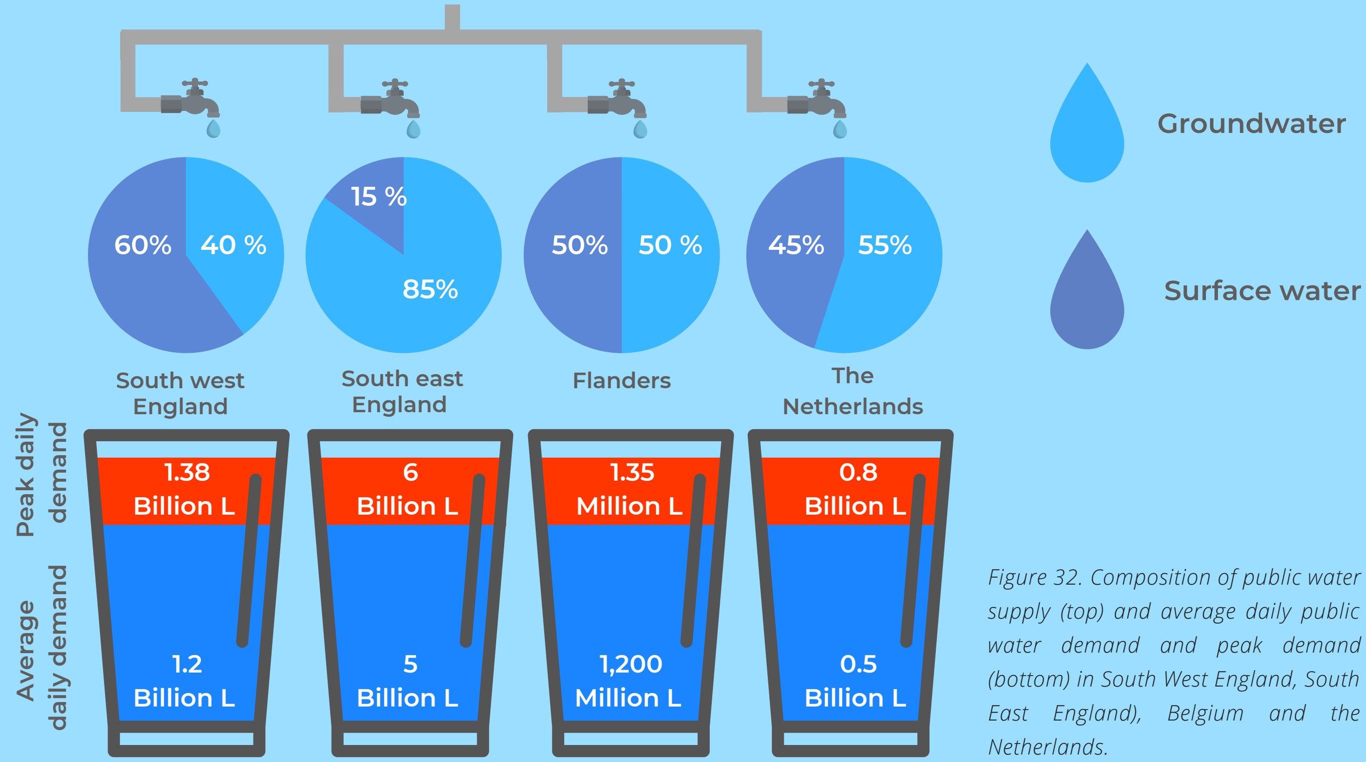


Figure 32. Composition of public water supply (top) and average daily public water demand and peak demand (bottom) in South West England, South East England), Belgium and the Netherlands.

SOUTHERN ENGLAND

- A high proportion of catchments in the South East would be unable to support additional abstraction. This impacts groundwater levels and river flows and reduces our resilience to extreme events.

- Already high demand for public water supply can increase by 20% in the summer, when flows are lower and pressures on freshwater ecosystems higher.

- Public Water Supply is the biggest user of water, but there is high and growing demand for other users such as agriculture, with implications for seasonal usage.

- A high demand for water already drives need for water efficiency in South East England, but personal demand figures are still higher than the UK average.

- Treated effluent from wastewater treatment can contribute a significant proportion of water available in the river, increasing resources for abstraction downstream as well as supporting low flows.

- Although forecast models predict that the south west of England will have a positive supply demand balance at least until 2080, without improved resilience to the catchment landscape there is a significant risk of long-term future deficits in water supply for humans and the environment.

KEY MESSAGES

BELGIUM - FLANDERS

- Flanders is a water scarce region with limited annually renewable water resources. The public water supply is highly dependent on groundwater resources.

- Flanders is highly dependent on the inflow of water from neighbouring regions to operate the canal systems. For both Meuse and Scheldt, the commitments made in the international conventions could not be met during past droughts.

- A range of different sectors are increasingly abstracting groundwater resources. A decrease in precipitation surplus and increase in abstracted volumes may push the overall abstraction pressure to unsustainable levels.

- Groundwater levels are not recovering from past drought episodes. Groundwater levels are becoming critically low, because the abstraction from these deep groundwater aquifers is larger than their recharge. About 40% of the effective rainfall is lost through superficial drainage, overland flow and runoff. If we could transform 25% of these losses into groundwater recharge, future drought episodes can easily be bridged.

- Unconfined groundwater levels are becoming critically low in the summer months. Critical low water flows in many rivers led to the implementation of water saving measures during the summer of 2018.

THE NETHERLANDS – NOORD-BRABANT

- The current average total annual abstracted volume of ground water in Noord-Brabant exceeds the estimated replenishment of ground water resources. This is an unsustainable situation with negative consequences for the economy and the environment.

- Due to climate change and related future water demands (especially in dry periods), the negative consequences might increase.

- Additionally, given the critical water availability – demand balance in the Flemish Region of Belgium, and the connected, shared ground- and surface water bodies in the Campine region, there is an urgent need for a joint Flemish-Dutch strategy for climate-proof land-water management.

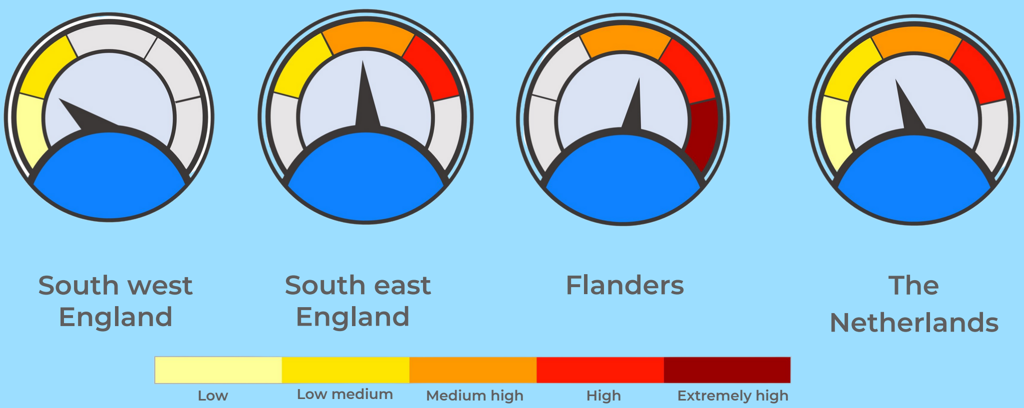


Figure 32. Water stress South West England, South East England, Belgium and the Netherlands.*

* *The Water Exploitation Index plus (WEI+) is a measure of total fresh water use as a percentage of the renewable fresh water resources (groundwater and surface water) at a given time and place. It quantifies how much water is abstracted and how much water is returned after use to the environment.*

FUTURE PRESSURES

The impacts of climate change are intrinsically linked to the water cycle and manifest in a range of ways that vary across different geographies and time. There are different pathways the world could take in our efforts to reduce global greenhouse gas emissions. These different pathways result in different concentrations of greenhouse gases in the atmosphere, and in turn different levels of warming. These alternative futures are reflected in the use of different emissions scenarios. While the scenarios play out similarly over the next few decades, it is towards the end of the century that the effects of higher levels of emissions really become apparent. This longer timeframe is therefore important in considering long-term planning. Although a range of uncertainty remains due to the complexity of factors involved, there is a clear trend: the lower the concentration of GHG in the atmosphere, the milder the effects of climate change will be. Across the 2 Seas regions, extreme weather events are becoming more likely and drier summers and more frequent droughts are part of our future, alongside more intense rainfall events and wetter winters Figure 33, Figure 34, Figure 35. The impact of these changes on the ability of the landscape in our regions to supply and regulate water resources, and the associated natural capital, is set out in the following section.

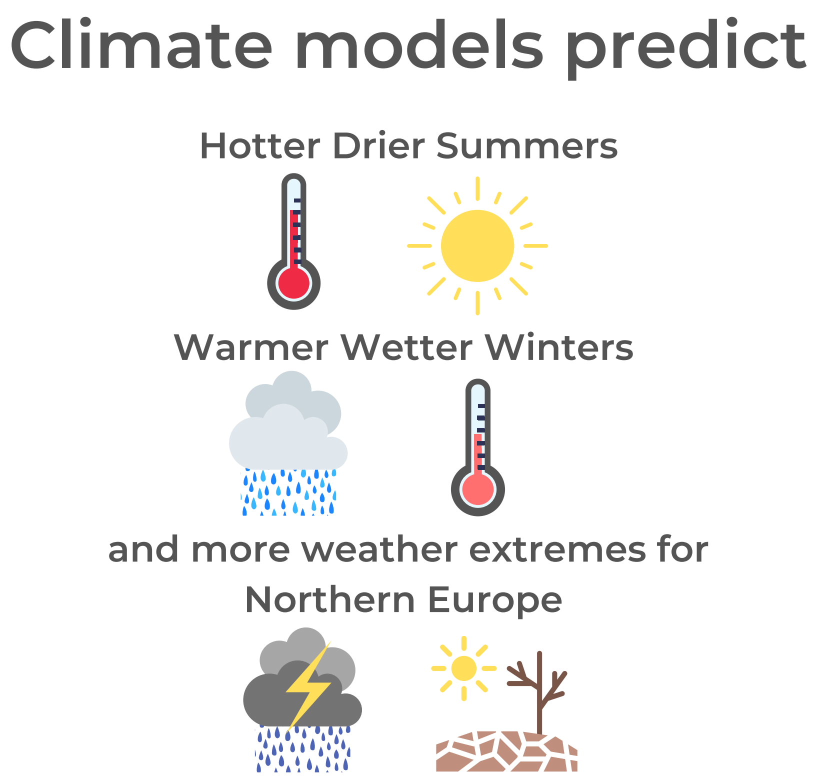


Figure 33. Climate model predictions across Southerns England (UK), Flanders (Belgium) and the Netherlands.

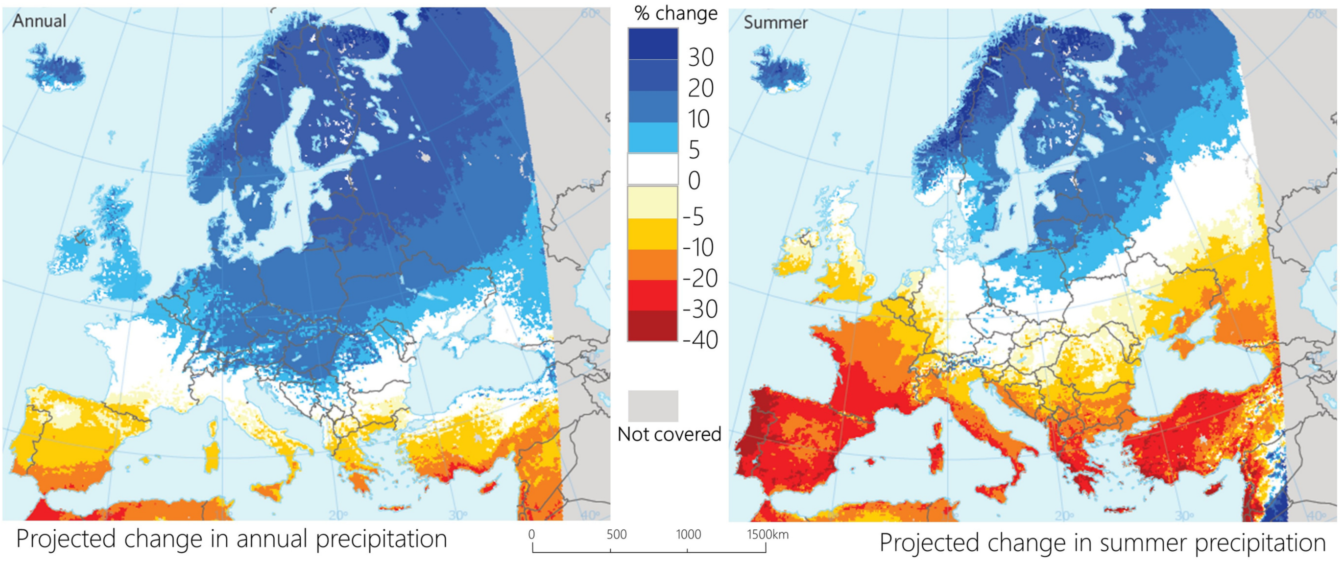


Figure 34. Projected changes in annual precipitation for 2071-2100, compared to 1971-2000, based on the average of a multi-model ensemble forced with the RCP8.5 high emissions scenario. All changes are marked with colour (i.e., not white) are statistically significant. Individual models from the EURO-CORDEX ensemble or high-resolution models for smaller regions may show different results (EEA, 2020) © European Environment Agency

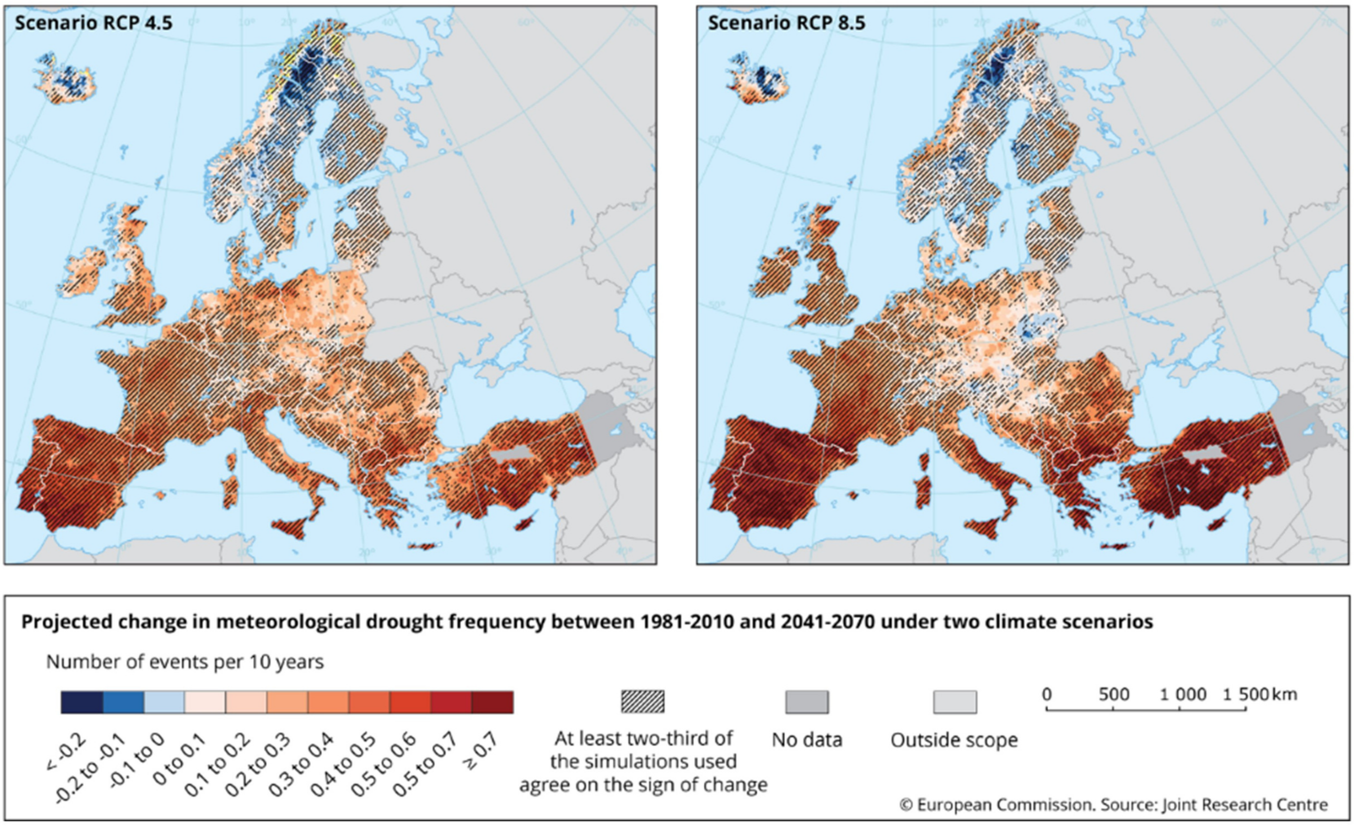


Figure 35. Projected change in meteorological drought frequency between 1981-2010 and 2041-2070 under two climate scenarios.© European Commission (Masante et al., 2020).

SOUTHERN ENGLAND

Effects of climate change on the UK are often summed up as "warmer, wetter winters and drier, hotter summers". The summer of 2018 has become emblematic for what this could look like, and indeed, while the temperatures that occurred in this year had a 1 in 10-year chance of occurring, this increases to a 1 in 2-year chance by 2050, and, by 2080, could be anywhere from 1 in 2 to every year depending on the emissions scenario (Lowe et al., 2018).

Winter rainfall is expected to increase, while summer rainfall will decrease but occur in more intense events. Magnitude and frequency of short droughts could increase (Watts et al., 2015). These changes are very localised. The South East of England is one of the regions experiencing the highest changes across the UK. Nationally by 2050, restrictions on water use (such as temporary use bans) will be twice as likely as in the period between 1975 and 2004 if no additional action is taken. This is due to a combination of factors including population growth and climate change. By 2100, this could be four times as likely (Environment Agency, 2020b) or even higher in the South East.

Ecosystems are already being affected by changes in climate. The growing season has already increased by 29 days on average compared to the 1961-1990 baseline and the number of days of air frost has been declining. This is changing species interactions (e.g., by changing time of flowering and egg laying) as well as composition (increased drought risk will change tree composition and chalk grasslands). Existing impacts on current river flows from climate change are difficult to estimate as they are combined with other pressures from historic land use change and abstraction.

Daily river flows in the future show a trend for lower summer flow and higher winter flows across the UK Figure 36. For freshwater systems, climate change is likely to also lead to increases in water temperatures and exacerbated effects of nutrient and sediment pollution, a change in species composition (affecting species such as salmon and trout while increasing distribution of bream and roach) as well as higher vulnerability of crucial parts of the ecosystem such as wetlands (Watts et al., 2015).

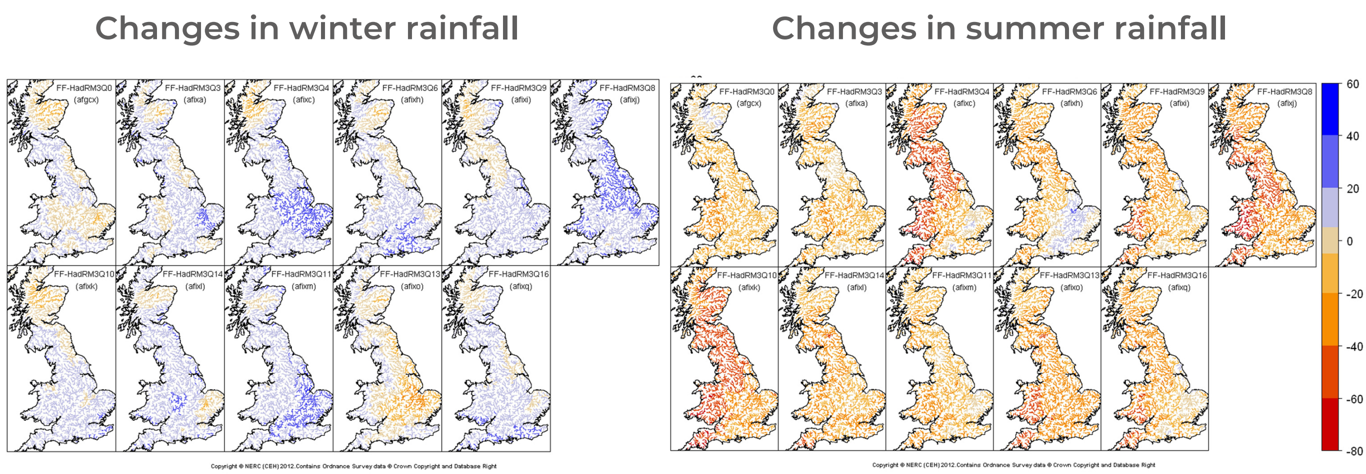


Figure 36. Maps of changes in river flow in Great Britain for the 2050s obtained from the hydrological model CERF driven by Future Flows Climate scenarios. Changes in summer flow (top) predominantly show decreases in runoff through Great Britain but range from +20% to -80%. The largest percentage decreases are mainly in the north and west of Great Britain, although the range in these areas between scenarios can be large (0 to -80%). Changes in winter flow (bottom) show a mixed pattern in England and Wales with drier, similar or wetter signals within -20% to +40% change – one scenario up to 60% in a small region. In contrast flows in Scotland show a small increase or decrease, although this is still mainly within +/- 20% with changes in the east reaching up to 40%.

The groundwater recharge period, the time of the year when rainfall exceeds the water use of plants and can drain beyond roots towards the groundwater, is shortening due to the lengthening of the growing season that can already be observed in the UK. Implications for recharge are complex: winter rainfall increases on average, which could mean increased volumes of recharge. As the period where this rainfall can reach the groundwater shortens, however, it becomes more vulnerable to shorter droughts which are likely to become more frequent. The quality of recharge could also worsen as heavier rainfall events carry more pollution into the aquifer, or even lead to a higher proportion of runoff being lost. Impacts are likely to be localised and depend on the type of aquifer and local land use (Jackson, Bloomfield and Mackay, 2015b) .

Soils will become more drought prone and less suitable for today's agriculture, with a higher risk of erosion and compaction Figure 37. With a 10% increase in winter rainfall, soil erosion could increase by 150%. Erosion rates by the 2080s could increase by an average of 0.1 to 0.6 t/ha/year (Brown et al., 2016), meaning a loss of valuable topsoil and pollution of watercourses. A potential longer growing season, less waterlogged areas, and the potential for new crops with positive implications for agricultural productivity are likely to be outweighed by increasing drought risk of soils, limiting the productivity of land significantly in the South East, with the biggest proportion of land falling under the lowest agricultural grade by 2050 (Keay et al., 2013). Additionally, more land will be at risk of flooding, with implications for soil compaction and the productivity (Environment Agency, 2018). Soil type and health determine how soil function will be impacted by climate change. Healthy soils, for example soils with higher biodiversity, may be more resilient to drought.

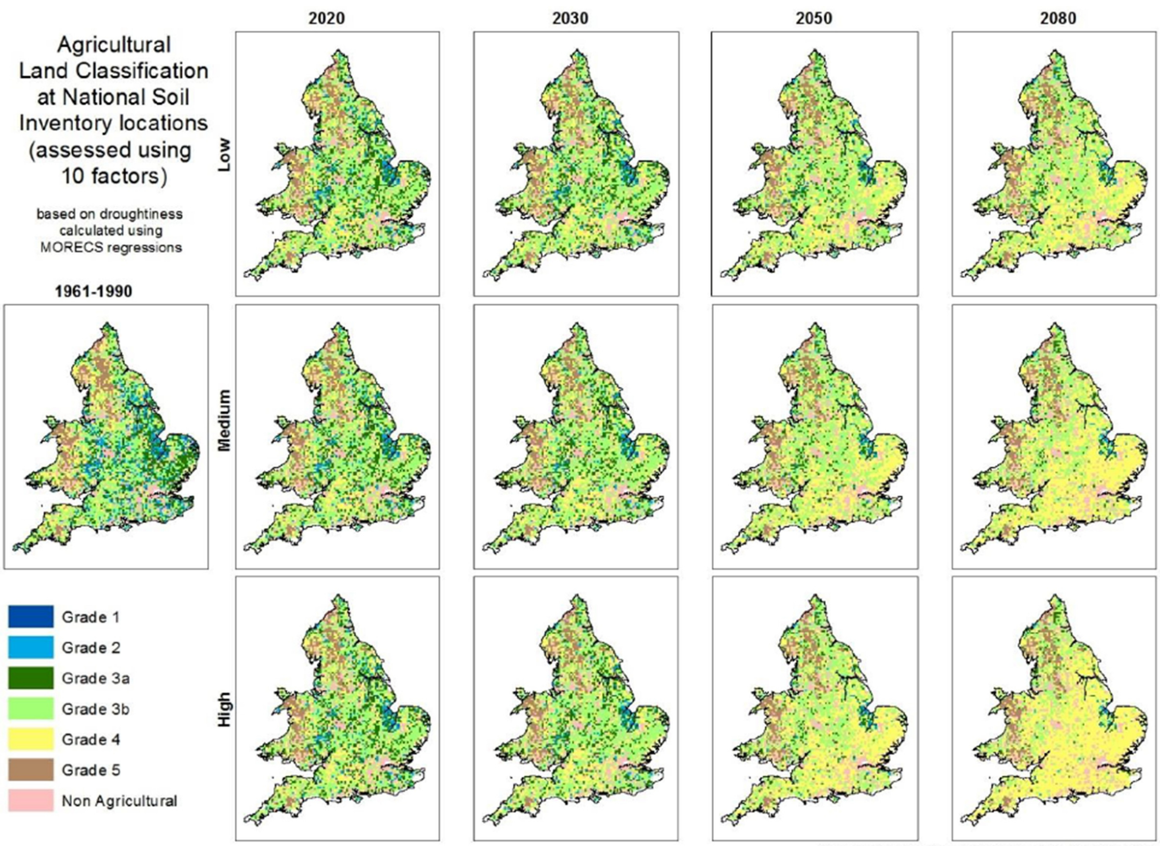


Figure 37. Projected Agricultural Land Classification Grade of the NSI sites with droughtiness using new MORECS regression and adjusted potato classification under different climatic scenarios. By 2080, laarge parts of Southern England could fall fall into lwoer grade agricultural land even under a medium emissions scenario © Cranfield University and Crown Copyright, Met Office 2012.

SOUTH WEST

In the South West, the predicted impacts of climate change are likely to lead to an increase in the variability of river flows throughout the year, with lower flows in the summer months. This is already being experienced in the runoff dominated river systems of the South West. Figure 38 shows that many rivers had exceptionally low flow rates in May 2020. The figure also shows that late spring/early summer rainfall has been exceptionally low over the past two years and the soil moisture level dropped to 24.9% water content in July of 2018 during a significant meteorological drought in the UK. Dry summers will be more frequent with an average of 24% less precipitation, and temperatures could be as much as 3.9oC warmer by the 2080's (MET, 2018). Winters will also be warmer, potentially 2.8oC warmer and 23% wetter.

Overall, future predictions for the South West show a positive supply demand balance by 2050 of 219 000 m3/day. This is reliant on a reduction in demand and leakage, without which, and with unpredictable changes in climate, and with unpredictable changes in climate, and with unpredictable changes in climate, and with unpredictable changes in climate a shortfall in supply could exist. Changes to the demand for water will come not only from population and economic development but also from the adaptation of industries, such as farming, to climate change, the effects of which are not fully understood.

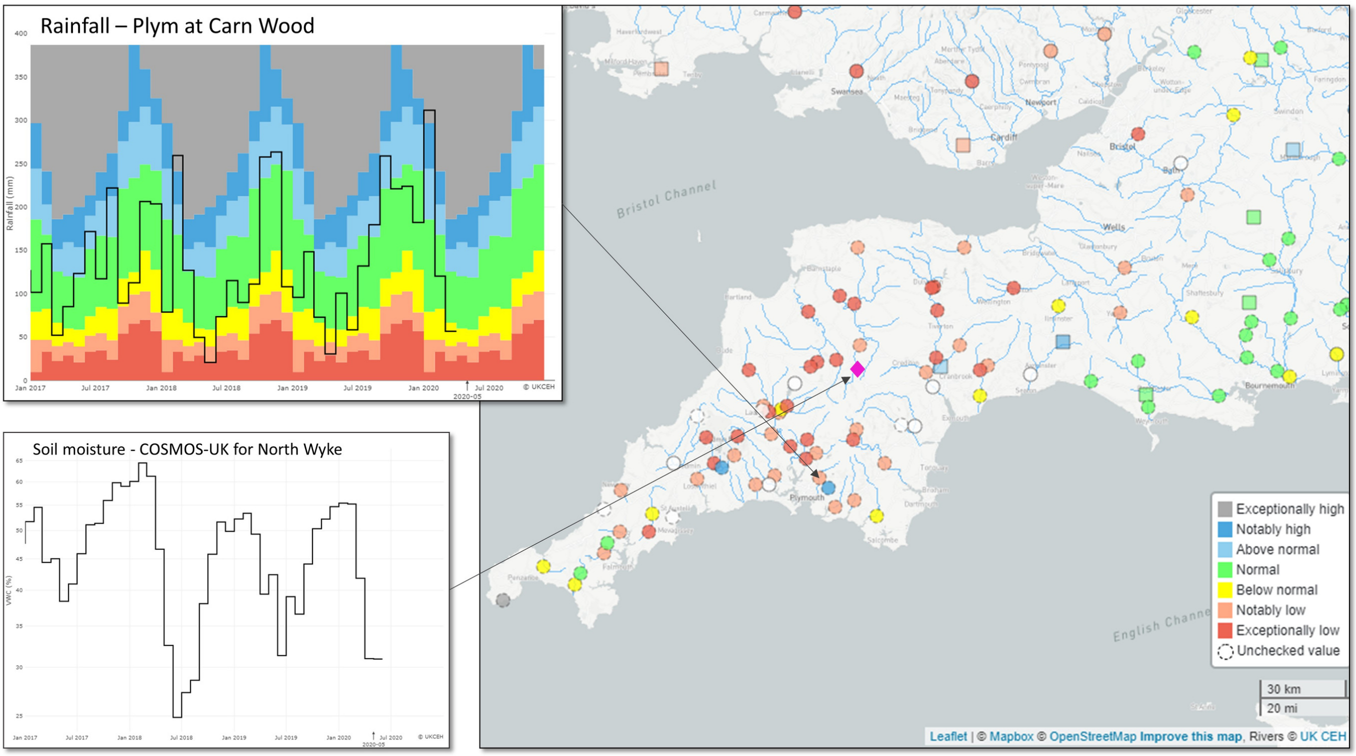


Figure 38. Recent hydrological conditions in the south west. Left top: rainfall (mm) Jan 2017 – July 2020. Left bottom Soil moisture levels (VWC %) Jan 2017 – July 2020. Right: July 2020 river flow rate.© Mapbox ©OpenstreetMap © UK CEH

SOUTH EAST

Summer rainfall is reducing, by 15% in the 2040s (low emissions scenario) to 37% in the 2080s, with extreme years with even higher reductions becoming more common. Summer temperatures increase by over a degree on average over the next decades, and by almost 5oC by the 2080s. At the same time, winter rainfall increases by 10% in the 2040s to 28% in the 2080 (Met Office Hadley Centre, 2018b).

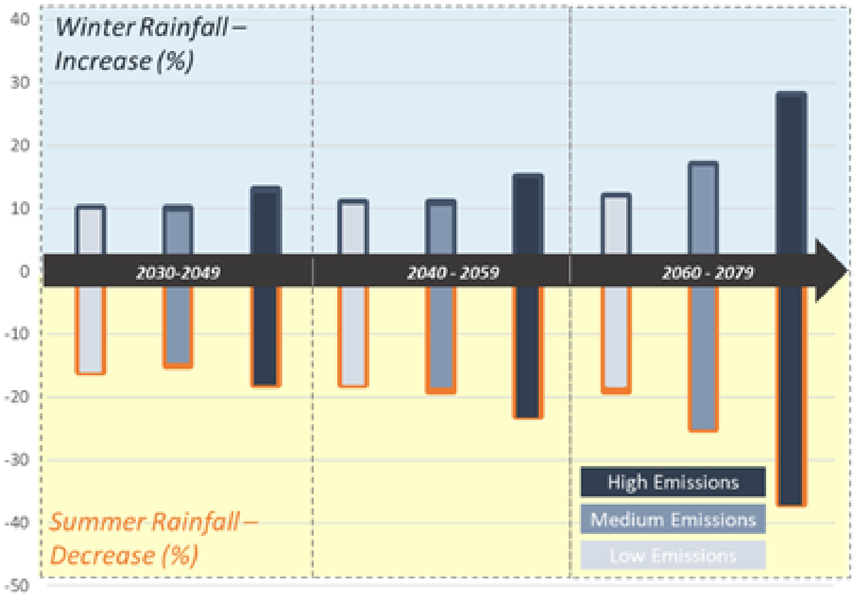


Figure 38. Recent hydrological conditions in the south west. Left top: rainfall (mm) Jan 2017 – July 2020. Left bottom Soil moisture levels (VWC %) Jan 2017 – July 2020. Right: July 2020 river flow rate.

The response of river flows in South East England to these changes will differ between groundwater and surface water dominated catchments, with groundwater rivers more often showing an increase in annual flows. This is related to a potential increase in recharge in some of the chalk aquifers (Mansour and Hughes, 2017). However, a lot of uncertainty is associated with projections of recharge and impacts are likely to vary locally (Jackson, Bloomfield and Mackay, 2015b).

While recharge in the SE river basin district overall could increase (Mansour and Hughes, 2017), locally significant reductions are possible. For example, recharge in the Stour catchment could decrease in the future by 4 - 37% (Mansour and Hughes, 2014). Based on previous water company projections, deficits in the supply demand balance (not only due to climate change, but also population growth etc.) are expected by the 2030's in most areas in the South East. Impacts on water quality can also be expected, demonstrated for example for the River Lambourn, where models showing decreasing flows in the summer indicate increasing phosphorus concentrations, and higher sediment loads in autumn months, especially after dry summers.

RESPONSES OF WATER RESOURCE PLANNING TO FUTURE RISKS AND CHALLENGES

There is a significant need for additional water to respond to an increasing population, reduction of resource availability due to climate change, the need to have more water available in preparation for more extreme droughts, as well as the need to reduce existing abstractions to reverse negative impacts on the environment Figure 40. Different areas are affected differently: in the South East environmental protection (reducing abstraction to reduce impact on sensitive ecosystems) and increased drought resilience are key variables, while the South West is evenly affected by all pressures. To realistically meet the public, non-public and the environment's demand for water, this means that both additional water must be made available and per person demand must be reduced.

Particularly catchments with impermeable geology and lack of groundwater storage are likely to be at risk of significantly reduced water availability even in short droughts, while groundwater-fed catchments will be impacted by longer droughts, especially over the winter (Brown et al., 2016). Climate change is expected to significantly impact water resource availability, reducing the availability of water from public water supply sources (Deployable Output) by the 2050s by 6% (medium emissions scenario) to 11% (high emissions scenario) and by the 2080s by 8% (medium) to 15% (high). Deficits are especially significant in the South East, and although groundwater is overall expected to be more resilient to climate change, parts of the chalk aquifer in the South East are expected to be vulnerable by the 2080s (HR Wallingford, 2015). Additionally, demand will increase with warmer temperatures and lengthening growth seasons, putting further pressure on water resources.

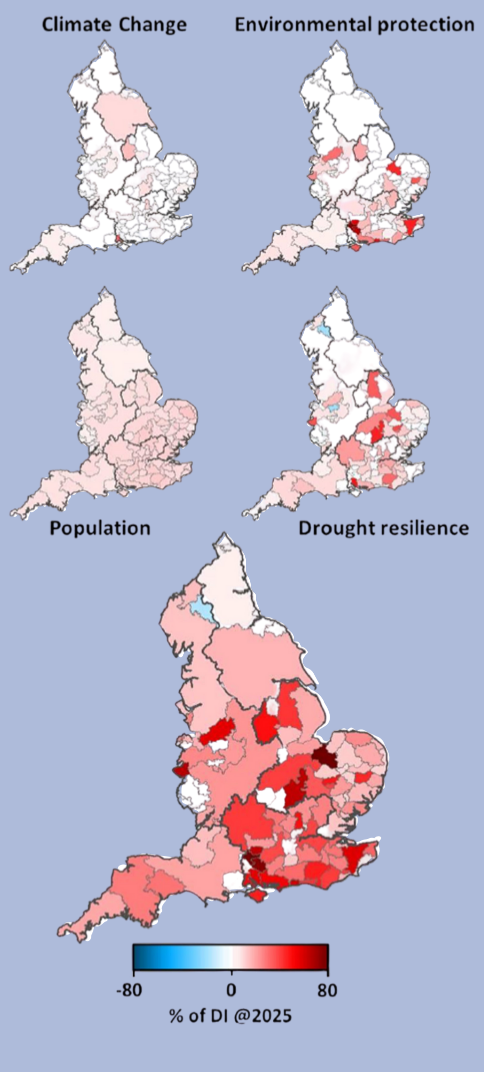


Figure 40. A range of pressures on water sources coupled with additional demand means that additional water is required to meet demand. These requirements are different between regions and catchments, and offer a range of opportunities for Ecosystem-based Adaptation to contribute to meeting the challenge. Source: Environment Agency, 2020.

Direct impacts on the public water supply through loss or contamination are summarised below:

- Low river and aquifer flows reduce the dilution of pollution and resource availability
- Aquifers are at risk of contamination from flooding
- Increased risk of pollutants such as pesticides, nutrients and sediments being carried into the watercourse from intense rainfall
- Increased turbidity from increased runoff and flashy flows impacting the operations of treatment works
- Increased water quality risks in reservoirs, for example through algal blooms due to low flows and nutrient concentrations
- Increased sediment pollution can result in the silting of intake structures of supply infrastructure
- Increased winter rainfall leading to flooding of infrastructure

SETTING A REGIONAL ENVIRONMENTAL AMBITION

Within water resource planning in the UK, there is increasing recognition of the importance of the wider environment and the natural assets that are building blocks of resilient water resources. Regional Water Resource groups are required to develop a long-term plan that not only ensures sufficient supply but also sets out how damaging abstractions will be reduced and set an environmental ambition for the region. This should support nature recovery, build resilience in the environment, and enhance natural capital.

The aim, objectives and outcomes of PROWATER have several synergies with the Defra 25 Year Environment Plan and the regional environmental ambition planning frameworks. It aims to build environmental resilience to the impacts of climate change by embracing a catchment wide approach, working with natural processes to deliver opportunities that improve the environment and provide more water. Changing the way water is managed at the landscape scale will improve the resilience of water supplies, delivering a net gain to the environment and supporting human society.

BELGIUM - FLANDERS

All climate scenarios for Flanders clearly indicate an increase in the ambient temperature Figure 41 (e.g. by 1.5 °C to 4.4 °C in the winter and by 2.4 °C to 7.2 °C in the summer) and a higher evaporation in the winter and summer (Brouwers et al., 2009). Despite significant natural variations, the effects of climate change are already visible in a number of indicators. For example, the annual average temperature in Uccle is now almost 2.4 °C higher than in the pre-industrial period. The average temperature in the four seasons increased, with spring showing the greatest increase. The potential evapotranspiration - a measure for the evaporation - has increased along with the temperature (Brouwers et al., 2015).

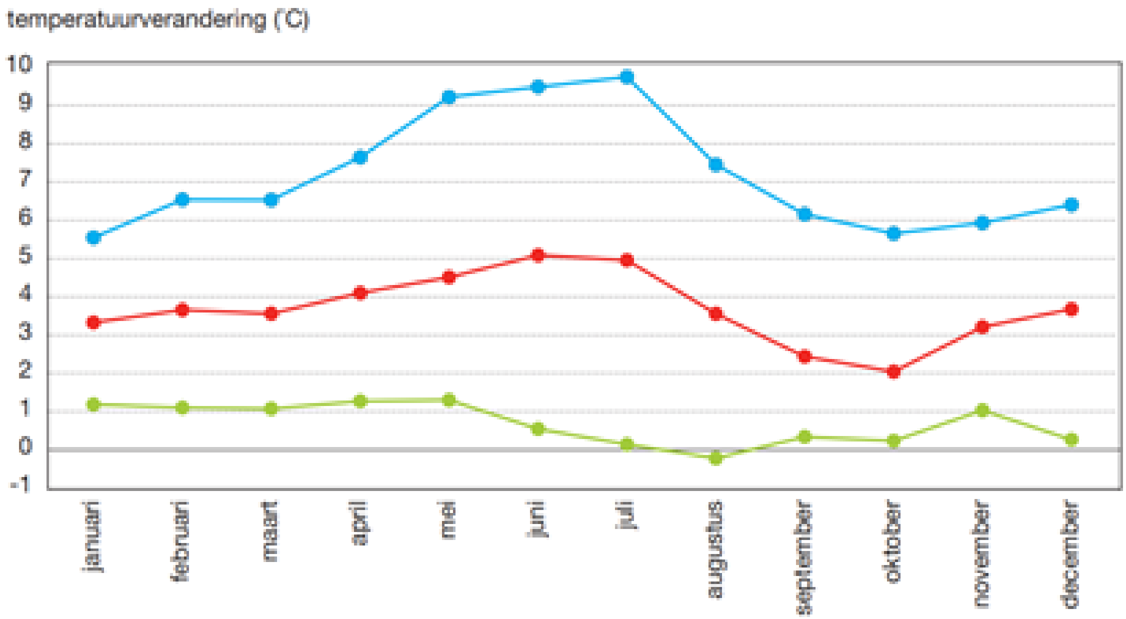


Figure 41. Climate scenarios (blue: high scenario, red: middle scenario, green: low scenario) for the absolute change in monthly mean temperature (Uccle, over 100 years) (Brouwers et al., 2015).

Also the number of days with extremely high temperatures (> 30 °C) also increases. The average number of tropical days increased from 2 to 6 days per year for a 30-year window. Heat waves and problematic droughts often coincide. The record drought year of 1976 also had 19 tropical days, which is the highest ever recorded. Because the soil lacks water to evaporate, temperatures increases faster. This self-enforcing feedback aggravates an already problematic situation. From 2015-2020, six consecutive "above normal" number of tropical days have been observed (resp. 7, 6, 7, 9 , 11, 12 per year). Such a situation has never occurred in the past.

The number of days without precipitation will increase sharply, especially in the summer Figure 43. Summer precipitation volumes could reduce by up to 52% by 2100 Figure 42. The number of dry days may increase from 173 now to 236 dry days in 2100 under the high-impact scenario Figure 43. The proportion of annual precipitation that evaporates may increase from 67% today to 77% in 2100 due to, among other things, higher temperatures.

All climate scenarios for Flanders clearly indicate an increase in the ambient temperature Figure 41 (e.g. by 1.5 °C to 4.4 °C in the winter and by 2.4 °C to 7.2 °C in the summer) and a higher evaporation in the winter and summer (Brouwers et al., 2009). Despite significant natural variations, the effects of climate change are already visible in a number of indicators. For example, the annual average temperature in Uccle is now almost 2.4 °C higher than in the pre-industrial period. The average temperature in the four seasons increased, with spring showing the greatest increase. The potential evapotranspiration - a measure for the evaporation - has increased along with the temperature (Brouwers et al., 2015).

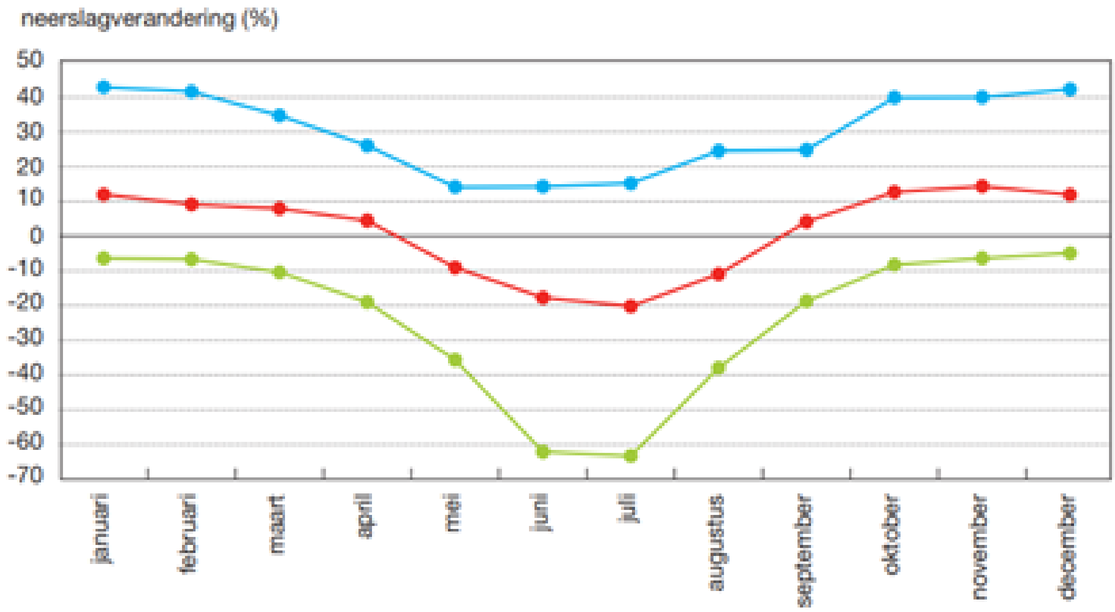


Figure 42. Climate scenarios (blue: high scenario, red: middle scenario, green: low scenario) for the change in monthly average precipitation (Uccle, over 100 years) (Brouwers et al., 2015).

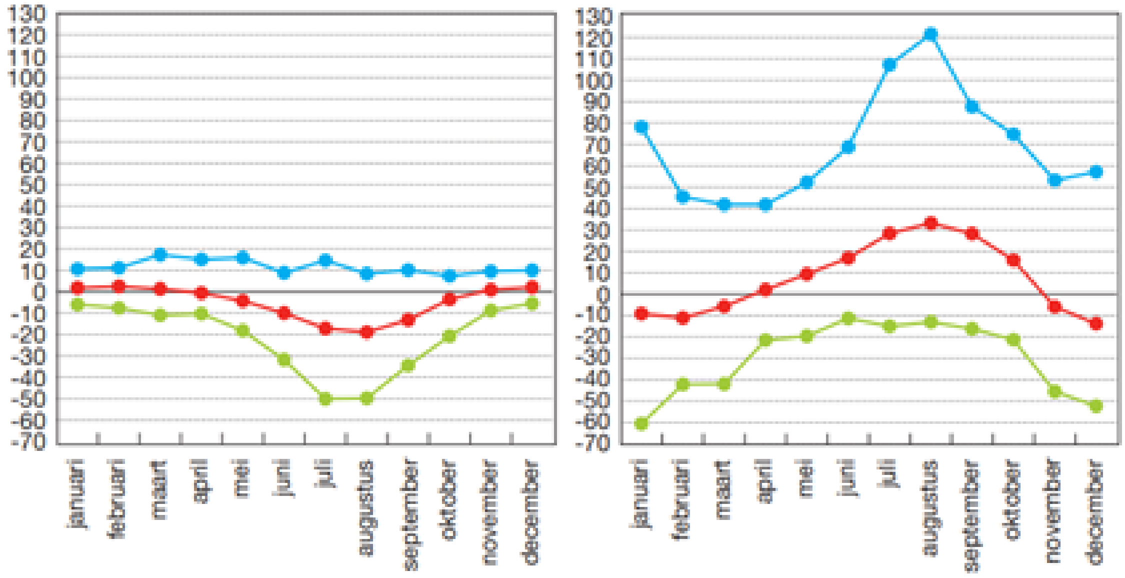


Figure 43. Climate scenarios (blue: high scenario, red: middle scenario, green: low scenario) for the change in number of wet days (left) and number of dry days (right) (Uccle, over 100 years) (Brouwers et al., 2015).

Less summer precipitation and higher evaporation will increase the cumulative precipitation deficit during the growing season (April to September). In 2017 this drought indicator peaked at 215 mm and in 1976 at 300 mm of precipitation deficit. Low-flow episodes in rivers are predicted to increase significantly in frequency and severity (Boukhris, Willems and Vanneuville, 2009; Baguis et al., 2010; Willems et al., 2010). Due to climate change, the average annual precipitation deficit could reach 485 mm by 2100. Such an extreme drought could then last four times longer than the extreme droughts of 1976 and 2018. Drought may also become more frequent in the future. The driest year that now occurs once every 20 years can occur once every two years by 2100. That is up to 10 times more often than now. A very extreme drought (as in 1976 and 2018) can occur once every 4 to 5 years.

Table 6. Overview of possible climate change for Flanders and Belgium, according to the low, medium and high climate scenario over 30, 50 and 100 years (Tabari, Taye and Willems, 2015).

Impact parameter	within...years	climate impact low (P5)	climate impact medium (P50)	climate impact high P95)	comments
annual average temperature	30	+0,2 C°	+1,1 C°	+2,2 C°	The coast has a dampening affect warming, but the effect is small compared to
	50	+0,3 C°	+1,8 C°	+3,6C°	
	100	+0,7 C°	+3,7 C°	+7,2 C°	
mean number extremely hot days a year	30	0	+5	+19	The number of extremely hot days increases most in the centre of Belgium
	50	0	+8	+32	
	100	0	+16	+64	
mean number extreme cold days a year	30	0	-2	-10	The number of extremely cold days decreases the most in the 50 Ardennes.
	50	-1	-4	-17	
	100	-1	-7	-33	
total winter precipitation	30	-0,4%	+3%	+11%	Winter precipitation picks up stronger along the coast.
	50	-0,6%	+6%	+19%	
	100	-1%	+12%	+38%	
total summer precipitation	30	-16%	-4%	+5%	Extreme summer precipitation intensities can rise sharply. Spatially a north-south pattern emerges with a greater desiccation in the south of the country.
	50	-26%	-7%	+9%	
	100	-52%	-15%	+18%	
number of wet days in winter	30	-1%	+0,5%	+2%	
	50	-2%	+0,8%	+4%	
	100	-5%	+1,5%	+8%	
number of wet days in summer	30	-12%	-5%	+1%	
	50	-21%	-8%	+2%	
	100	-41%	-15%	+4%	
total potential evapotranspiration in winter	30	+0,5%	+3%	+11%	
	50	+1%	+6%	+18%	
	100	+2%	+12%	+35%	
total potential evapotranspiration in summer	30	+0,5%	+5%	+14%	
	50	+1%	+8%	+23%	
	100	+2%	+17%	+47%	
mean daily wind speed in winter	30	-8 %	0 %	+3 %	
	50	-14 %	-0,5 %	+6 %	
	100	-28 %	-1 %	+11 %	

THE NETHERLANDS - NOORD BRABANT

Four different climate scenarios have been drawn up by the Royal Meteorological Institute of the Netherlands (KNMI). These four different scenarios are built up by taking changes of temperature, sea level and precipitation rate into account. These scenarios demonstrate the weather predictions in the years 2050 and 2085. According to all four climate scenarios drawn up by the KNMI Figure 44, the temperature in the Netherlands will rise (Tank et al., 2015).

Figure 45 shows that in wintertime an increase in the precipitation rate will occur in all of the scenarios. Looking at the summer, there are two scenarios where there will be a slight increase in precipitation rate in the year 2050 and 2085. These are the scenarios 'Moderate/Low value' and 'Warm/Low value'. The other scenarios show a clear picture of a decrease in summer precipitation (KNMI, 2014).

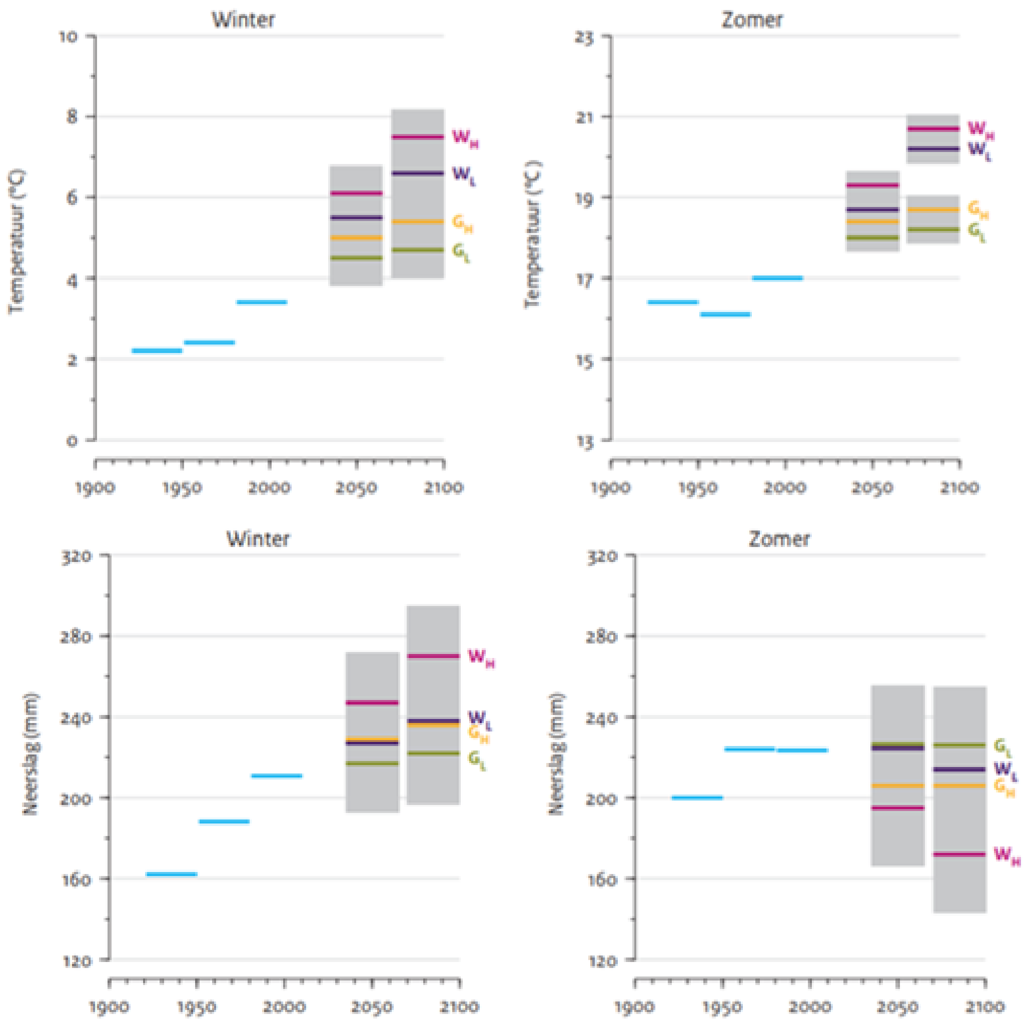


Figure 44. Winter and summer temperature in the Bilt: observations (three 30-year average coloured in blue), KNMI'14 scenarios (2050 and 2085 in different colours) and natural variations shown in grey.

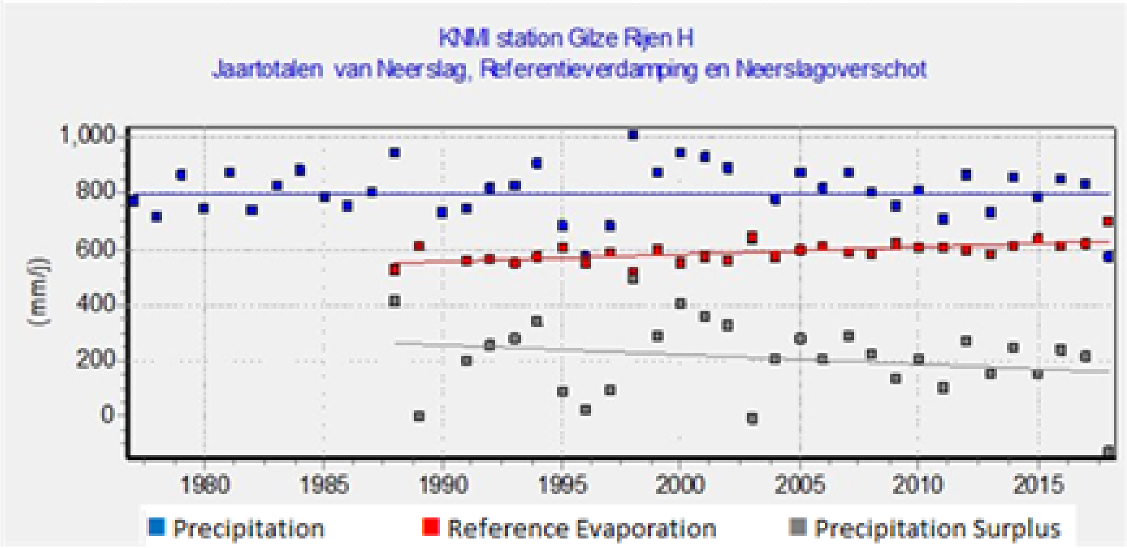


Figure 45. Yearly precipitation (blue), Reference evaporation (red) and Precipitation surplus (grey) from the weather station Gilze Rijen in Noord-Brabant from 1978 till 2018. Source: KNMI, 2019.

The weather station of Gilze Rijen is located in Noord-Brabant and has been monitoring precipitation and reference evaporation since 1990 Figure 45. For the Netherlands, the average yearly precipitation has been increased by 8% over the last 30 years (from 818 to 881 mm/year). The evaporation surplus has been reduced by 6% (total reduction of 16 mm/year between 1990 and 2018). The results of the monitoring data and corresponding trendline are in line with the climate scenarios of the KNMI in which yearly precipitation will slightly increase. However due to increased temperature the precipitation surplus is reduced over time. Current trendline estimates a yearly increase in evaporation of 2.5 mm per year together with an increase in precipitation of 1.95 mm per year, resulting in a reduction in precipitation surplus over time. Moreover, this increase in precipitation will mainly occur during winter and peak storms when most of the water is discharged out of catchment towards the larger rivers (Philip et al., 2020).

Credit: FlickrCC Santosh Kumar

LEARNING FROM PAST DROUGHTS

Droughts are extreme events with significant impacts on the environment, society and the economy and can present in different ways. As detailed by the following case studies, each drought is different and can develop over several years or within a single year. Hydrological differences between catchments will also determine how and when the effects of the drought will be experienced. For example, the effects of a winter drought maybe be more acute the following summer as opposed to the season in which it occurs. It is this unpredictability of weather that requires us to make maximal use of the precipitation surplus when it occurs.

Ecosystem-based Adaptation (EbA) measures that hold water in the landscape can support maximising use of precipitation surplus when it occurs, thus reducing the impact of increasingly frequent and persistent droughts on water supply and the environment. EbA measures should be implemented alongside complementary measures such as demand control, abstraction monitoring, leakage reduction and effluent water purification to effectively reduce the impact of extreme drought events, such as the 1976 and 2018 droughts (A. Basta, P. Ciais et al.2020). These extreme drought events are likely to occur more often in the future.

Credit: CC BY-SA 2.0 Hefin Richards

CASE STUDY - THE 2018 DROUGHT IN ENGLAND – A GLIMPSE OF THE FUTURE?

In 2018, a summer heatwave following an extraordinarily wet winter across Europe put water resources on the agenda again. June and July were some of the driest and hottest months on record, with no rainfall in parts of South East England for six weeks. Both rainfall and temperature in the summer months were in line with what will be considered average conditions by 2050. Impacts included the reduction of agricultural productivity, spread of wildfires and fish kills.

The year showed the climatic extremes that are expected to become more prominent with climate change: from an extraordinarily wet winter leading to above average river flows in runoff dominated catchments (and associated flooding), to conditions of extremely low flow in a hot and dry summer. Above average spring rainfall in the South East also led to groundwater levels being relatively high and able to not only supply public water supply but also groundwater-fed rivers which later in the year showed more stable flows than less permeable catchments relying on rainfall.

The spring had also seen the “Beast from the East,” an unusual cold spell that caused a wide range of problems for water companies and their customers as freeze-thaw events led to burst pipes and thousands of customers without water. This particularly impacted livestock farmers reliant on mains water, who found themselves without any access to water for their cattle.

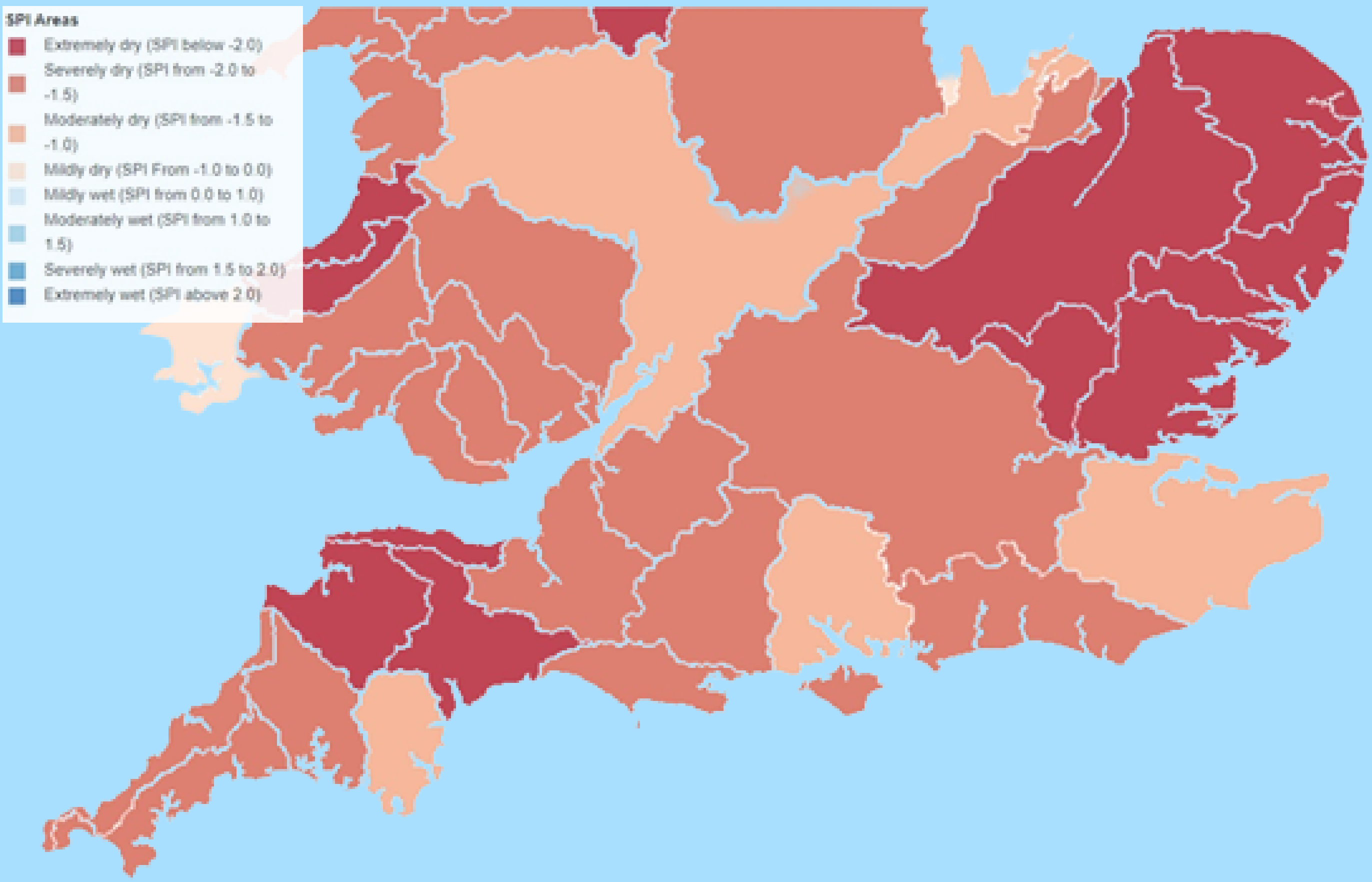


Figure 46. The Standard Precipitation Index (SPI) for 3 months ending in July 2018. The Standardized Precipitation Index (SPI) is the most commonly used indicator worldwide for detecting and characterizing meteorological droughts. © CEH ©NRFA © Ordnance survey

The winter and spring flooding were followed by a hot and dry summer (58 days without rain in the South East, at average temperatures of 24 °C). Recent analysis has also identified the warm and sunny conditions in early spring as exacerbating effects of the drought by spurring on vegetation growth which depleted soil moisture early in the year. Summer rainfall was below average across the UK (< 60 % of average for large areas of central England); it was the sixth driest summer (June-August) for England and Wales (in a record from 1910). For the North West England and Yorkshire regions it was the fourth driest May-August in records from 1910 (NERC (CEH), 2018).

The weather extremes of 2018 exemplify the need to increase resilience of water supply, agriculture and infrastructure to both flooding and drought within short time frames.

IMPACTS

Water supply

Reservoir stocks were more than 20% below the late August average in Wales (e.g. 29% below for the Elan Valley) and parts of the Pennines (e.g. 27% below for Derwent Valley). Combined stocks for England and Wales were the fourth lowest for late August in a record from 1988 (NERC (CEH), 2018).

Agriculture

Across the UK reduced cereal yields indicate the impact of the drought on agricultural production (wheat yields 6 % reduced, spring barley 10 %). Events like this have affected 50% of farm businesses in the UK in the last 10 years, leading to variable yields in rainfed crops and grass, impacting milk yields and the availability of autumn forage, as well as reducing success of wild bird and flower mixes sown as part of stewardship agreements (NFU 2018). Analysis has found different responses to the drought across Europe under different landcover types, showing a higher resilience of forests and grasslands to the drought than of croplands as they adapt to lower water availability (Bastos et al., 2020).

Environment

For the summer (June-August) as a whole, notably low accumulated flows were registered across western England and Wales, parts of Yorkshire and eastern Scotland (the Spey and Whiteadder registered their lowest summer mean flows in records from 1952 and 1969, respectively) (NERC (CEH), 2018).

Temperatures:

- **Summer: + 2 oC above baseline**
- **Winter: + 0.5 oC above baseline**

Rainfall:

- **Summer: 10-30% below average**
- **Winter: 10-30% above average**

CASE STUDY - THE 2010 – 2012 DROUGHT IN ENGLAND

The variable British climate was epitomised by the weather in 2012 when drought mitigation was swiftly replaced with flood management after one of the most significant prolonged droughts for a century was dramatically concluded by exceptional rainfall from April to July. The typical replenishment periods of 2010-2012 were repeatedly dry while wet to average summer precipitation levels did little to impact water resources.

November 2009 Exceptionally wet

Persistent high pressure blocking the wet Atlantic weather from the Jet Stream

Spring 2010 <70% of average rainfall
Driest spring since 1984

Summer 2010 Return to wet Atlantic weather
SE received more than twice the average rainfall for August

Autumn 2010 Below average rainfall for southern England

Winter 2010/11 Cold & snowy but only 1/3 of average precipitation

Spring 2011 England receives <20% of average rainfall March-April
Drought concerns begin

June 2011 Drought conditions declared in Central and Eastern England

Summer 2011 Most of UK received above average rainfall
In some areas of Kent more rain fell in one day than in the whole of spring

Autumn 2011 SE England received <50% of average rainfall

Winter 2011/12 Return to average rainfall levels

Spring 2012 <50% of average rainfall each month

March 2012 Areas declared to be in drought extended to Southern, Central and SE England
Potentially the most serve drought in the SE since the summer of 1976

Summer 2012 April - July had the highest recorded rainfall levels for England & Wales
The drought ended and was replaced by widespread flooding
Wettest summer in the UK since 1912
Groundwater levels recovered in the chalk aquifers of SE England - *very unusual for summer*

Figure 47. Timeline of events during the 2010-2012 drought in England.

IMPACTS

Water supply

- Even with above-average summer rainfall in 2011 early-July stocks in Wimbleball reservoir (Devon) equalled their lowest on record.
- The very dry spring and autumn soil inhibited recharge and restricted the length of the recharge season. Groundwater levels were widely depressed by the autumn of 2011, Tilshead borehole (Wiltshire) went dry for the first time since the intense drought of 1976.
- Minimum groundwater levels are normally recorded during the late summer or autumn but in 2012 natural base-levels had been reached or closely approached by the early spring at several wells.
- Reservoir levels in Kent were very low in February following two dry winters in a row.
- Drought plans were being followed; including demand management actions including media coverage and leakage reductions; and supply enhancements including outage reductions, and liaison with the Environment Agency.

Agriculture

- Up to 85% of the UK's cereal crops were affected, around 20% of winter wheat and barley crops were severely hit. Wheat yield losses cost UK growers around £40 million, simply because of crops not having enough water when they needed it.
- Grass shortages across the country in 2010, especially in the north, south and east, posed massive challenges to farmers. The lack of rain led to reductions in silage yields of up to 40% compared to the previous year and hay crops down by as much as 50%.

Ecological

- Low-river flows, the contraction of the stream network, low oxygen levels, limited effluent dilution and the development of algal blooms, and further drying of wetlands.
- Many river flows were the lowest on record in late November 2011, by early spring 2012 many spring fed rivers had recorded 20 or more successive months with below-average flows.

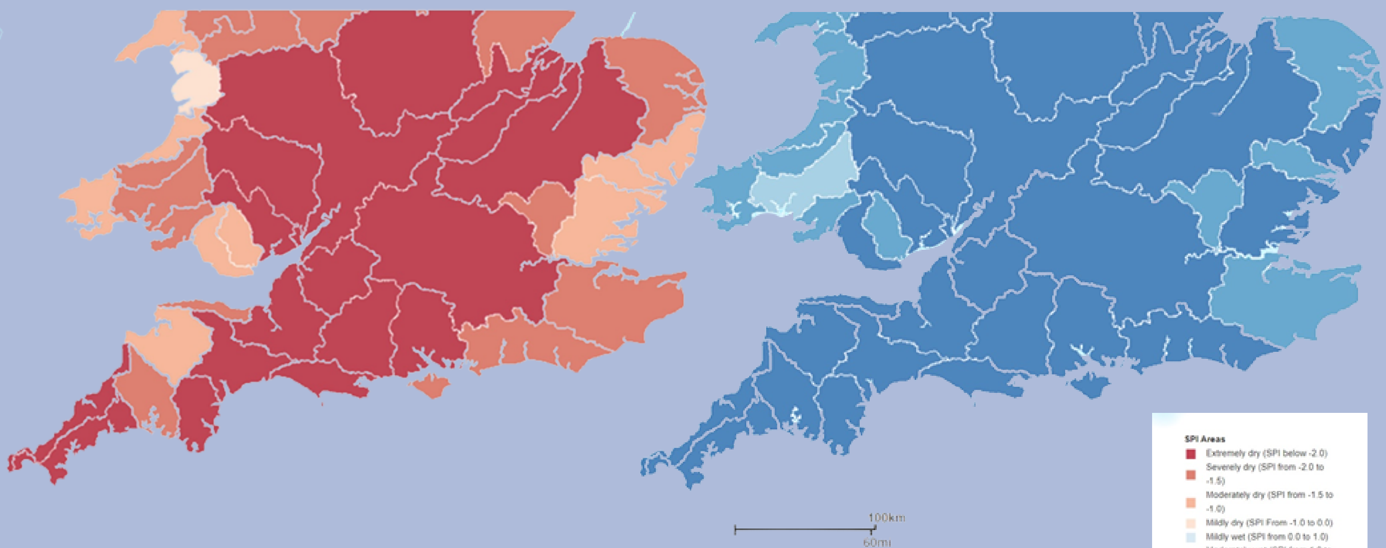


Figure 48. Top – The Standard Precipitation Index (SPI) for the 24 month period ending in March 2012. Bottom – The SPI for the 12 month period ending in March 2013. Source: UK Drought Portal CEH © CEH © NRFA © Ordnance survey

CASE STUDY - THE 2004 – 2006 DROUGHT IN ENGLAND

Below average rainfall during the two winters prior to summer 2006 led the south of England into the worst drought in 30 years, these were the driest two consecutive winters since records began in 1767. Winter months are crucial for replenishment of surface and groundwater sources, reduced rainfall during this period especially over consecutive winters puts substantial stress on water storage.

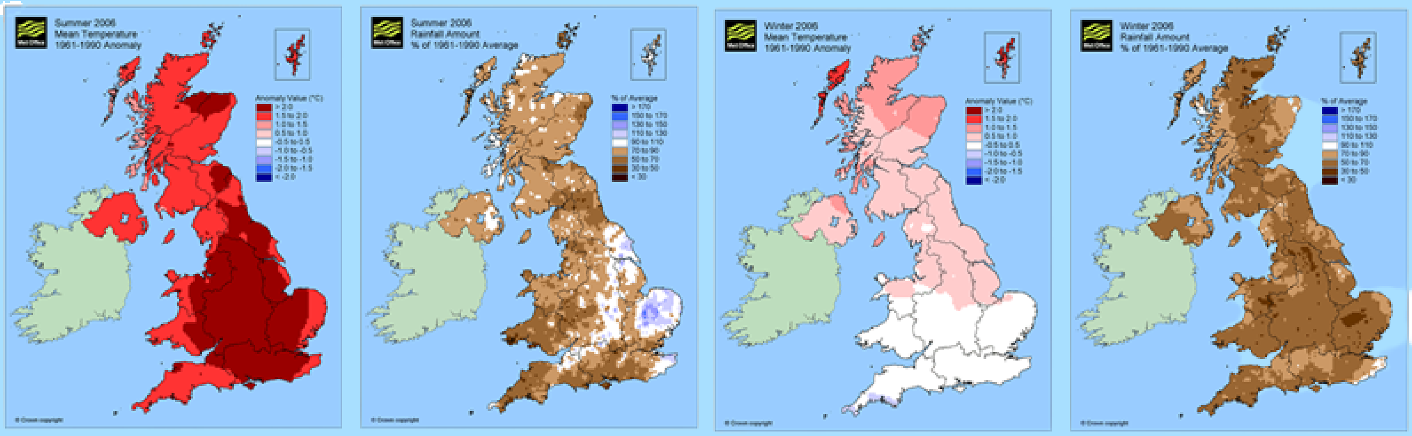


Figure 49. Rainfall and temperature anomalies compared to the long-term average for the 2004-2006 drought across the UK, showing both dry summer (up to 50% reduced in South East and South West) and winters as well as higher than average temperatures in both seasons.

The drought began in towards the end of 2003 in southern England and in 2004 it spread to neighbouring regions in southern England and Wales, as well as Northern Ireland. The highest severities were found in southern England, especially in areas dominated by groundwater sources. Groundwater levels were below average levels at the end of 2004. Further recession of groundwater in summer 2005 resulted in levels observed during the historic 1976 droughts. Above average rainfall in July had little benefit to recovery of groundwater, but may have helped to mitigate some summer demand. The late onset and reduced rainfall of 2005/06 resulted in a continued groundwater recession in the south during the autumn, and minimal recharge during the whole winter period. Heading into summer 2006 surface flows, reservoir storage and groundwater levels were low. The drought began to diminish in December 2006 and ended in February 2007.

This drought demonstrates the vulnerability of England and Wales to low winter rainfall, particularly over subsequent winters, and is reflected by the water companies in their 'three dry winters' planning scenarios, which was prompted by this drought. Regional differences were significant, with the South East recording the lowest spring/winter rainfall since 1976 in 2005, while the rainfall total for England and Wales was considerably above average. Over the whole period the Thames River Basin District received only 78.2% of the long-term average rainfall (the 4th-driest period on record), and the South East River Basin District 77.2% (3rd driest on record). Above average levels of precipitation during winter 2006/07 meant that a third dry winter was avoided, resulting in increased winter flows, substantial aquifer recharge, leading to recovery of spring-fed rivers in the late autumn; and subsequently flooding events in the next year.

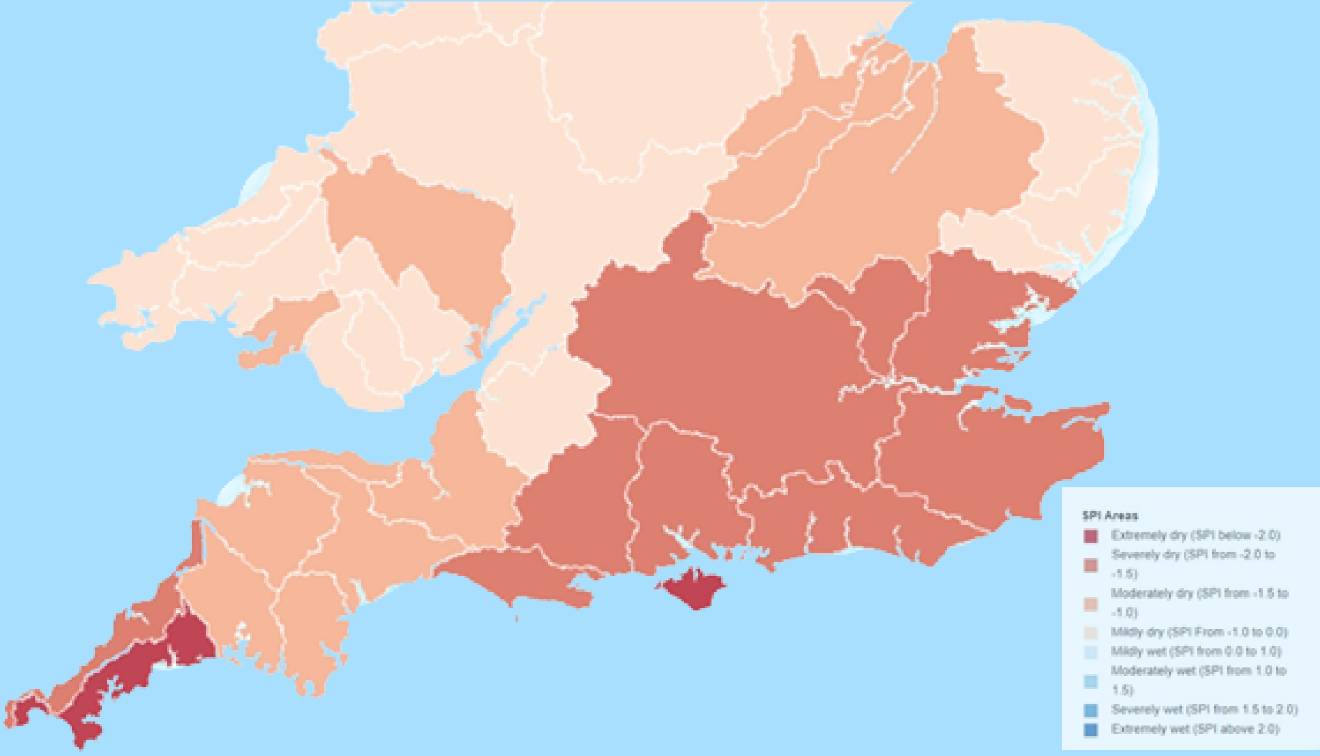


Figure 50. The Standard Precipitation Index for the 24 month period ending in August 2006. Source: UK Drought Portal CEH © CEH © NRFA © Ordnance survey

IMPACTS

Water Supply

- The lowest river flow on record, 207 Ml/d, was recorded in the River Medway at Teston in 2006.
- Below average winter rainfall and above average evapotranspiration restricted groundwater recharge. In the Chilterns a 30% effective rainfall deficiency translates into a 60% recharge deficiency.
- Bewl reservoir (fed by sources from the Medway) was at the lowest on record entering 2006 as no seasonal recovery occurred over the 2005/06 winter.
- In Kent, the water demand for 2005 winter exceeded South East Water's predicted demand of a whole dry year (i.e. a year in which unrestricted demand can only just be met by available supplies) approximately 10% ahead of the forecast, and placed additional stresses on the water resources. Drought management actions included hose pipe bans in 2005 and 2006, alongside communications media campaigns to encourage the public to reduce their water use, and additional abstraction from the Medway to increase supply.

Environmental

- The widespread failure of springs leads to sustained low flows and contraction in the stream network and many ponds dried up.
- A lack of spates and the drying up of headwaters was an issue for migratory fish, which were unable to reach their spawning grounds.
- Impacts for fish habitat on mainly surface-water reliant rivers, e.g. River Lymington only had 5% of habitat suitable for juvenile trout.

CASE STUDY – THE WATER SCARCITY AND DROUGHT PERIOD 2017-2019 IN FLANDERS, BELGIUM

The information about the Flemish case study has been derived from the drought evaluation reports for 2017, 2018 and 2019 (Coördinatiecommissie Integraal Waterbeleid, 2018, 2019, 2020). The Flemish Environment Agency publishes reports at regular intervals during dry periods in which the state of the water system is described using meteorological and hydrological indicators. It estimates how extreme the situation is with respect to historical observations and compared to historical droughts such as in 1976 and 2011. In addition, the Flemish Coordinating Committee for Integrated Water Policy (CIW) developed drought evaluation reports for the years 2017, 2018 and 2019. These reports also include an overview of policy interventions and impact assessment.

The years 2017, 2018 and 2019 were marked by heat waves, severe droughts and water scarcity in Flanders. Droughts and heat waves are interrelated because dry soils and vegetation cannot dissipate the solar energy through evapotranspiration. When soils dry out, heat waves are more probable. Especially tropical days lead to very high water consumption by agriculture (irrigation to protect from heat damage) and households (irrigation, swimming pools, showers). The first persistent drought occurred from the end of the summer of 2016 till the end of the summer of 2017. The first six months of 2016 had been unusually wet, but from July 2016 until July 2017, only about two-thirds of the normal rainfall fell in Uccle, which is the 7th lowest precipitation total recorded for that period (557.3 mm) since 1833. The Royal Meteorological Institute of Belgium (KMI) recognises the precipitation totals in winter 2016/2017 and spring 2017 as “very unusual”, occurring on average only once every ten years. Especially in the eastern and south-eastern part of Flanders it was drier than average this winter 2016/2017. In the spring and summer of 2017, it was especially dry in the south and south west of Flanders. The drought enabled a first heat wave in June and generally warm and dry summer. In total 2017 had 7 tropical days (+ 30 °C).

Precipitation was relatively normal in autumn and winter 2017/2018. After April 2018 being wetter than average, May until July 2018 was exceptionally dry for large parts of Flanders. August 2018 until February 2019 was drier than average in Flanders, so that groundwater levels were not able to recover in autumn and winter. In addition, the temperatures in the summer of 2018 were the highest since 1833, which contributed to a particularly high precipitation deficit that year. Consequently, the catchments experienced a long period of drought and afterwards were unable to recover.

The precipitation in the winter of 2018/2019 was close to normal for the time of the year, but it was not enough to compensate for the accumulated precipitation deficit of the previous year. The low groundwater levels again enabled high air temperatures, leading to several heat waves and 9 tropical days in 2018. Furthermore, during spring and summer 2019 precipitation levels remained below average, followed again by a summer by above normal temperatures and three heat waves. In total 2019 counted 11 tropical days. In September and October 2019, precipitation levels increased, but November and December were again lower than normal, so there was no significant elimination of the precipitation deficit at the end of 2019.

IMPACTS

Water supply

The droughts resulted in below average to extremely low flows in many unnavigable watercourses. In July 2018 the lowest flow rates were observed since the beginning of the measurements. In autumn and winter base flows remained too low for that time of the year. The same applies for the winter of 2018/2019. Historically low water levels and flows were recorded in unnavigable watercourses in many locations in summer 2019 as a result of the normal decrease in summer flows and already low flows. Rainfall did not have a significant effect on the base flow. From October, flows continued to increase but remained rather low for the time of the year in many places. The droughts resulted in low flows in navigable watercourses as well.

Unconfined groundwater levels decreased to very low groundwater levels in July 2017, especially at that time of the year. The replenishment in November, January and March had been insufficient, also because the warm winter increased evapotranspiration losses. The extremely dry spring in 2017 made unconfined water levels drop fast. The wet autumn and winter 2017/2018 resulted in a short recovery of groundwater levels in May 2018. Subsequently the groundwater levels consistently dropped everywhere due to a total lack of precipitation and high evaporation. More than 80% of the measurement points had historically low groundwater levels and this situation continued until February 2019. The groundwater levels were thus not able to recover in the winter of 2018/2019. From January till June 2019, there were two wet periods, but only a few sites could recover to normal water levels. There was again an increase in relative very low and low groundwater levels in summer, which correspond with the low flows in watercourses that period. At the end of September 2019, 90% of the monitoring locations showed very low absolute groundwater levels. Again for 80 % of the monitoring sites, unconfined levels remained below normal the entire winter season. An extremely wet February/March resulted in a short recovery followed by another dry summer. It is apparent that since 2017, unconfined water levels have not recovered substantially. Occasional wet periods seem to result in a quick recovery for only a subset of the monitoring sites. We assume these sites are dominated by local recharge and have a natural quick response to the short term rainfall surplus.

The groundwater level indicator Figure 51 shows the relative situation of the groundwater levels compared to the long-term baseline for a particular point in the year. The dark brown colour indicates a below normal level which should occur only once in ten years.

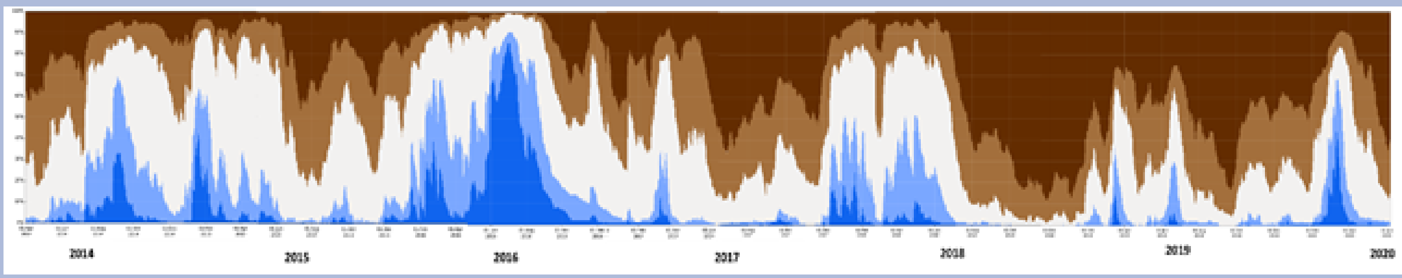


Figure 51. Evolution of unconfined groundwater levels in the Flemish Region. White colours indicate a normal water level (P30-P70) for that period of the year. The white colour should cover about 40 % of the graph. Light blue colours indicate the above normal water level (P70-90) for that period of the year. Brown colours indicate below normal water level (P10 –P30). The dark brown colour corresponds to water levels that are exceptionally low and should only occur once every ten years. The wettest spring ever recorded in 2016 was followed by a dry winter in 2016-2017 and an early drought and heatwave in 2017. Groundwater levels never recovered after the 2017 drought. The 145 monitoring points should be representative of undisturbed groundwater levels (VMM, SCK and De Watergroep, 2020b, 2020a).

Drinking water - households

In June 2017 the use of piped water increased by 25% and peak demand even rose up to 40% more than average occurred for this month. This remained until the end of June when drought measures were announced. Much of this high water consumption can be related to the heat wave that lasted from the 19th to the 25th of June. Especially in the west of Flanders the demand was so high that alternatives for surface water abstraction had to be sought (i.e. groundwater abstraction, purchase from other drinking water companies). Fortunately, drinking water supply could be guaranteed during the droughts of 2017, 2018 and 2019, even at the highest peak demand levels.

In 2018 and 2019 the groundwater levels and availability of surface water decreased gradually. For some locations new built reservoirs helped to overcome periods of droughts. Regarding surface water availability, there were considerable differences between the Meuse and Scheldt catchments. Groundwater levels were still low at the start of the meteorological drought as they were not sufficiently replenished during the 2018/2019 winter, leading to even more extreme record lows in summer 2019. This caused a reduced raw water availability from groundwater in 2019 compared to 2018. The prolonged droughts and heat waves triggered an extremely high demand for piped water, also because most of the private rainwater tanks were already depleted.

The available buffering effect of reservoirs and the availability of groundwater resources are sufficient to ensure a stable supply of drinking water. Nonetheless, the recent droughts have been a wake-up call to increase buffers for drinking water supply. The main problem is the peak demand, which was high because other water sources such as private rainwater tanks were depleted. The maximum production- and transport capacity cannot be exceeded, as water production centres are located close to the surface- and groundwater resources from which it is distributed to the users. Peak demand could reduce water pressure and cut-off the end of pipe customers from water. After all, there are physical limits to the water distribution system. Therefore, drinking water companies appealed to the public to make economical use of water during the droughts in order to guarantee the long-term supply, but also to prevent peak usage levels.

In 2018 the action plan to prevent drinking water scarcity was set up. Long-term supply plans focus on diversification of sources, by type (groundwater, surface water, reuse of wastewater) as well as by distribution, on optimisation of sources, on construction of strategic reserves and on the strengthening of quantitative and qualitative protection policy. Supply on a larger scale is also guaranteed by interconnectivity between drinking water companies. These plans were heavily oriented towards optimisation of the distribution and production capacity and there was little attention to increasing natural water availability. EbA should have received more attention within these plans.

Agriculture

Agriculture in the west of Flanders was impacted by the drought of 2017. Crops were irrigated in order to avoid crop failure and limit economic damage in 2017. In the coastal region, farmers abstracted more surface water to combat salinisation, which led to an abstraction ban. Salinisation has a negative effect on nature, agriculture and drinking water production. Watercourse could not be used as drinking water for livestock due to increased salinity. High nitrogen stocks in the soil from reduced crop yields resulting in less N-absorption from fertiliser applications may in turn affect water quality. The drought of 2017 has been recognised as an agricultural disaster by the government and cost around EUR 98 million, of which EUR 25-30 million was paid out. The damage cost was even worse in 2018; almost EUR 100 million was paid out and also that drought has been recognised as an agricultural disaster.

The water shortage of 2018 occurred during the growing season of most crops and beyond, damaging an area of extensive traditional crops, such as maize and grasslands. Vegetable crops were also impacted when irrigation was not possible. Relative to 2017, the damage to potato and beet crops and fruit was larger, but cereals were less affected due to the later timing of the 2018 drought. Besides crops, the higher temperature caused heat stress to the livestock, leading to reduced feed intake and milk production. The drought of 2017 mainly affected the provinces of West- and East-Flanders, our most important agricultural regions. The drought of 2018 was felt in the whole of Flanders.

Because drought in 2019 started later, damage to crops in 2019 was limited compared to the previous year. A less uniform pattern in different crops and different regions could be observed in 2019 compared to 2018. Yield losses were limited due to precipitation after the warmest period. The high temperatures in August and prolonged droughts in September 2019 caused damage to some crops (potatoes and industrial vegetables), especially in West Flanders. The three heat waves caused a lot of problems such as sunburn damage to apples and heat stress to livestock.

The total water use in Flemish agriculture was estimated by VMM at 74 million m³ for 2018. This means that agriculture already accounts for 10% of the total water use (excluding cooling water) in Flanders. In addition to groundwater, mains water (10% in 2018), surface water (8 %) and rainwater (7 %) also account for a considerable share of total demand. In 2017 and even more so in 2018, surface water use by agriculture was significantly higher than in previous years (almost three times higher than that for 2016). The figures in the VMM database also indicate an increase of about a quarter for groundwater, compared to 2016. Demand for piped water and rainwater also increased, but to a lesser extent.

Other industries

Besides agriculture, also other economic sectors were impacted by drought, such as shipping, energy production, industry and recreation (e.g. recreational vessels). Measures for shipping include activation of pump and turbine water saving technology, grouped lock operation, drought restrictions. The increased travel time and also had implications for the broader economy. Drought and water scarcity had negative consequences for various sectors and companies, both direct and indirect before or after them in the value chain. For instance, the construction sector and fruit and vegetable processing companies have substantial water use. There was concern about how the government would deal with the allocation or distribution of water in acute situations for these companies for which water is crucial in the production processes. The shut-down of production processes could cause major economic damage.

Ecological

Droughts have an impact on water quality in general (e.g. higher water temperatures, lower oxygen concentrations, higher concentrations of pollutants) leading to a deterioration of ecological status, which resulted in algal growth, botulism and fish mortality. When the flow rate is low or when the water levels drop too low for ecologically sensitive watercourses, there is a good chance that irreparable damage will occur. Especially in the small brooks, the protected fish species are often relict populations which are not very mobile. The reduced flow in the Scheldt leads to a build-up of suspended matter in the Sea Scheldt, which causes damage to the ecosystem due to oxygen deficiency, reduced penetration of sunlight and consequently a reduced primary productivity. This problem is mainly because most of the water from the Upper-Scheldt is diverted to feed the canal system.

The prolonged drought of 2017 and subsequent low water levels caused for example massive fish mortality in the Baudouin canal, algae growth in the Lys river and increased conductivity in the Albert Canal (leading to additional costs for the production of demineralized water). Frequent pond fish mortality occurred in 2019. Drying up ponds also affects the reproductive success of amphibians and dragonflies.

Reduced unconfined water levels and increased salinisation also affect groundwater dependent ecosystems. The droughts have also had an impact on wetlands, but the effect is difficult to estimate. There is a complex relationship between species composition and abiotics, in which drought also has indirect long-term effects through mechanisms such as (internal) eutrophication and displacement by (invasive) species. The impact is thus determined by several factors. The impact also depends a lot on the preceding spring groundwater level and the cumulative effects of drought episodes during previous years. The effect of an occasional, extremely low groundwater level during summer can also be strongly mitigated when there is sufficient precipitation and the soil moisture content remains sufficiently high.

But there are also other ecological impacts. Due to drought, soil dried out and many meadows and farmland birds had problems finding food. This impacted their reproductive success. Relatively new in Flanders was the potentially toxic blue-green algae blooms (cyanobacteria) on various canals and unnavigable courses in the beginning of August 2018, which also occurred in 2019.

Droughts in 2019 caused high mortality among adult conifers and damage to deciduous trees (e.g. beech, sweet chestnut, common maple and rough birch), including premature leaf discoloration, leaf fall and dying-off. Reduced sap flow makes trees more vulnerable to infestation with (invasive) insects such as bark beetles. This led to a massive die-off of spruce. Encroachment by common species has increased in high nature value heath- and grasslands, leading to fewer typical species in those habitats. Increased risk of fires also occurred in 2018 and 2019, especially in the heathland areas in the provinces of Antwerp and Limburg.

Drought and water scarcity management

Flanders established the Drought Commission in June 2018 in order to improve consultation and coordination between different authorities to ensure a more coherent implementation of measures. The coordinating committee for integrated water policy, the ministry of mobility and environment and the Flemish Crisis Centre are represented in this commission and meet in periods of prolonged droughts and general water shortages. On the local scale provincial consultation meetings take place under the coordination of the provincial governors.

Flanders is developing a water scarcity and drought risk management plan to make the region less vulnerable to the effects of water scarcity and droughts. Risk management is based on two pillars:

- The pro-active pillar consists of measures to achieve a good state in order to reduce the probability of a crisis.
- The reactive pillar comprises of measures that are crucial before and during a drought crisis in order to limit the harmful effects of the crisis.

The policy uses a multilayer approach focussing on protection (reducing the likelihood of water scarcity), prevention and preparedness (reducing economic and ecological damage in case of water scarcity). Shared responsibility and cooperation of water managers, water companies, other governmental organisations, sectors and citizens is assumed in order to reduce current and future risks.

The aim of the plan is to balance the water demand and supply. It involves measures to increase and maintain water supply on the one hand and measures to reduce water demand on the other hand. When water demand exceeds the water supply, measures to limit ecological, social and economic damage are undertaken.

The Flemish government is currently working on the reactive assessment framework for priority water use during droughts, which will be used to assess precautionary measures and priority water use in the run up to or during a water scarcity.

The urgent need to increase the water availability in Flanders has also become a priority of the Flemish government, as reflected by the launch of the “Blue Deal” program and the recent creation of the “High level task force drought” to steer its implementation. This task force unites 4 Flemish ministers, all provincial governors, as well as policy makers of the administration and scientific support. The Blue Deal program foresees more than 70 strategic actions and a first tranche of 75 million euros for the coming years to increase water availability, and reduce drought impacts. Besides a technology and innovation approach to achieve a more efficient water management and reduced consumption, there is also a track on ecosystem based adaptation measures to increase natural water availability. In this track, agriculture and nature should be part of the solution to droughts. With the Blue Deal, the Flemish Government wants to increase its efforts in the fight against water scarcity and droughts by tackling the drought issue in a structural way, with an increased use of resources and the right instruments, with the involvement of industry and farmers as part of the solution and with a clear example role for the Flemish and other authorities.

KEY MESSAGES

- Summer rainfall is reducing on average while winter rainfall increases, and extreme events such as droughts and flooding are becoming more common across the year.
- Episodes with extreme precipitation are less effective for water infiltration and retention in the landscape and increase flood risk.
- Changing climate and population growth will exacerbate water demand pressures resulting in greater water stress.
- Implementation of EbA measures can increase the water infiltration and retention capacity of the landscape to counter climate change impacts and result in sustainable water resources and catchments that are more resilient to both drought and flooding.

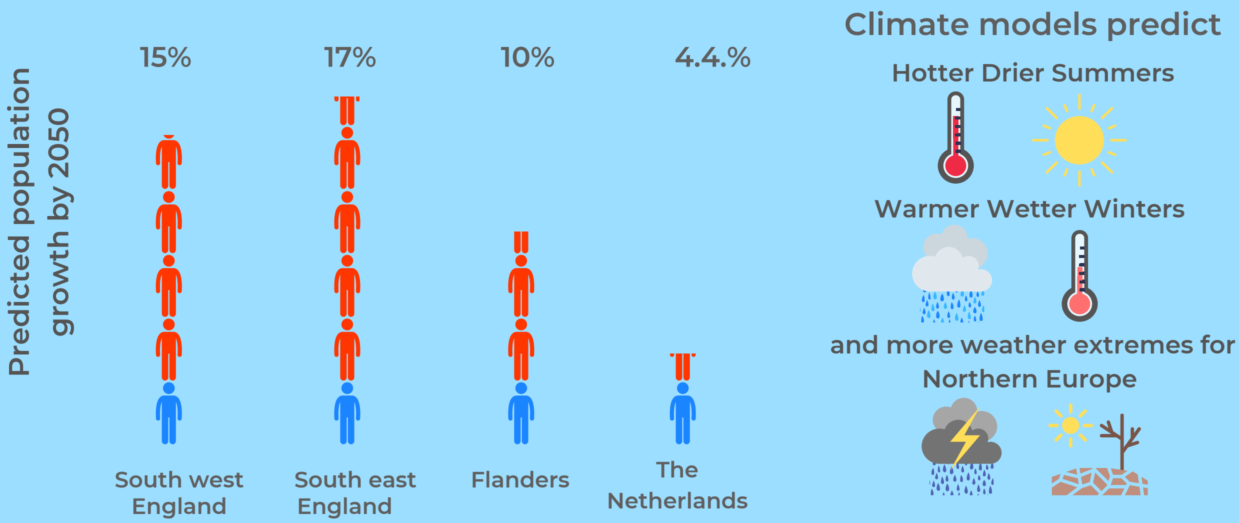


Figure 52. Predicted population growth by 2050 (left) and climate model predictions (right) across the regions.

SOUTHERN ENGLAND

- Nationally by 2050, restrictions on water use (such as temporary use bans) will be twice as likely as in the period between 1975 and 2004 if no action additional to current water resource plans is taken.
- Daily river flows show a trend for lower summer flow and higher winter flows across the UK, with impacts on water quality and wildlife. Water resources responses are catchment specific.
- Consecutive dry winters present the biggest drought risk, 2012 was a significant drought following 2 dry winters.
- The groundwater recharge period is shortening and becoming more vulnerable to droughts, with the risk of groundwater recharge decreasing locally.
- Soils will become more drought prone and less suitable for today's agriculture, with higher erosion and compaction risks. Freshwater ecosystems as well as terrestrial ecosystems are impacted by these changes.

KEY MESSAGES

- In 2004-2006 the response to the drought occurring was focused on maintaining the public water supply and as a result the environment suffered.

- Previous droughts and responses to them show that: good soil management can support agriculture through dry periods, the increasing intensity and frequency of droughts requires efforts to increase the resilience of natural ecosystems and that the variability of weather events with flooding following droughts could be balanced better by increasing the retention capacity of the landscape in a way that would benefit public water supply, agriculture and the environment.

BELGIUM - FLANDERS

- The effects of climate change on Flanders can already be observed in the long-term meteorological data. Temperatures and extreme precipitation have increased in recent decades. Droughts have been increasing more recently. Climate scenarios predict higher temperatures, higher evaporation rates and less rain in the summer for the Flemish region. Consequently, the cumulative precipitation deficit will increase during the growing season.

- The ecological impacts are high, ground and surface water dependent ecosystems suffer from direct and indirect impacts.

- Policies and plans target short term measures for water security and drought risk management, there is too little attention for pro-active measures, such as EbA measures that actively increase water infiltration and retention capacity of the landscape on the long term.

THE NETHERLANDS – NOORD-BRABANT

- Overall average summer rainfall is reducing and average winter rainfall is increasing, and extreme events such as droughts and flooding are becoming more common.

- There is a significant difference between trends in April-September precipitation between coastal and inland region in the Netherlands, but drought scenarios are often studying the whole country of the Netherlands.

- Peak storms events are less effective to store water and most of the water is discharged out of catchment towards the larger rivers.

THE ROLE OF ECOSYSTEM-BASED ADAPTATION MEASURES

The natural diversity of ecosystems and their processes underly the long-term stability of groundwater levels and river flows. Historic changes and existing pressures on our landscapes have decreased their ability to provide water, resulting in increased peak flows, reduced recharge rates and increasingly vulnerable landscapes. This affects the replenishment of aquifers and the stability of river flows, limiting the availability of the water resources humans rely on. These changes have also had an impact on river hydrology, soil nutrient retention, soil carbon sequestration and biodiversity.

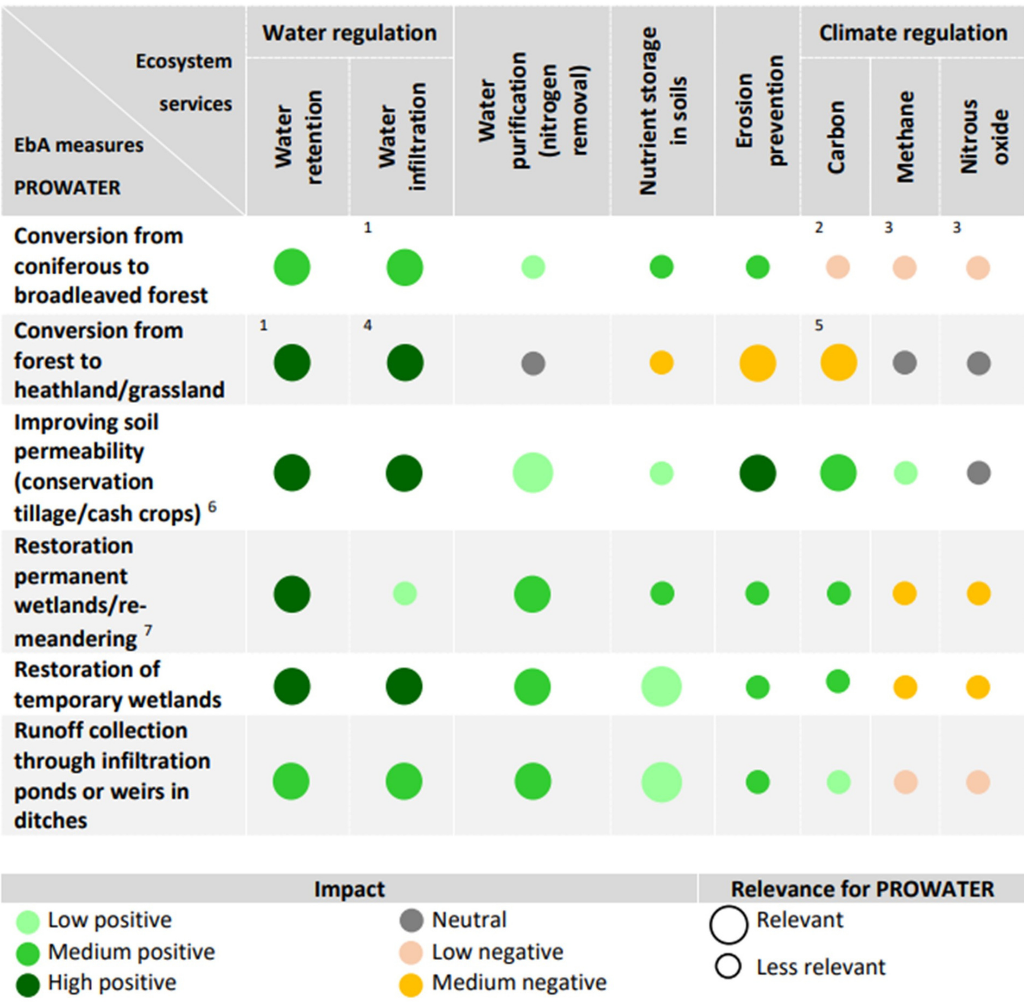
The replenishment of strategic reservoirs and aquifers can be supported by restoring the natural diversity and function of our natural capital through EbA measures, allowing periods of drought and water scarcity to be bridged through the sustainable management of resources.

This "Ecosystem-based Adaptation (EbA)" can compensate for the anthropogenic impact on natural hydrological functions and improve resilience of water resources for people and the environment to future climate change. EbA measures are a form of Nature-based Solution, supporting integrated and holistic management of land and water with respect to climate change Figure 53.

Figure 53. Nature-based Solutions thematic diagram. Source: ©IUCN

A range of EbA measures can be used to improve the resilience of water resources. The measures on the following pages (as described in Figure 54) focus on supporting the retention and infiltration capacity of water in the landscape, whilst also delivering additional environmental benefits. Measures may involve the creation of new or different natural assets (for example, forest conversion, tree planting and wetland creation), or improved management practices of existing assets (such as agricultural practices that reduce and remediate soil compaction).

EbA may not always be able to offer a standalone solution to extremes, but it can be implemented alongside complementary 'hard infrastructure' solutions such as infrastructure upgrades. EbA can be more cost effective (alone or in combination) than traditional approaches to resource management, and offer benefits that go beyond water supply, including biodiversity and climate change resilience. This is already being recognised: Several water service providers around Europe are investing in nature-based solutions alongside their grey infrastructure investment program, to cut costs and generate additional benefits (Trémolet, 2019). From 2014 to 2020, an average of EUR 5.5 billion per year was committed to the restoration and conservation of watersheds and to sustainable management activities in the European Union (Forest Trends, 2017).



1 The effect depends on the type of soil. Forest cover and interception have a positive effect on heavy soils, as they buffer extreme precipitation events and promotes infiltration. In contrast, sandy soils in general reduce infiltration.
2 Conifer trees have dense canopies that intercepts a certain portion of light which causes a lowering of soil temperature. This reduces in turn slow down decomposition which leads to an accumulation of organic matter and increased carbon sequestration (Barsoum and Henderson 2016).
3 Processes responsible for methane and nitrous oxide emissions vary in time and space and depend on soil texture, topography, precipitation and nitrogen limitations (Díaz-Pinés et al. 2018).
4 The effect is strongly dependent on the soil type, scale of planting, forest design and replaced landcover. The effect mentioned in the table is the case for sandy soils, but is different for chalk soils. Conversion from broadleaved woodland to grass has a little impact as the uptake of root water can be maintained, even during drought periods (Calder et al. 2002; Nisbet 2005).
5 The C stock under grassland can be at the same level as under forest, provided that the grassland is permanent and natural grassland or either extensive grassland with livestock. 6 Deep compaction is not taken into account in PROWATER, but must be investigated as it can be a problem. 7 Restoration of permanent wetlands and rivers involves several measures and mostly include river bank stabilisation, which has a positive effect on water quality, nutrient storage in soils, erosion control and carbon sequestration.

Figure 54. Summarizing the effect of the different EbA measures on ecosystem services. The impact on ES the local context (e.g., soil type, slope, soil management, and so on). This table supplies a general view of the EbA measures on ES (Staes et al. 2020).

This chapter provides an introduction to the EbA measures investigated by the PROWATER project. For a more in-depth review of the measures and quantifying the benefits they can deliver please refer to the following PROWATER project publications:

- Van der Biest Katrien, Staes Jan, Bauer Katharina, van Heemskerk Jaco, Broeckx Annelies (2019). Review of spatial prioritisation methods for Ecosystem-based Adaptation measures to drought risks. Deliverable 2.1.1. of the PROWATER project, Interreg 2 Seas programme 2014-2020, ERDF No 2S04-027.
- Staes Jan, Broeckx Annelies, Bauer Katharina, Neville Jo, Stacey Freya, Van der Biest Katrien (2020). Review of quantification methods for ecosystem services of Ecosystem-based Adaptation measures to drought risks. Deliverable 2.2.1 of the PROWATER project, Interreg 2 Seas programme 2014-2020, EFRD No 2S04-0

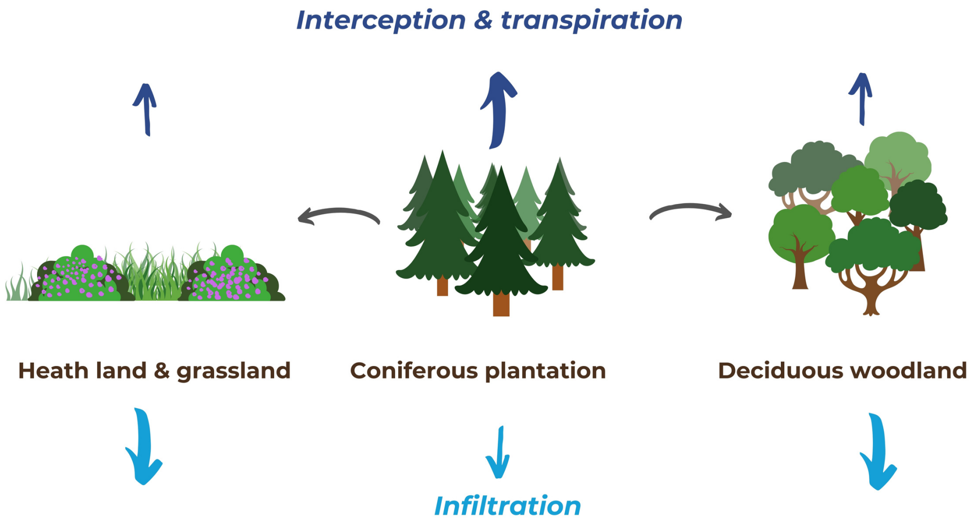
These can be found on the project website:

https://www.pro-water.eu/downloads

Credit: FlickrCC Mark Robinson

FOREST CONVERSION

While forests have a wide range of benefits, not all forests are suitable in all places. Unmanaged forests can have high rainfall interception, especially pine and fir, reducing the amount of water reaching the ground. Coniferous forests have been shown to have a significant impact on water resources by reducing deep infiltration and recharge rates, due to their dense canopy that remains in winter, as well as a high demand for water and deep rooting systems. Often such forests have been planted on elevated and dry sites. These sites are important for groundwater recharge as groundwater levels are deep. During the 19th century, large areas of mixed deciduous forests in Western Europe were converted to productive coniferous forests (Verstraeten, 2013). This has had a serious impact on the water balance of the landscape. Forest conversion to broadleaf forest or more open vegetation types, such as heathland or grassland, allows groundwater levels to rise during winter, which helps to mitigate the impact of droughts. Broadleaved native woodlands also have a much greater biodiversity benefit in comparison to conifer plantations.



A number of factors influence the impact of woodland on water use:

- **Soil type and depth**
- **Climate**
- **Species type**
- **Woodland age**

Figure 55. Illustration of forest conversion options; coniferous forest to deciduous forest which leads to higher infiltration capacity due to lower interception and transpiration of the deciduous trees, and coniferous forest to heathland leads to higher groundwater recharge due to the higher infiltration rate of heathland (lower interception and transpiration). Source: adapted from Staes et al. 2020

Evidence indicates that woodland cover reduces nearby stream flows compared to grassland cover. This can have benefits for flood management but needs to be considered carefully in the context of drought resilience. When replacing woodland cover, taking account of the location, the depth of soil and the land type it would be replaced with are essential. Especially in the context of chalk bedrock, conflicting evidence has been produced on the comparative impact of deciduous woodland and grassland. Overall, conifers have the highest rates of water loss alongside bracken, while more herbaceous vegetation such as grass, heather and arable crops have much lower evapotranspiration rates.

The conversion of grassland to woodland can be used to reduce the impact of flooding during extreme weather events. This is particularly relevant in surface water catchments that respond rapidly to intense rainfall. Woodland cover can intercept overland flow by obstructing overland flow paths and physically slowing the rate at which water is delivered to rivers through increased hydraulic roughness. In certain situations, tree roots enable water to be delivered to the soil, which encourages infiltration and the storage of water within the soil. Currently the strongest evidence for new woodlands ability to reduce flood risk is in small catchments (< 10km2) (Environment Agency, 2019b). Geology exerts a strong control over run-off pathways and the ability of catchment woodland to affect these. The more porous the geology, the less scope for woodland processes to affect rapid surface run-off (Environment Agency, 2019b).

SOIL MANAGEMENT

Soils regulate the movement of water via drainage and storage, while also acting as a filter. This is a key role in the provision of clean and plentiful water, ensuring the health and resilience of catchment systems. Soils are an important element of our natural capital that provides a range of ecosystem services as shown in Figure 56. The value of soil as an asset, and its ability to provide these services, depends on its inherent properties (such as soil type, intrinsically linked to the underlying geology) and its condition (influenced by land use, which often results in a range of degrading processes), as well as contextual factors such as its location and hydrology.

Soil compaction is the increase of bulk density or decrease in porosity of soil due to externally or internally applied loads. Soil sealing by infrastructure (paved surfaces) has a similar impact, but needs more technical remediation. Figure 56 Compaction can adversely affect nearly all physical, chemical and biological properties and functions of soil. It causes a decrease in large pores (called macropores), resulting in a much lower water infiltration rate into soil, as well as a decrease in interflow Figure 56.

Together with soil erosion, compaction is regarded as one of the most costly and serious environmental problems caused by conventional agriculture, with impacts on drought resilience, water quality and regulation of flows (FAO, 2003). Most of the negative effects of soil degradation occur indirectly, affecting regulating and supporting ecosystem services such as the provision of water, flood risk management and carbon storage (Morris et al., 2016). This means that those managing soils are not always aware of the impacts of degradation occurring. Incentives for remedial action may need to come from policy, regulation and those impacted by the effects of the degradation.

Credit: Unsplash Roman Synkevych

A range of measures forming part of best agricultural practice can be implemented to improve soil health for water resources on a field or farm scale, including adapting tillage practices, cover crops, livestock management and use of diverse swards. These can be used to address compaction, prevent erosion and increase organic matter to improve the infiltration and water holding capacity of the topsoil, alongside water quality benefits. On a field scale, cover crops for example have been shown to increase infiltration by about a third while also reducing nutrients leaching to groundwater (Basche and DeLonge, 2019); reduced tillage can double earthworm numbers and infiltration rates (Griffiths et al 2018); and the use of diverse swards reduces nutrient input and bulk density while increasing soil organic matter.

Ecosystem-based adaptation can restore and protect soil health to support infiltration and retention of water on a catchment scale, and increase resilience to the effects of climate change such as intense rainfall events, increased drought risk and loss of organic matter. Studies have shown that improvements in soil health can reduce runoff at a catchment scale by up to 50%, depending on rainfall, land use and soil type (Hess et al., 2010). This also indicates a high potential for improved recharge and flow regulation. An extensive body of evidence indicates the impact of land and soil management on water quality (Natural England, 2009), but the impact on regulation of flows and in turn water resources, especially on a catchment scale, is not as well evidenced yet. However, the role of soil management is clear when a natural capital approach is taken: the degradation of an asset that is key to the provision of water is a risk to the ability of catchments to continue providing this resource.

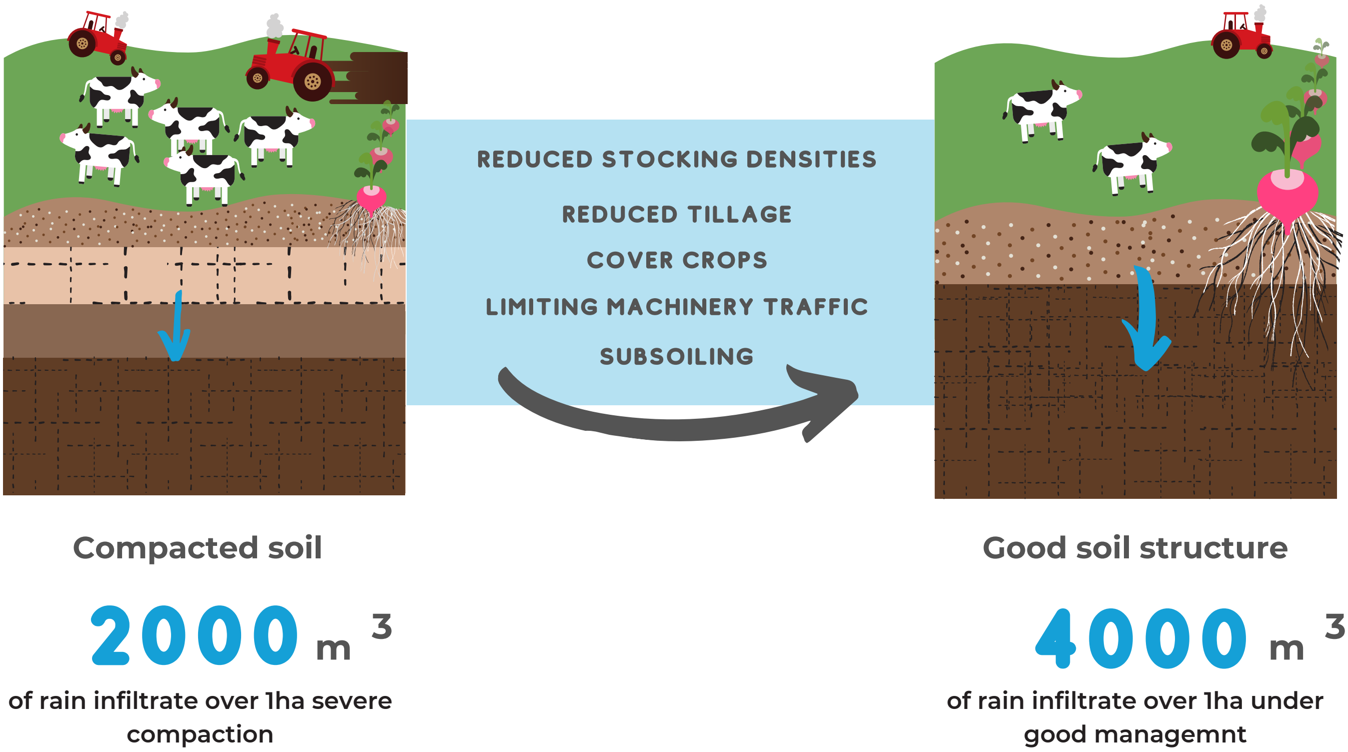


Figure 56. A comparison of compacted and non-compacted agricultural soils and management practices that can remediate soil compaction.

WETLAND RESTORATION & CREATION

Wetlands play a key role in the hydrological cycle and provide numerous ecosystem services (Mitsch and Gosselink, 2000; Bertassello et al., 2018). Wetlands encompass a wide range of habitats, including wet grasslands, wet woodlands, valley mire systems, fens and bogs as well as floodplain wetlands, to name but a few Figure 57. Wetlands have been drained in the past for agriculture and forestry. These sites now have a reduced retention capacity and are almost permanently drained. By reducing or removing the drainage of these sites, wetlands can be restored.

Wetland habitats associated with headwater streams, contain a large proportion of the freshwater network (by stream length) and are influential in regulating downstream flows and ecosystems. Headwater wetlands can act as a buffer for sediment and nutrients, but in a degraded state (for example through ditching and draining) they can become a source of pollutants, whilst also losing the ability to regulate flows (Mainstone, Hall and Diack, 2016).

Healthy peatland habitats act as sponges, retaining large volumes of water that build up through winter when evapotranspiration is low. These stocks of water are then slowly released through the summer providing reliable sources of water for rivers. However, in the past many peatlands were drained for agriculture and the harvesting of peat soils for use as fertiliser or fuels. For many sites, these past activities have been abandoned, but the drainage infrastructure is still present. The removal and remediation of these structures can allow the peatland to recover and function naturally.

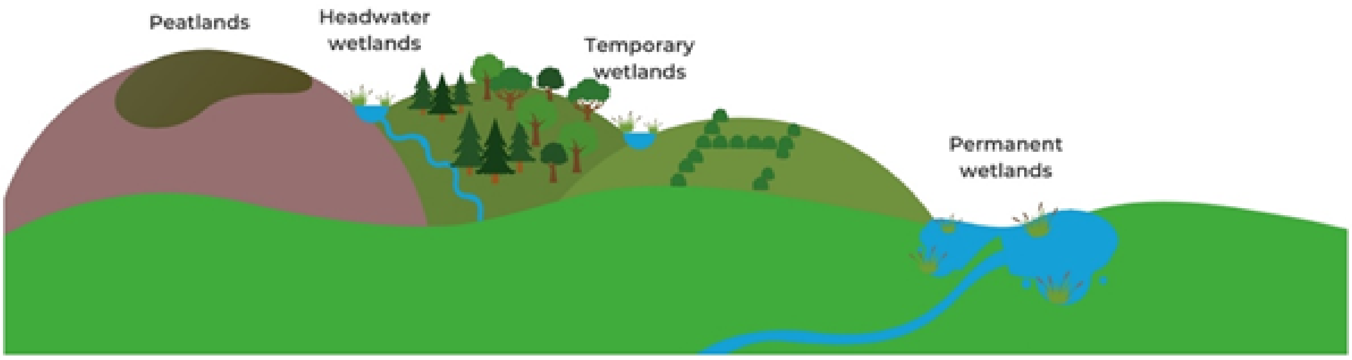


Figure 57. Different types of wetlands would naturally occur in many parts of the landscape and have different functions in the hydrological cycle.

Small scale temporary wetlands have long been viewed as problematic in terms of agricultural production and, consequently, have been subject to land drainage or infilling (Acreman and McCartney, 2009). Without artificial drainage, temporary wetlands would occur at many locations in upstream (dry) valleys and landscape depressions and would provide infiltration to groundwater or interflow. These sites are dependent on local interflow and run-off dynamics. Periods of excess precipitation can lead to temporarily waterlogged conditions. Instead of draining these sites, water should be left to be retained locally until infiltration is achieved. Restoration of hydrological functioning can be achieved through active management of the drainage system, reversal of drainage and/or installing retention ponds.

RIVER RESTORATION

Lowland river systems and their connected floodplains and valley bottom wetlands would naturally retain water permanently, but they are often impacted by drainage and channelisation. Floodplain wetlands act as sponges and can maintain river base flows during drought periods. In the past, a lot of streams were straightened to increase the rate at which water was removed, reduce local flood risk and increase the uniformity of agricultural parcels. This river channelisation negatively affects the hydrological and ecological functions of the river. It can result in a disconnection to the floodplain losing biodiversity and ecosystem services, the loss of riverbed substrate through scouring, a loss of structure and diversity of in-channel habitats and species, and an increase downstream flood risk as greater volumes of water are travelling a greater velocity during extreme precipitation.

River re-meandering and floodplain restoration does not only alleviate downstream flooding, but also has the potential to increase rivers resilience to droughts or extended dry spells. Subsoils in the floodplain can store a lot of water, ensuring it remains available to the ecosystems above Figure 58. Re-alignment of channelled pathways result in a significant increase in sinuosity (the extent to which rivers meander). In addition, the groundwater level may rise because of the increased route length, allowing weirs to be removed. The reduced channel capacity of re-meandered sections supports the natural hydro-morphological process that establishes variations in velocity and form of flows. Restoration of the channel form will also reconnect the river to its floodplain resulting in an increased flood frequency and inundation of the floodplain. Usually the flow rate will decrease, especially in the upstream areas of the restored watercourse. The most drastic consequences of a change in a watercourse, whether natural or forced, are an increase in its total length. As a result, peak flows at certain geographical locations in the river will be reduced as the volume is spread over time, which will reduce the risk of flooding.

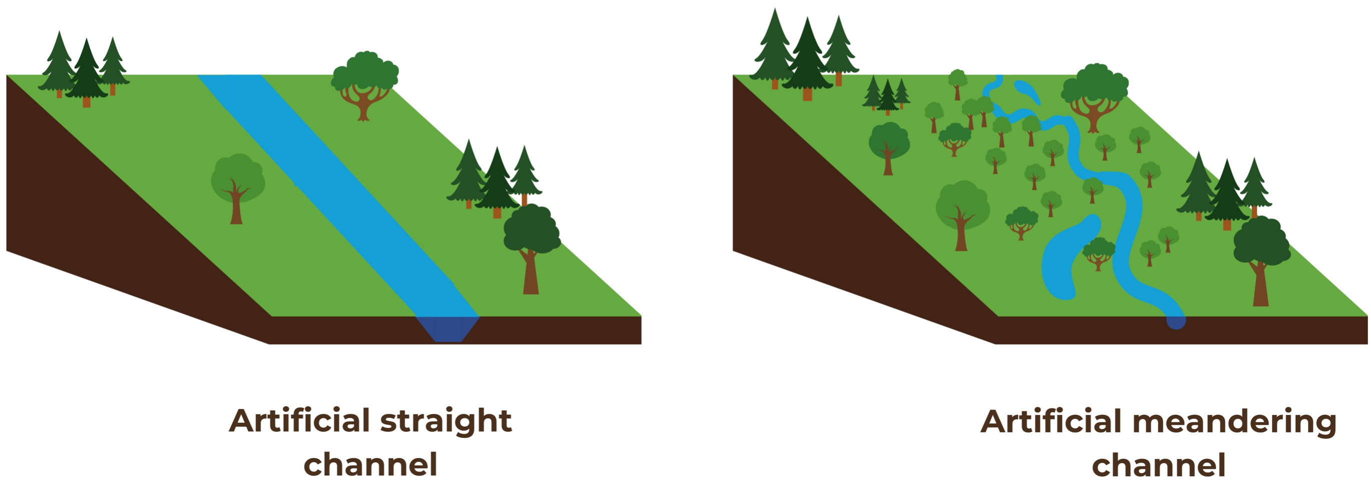
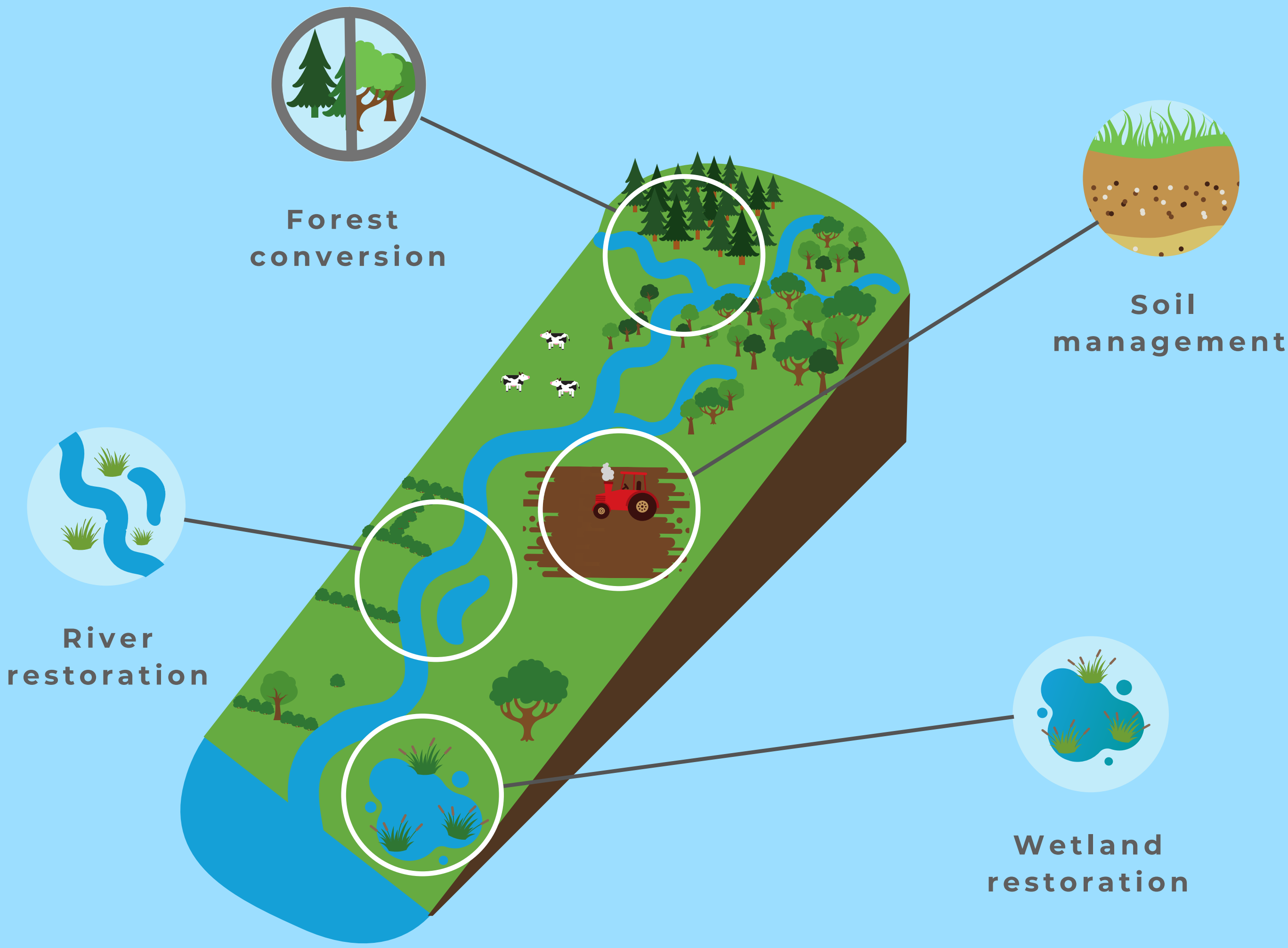


Figure 58. Diagrammatic sketch of restoration of the river meandering characteristics (adapted from Pan et al. 2016)

KEY MESSAGES

- EbA measures are a crucial complimentary building block to their existing resource plans, providing increased resilience to water supply in the form of increased water infiltration and retention, as well as many other benefits to catchments and to their customers

- EbA measures should be considered as a crucial cornerstone of sustainable water management and climate change adaptation, alongside other approaches such as demand management and regional water transfers, whilst also demonstrating the multiple benefits EbA measures provide through additional ecosystems services.



KEY MESSAGES

Forest conversion

- Coniferous forests intercept more rainfall than deciduous forests, heathland and grassland and can reduce the amount of rainfall that reaches watercourses and aquifers.

- The relationship between trees and water is complex and they can be beneficial or detrimental to infiltration and retention of water depending on the existing natural capital present.

- Woodland creation is also an important measure for reducing flood risk. Tree planting can help reduce peak flood events during extreme rainfall.

- Additional ecosystem services include carbon storage, erosion prevention, biodiversity and often recreational benefits.

Soil management

- Healthy soil drains, stores and filters water, improving food security and our resilience to floods and droughts.

- Additional ecosystem services provided by healthy soil include water purification, carbon storage, nutrient cycling and storage, erosion prevention, climate regulation.

Wetland restoration

- Wetlands play an important role in the hydrological cycle and can support groundwater recharge, augmenting low river flows and reducing flooding.

- Additional ecosystem services provided by wetlands include water purification, nutrient cycling and storage, erosion prevention, carbon storage, climate regulation and recreational benefits.

River restoration

- River restoration is an important measure to mitigate the effects of climate change. Heavily modified rivers are often less resilient and have lost their ability to hold water in both droughts and floods.

- Restoring rivers to their natural form can provide multiple benefits including improvements to water quality, biodiversity, water supply security, reductions in flood risk and pollution and recreational benefits.

OPPORTUNITIES FOR ECOSYSTEM-BASED ADAPTATION MEASURES

CASE STUDY: THE RIVER BEULT (MEDWAY CATCHMENT)

The Beult is a PROWATER demonstration catchment. It is a tributary of the Medway river with a catchment area of 270 km2, and is the only riverine SSSI in the county Figure 60. With a baseflow index of 0.41, the Medway is mainly influenced by surface water runoff, although some baseflow is contributed by flow from the Greensand in the South West of the catchment. The catchment also overlies the chalk aquifer in the North East, where most groundwater abstraction occurs. Mean annual rainfall across the catchment is 750 mm, and potential Evapotranspiration is 522 mm (70% of rainfall return to the atmosphere instead of becoming stream flow). This translates to an average flow in Medway at Teston of 10.976m3/s. The Medway catchment is likely to see overall increases in winter flows, but decreased spring and summer flows of up to 50% by the 2050s, as well as decreased autumn flows (based on Future Flows datasets). Flows in low flow events could reduce even further (4 out of 11 scenarios showing a decrease).

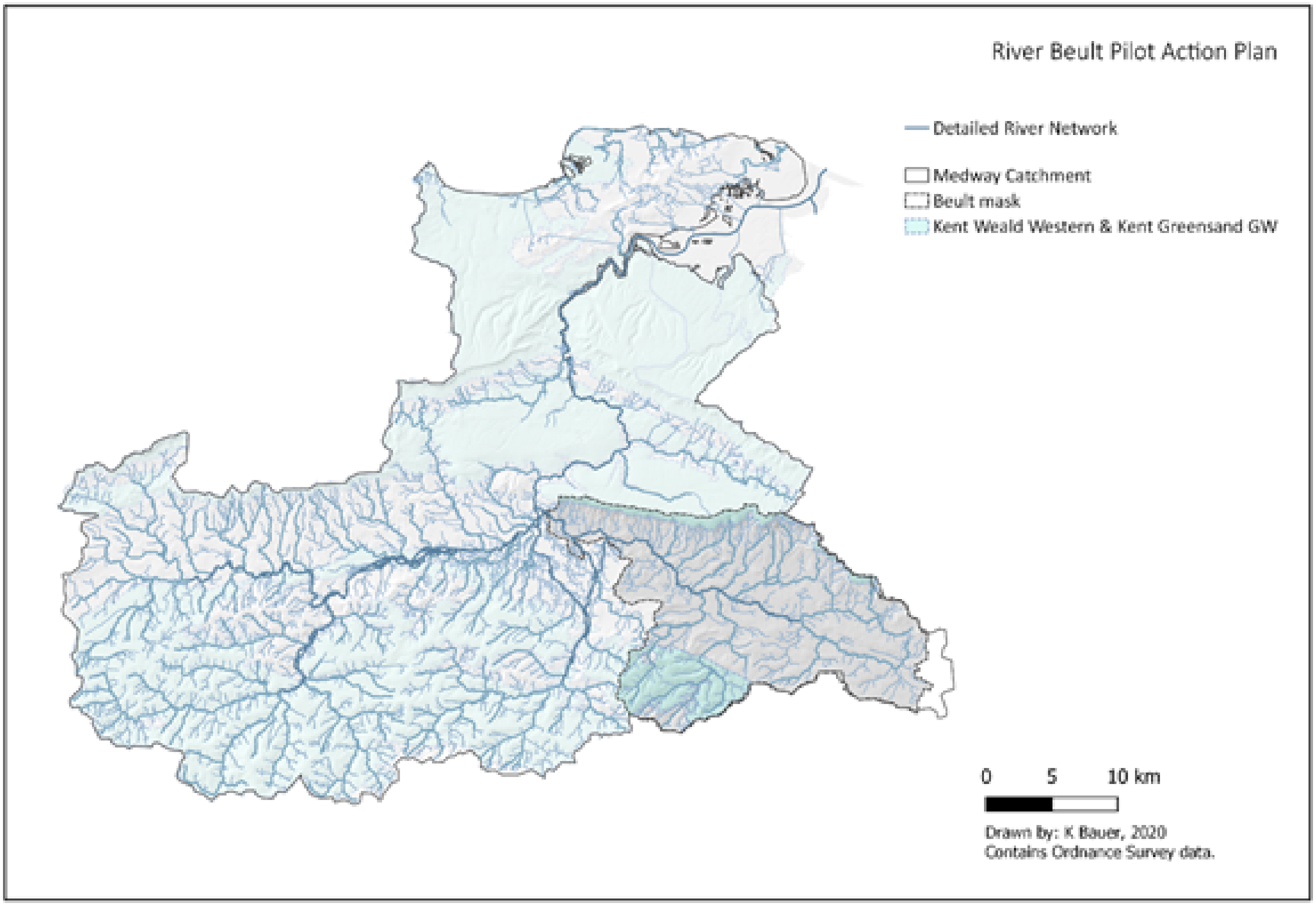


Figure 60. The Beult is a tributary of the Medway catchment in South East England.

The river Beult consists of 10 sub-catchments, only one of which is in good condition (WFD classification). During low flows, 0.06 m3 of water flow through the channel per second, while mean flows are 2.701 m3/s, demonstrating the range of flow conditions possible in this flashy catchment. Low flow events have increased over the record period (1958 onwards). Between 1958 and 1968 there were 173 days with flow levels below the Q95 (the flow exceeded 95% of the time, at 0.06m3/day) and 366 days for the most recent period of 2008-2019 Figure 61.

The main channel of the Beult, although designated as a SSSI, is heavily incised and impounded channel disconnected from its floodplain and restricted in connectivity especially at low flows. Six stop board structures in the channel control water levels. Degraded riparian vegetation and a lack of trees increases diffuse pollution and riverbank erosion. The channel provides limited structural and habitat diversity due to modification that has left it over-deep and over-widened. Impoundments alter the flow preventing the natural hydromorphological processes from shaping the river and impact water quality and sediment transport downstream. Water quality is impacted by a build-up of silt and high phosphate levels from sewage treatment works, exacerbated by low flows and high temperatures in the summer. **Introducing wetlands and reedbeds as well as healthy riparian systems can improve water quality, while narrowing the main channel can raise water levels restoring hydromorphological processes. Regrading the floodplain could additionally provide flood management benefits.**

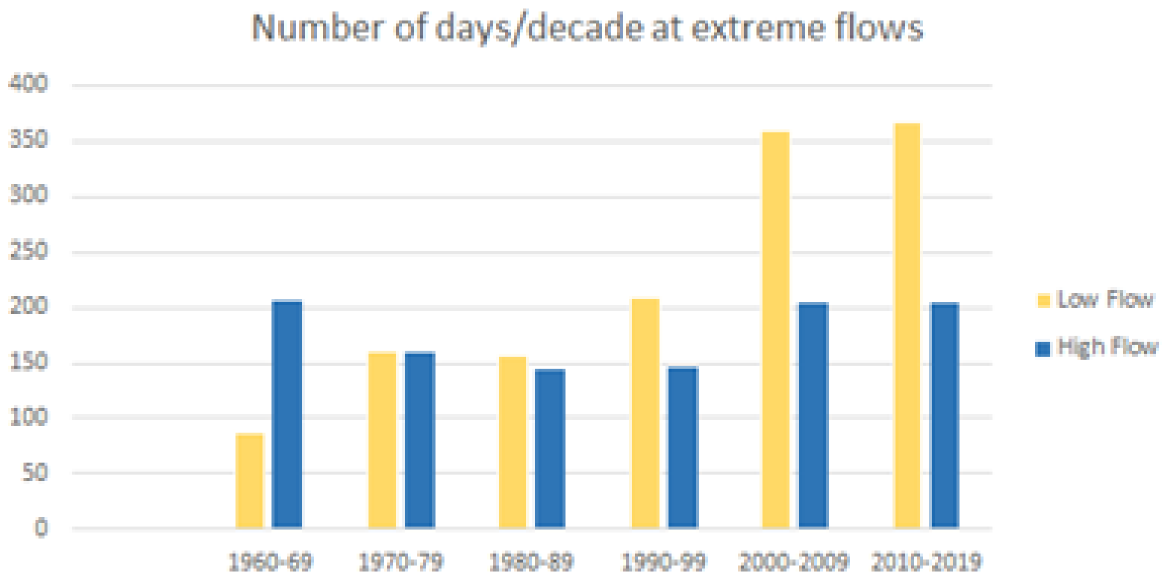


Figure 61. Days of recorded daily flows at extreme flow volumes (extreme in this case means that volumes are likely only above/below this 5% of time). Low flows show an increasing trend already, while high flows are less clear. In the period between 2010 and 2019, 366 days were recorded at low flows, with only three years (2010, 2013 and 2014) recording no low flows. While this cannot directly be linked to climate change, low flows are becoming increasingly likely and climate change will exacerbate the impact of low flows on the ecosystem (National River Flow Archive).

The slowly permeable clay soils provide little storage capacity in the catchment. As a result, the surface water network is dense, with many areas artificially drained to increase productivity of the landscape, increasing the risk of diffuse pollution from overland or drainage flow and the vulnerability to dry periods.

Organic matter content in the dominant type of soil here has been reducing both under arable and grassland management, reducing the ability of the soil to infiltrate and retain water. The heavy soils of the catchment, combined with gentle slopes, provide low soil erosion risk but soil capping and compaction are of greater concern. Soil erosion can become an issue on poorly managed soils on steeper slopes (such as in the north of the catchment) and under certain crops (such as maize). Compaction is a risk especially during wet periods, leading to structural damage to the soil and further increasing surface runoff and diffuse pollution. Climate change is increasing the risk of significant surface runoff and diffuse pollution as periods of wet weather are increasing in intensity and duration. Increasingly drier summers will dry out soils, reducing yields from grassland and arable crops, and increase the risk of flash flooding in intense summer storms as dry soils are unable to infiltrate water.

Soil management to build up organic matter, improve soil structure and reduce the amount of time soil lies bare could reduce surface runoff and allow more water to be held in the soil. This could reduce flood risk to settlements such as Smarden and Staplehurst, from short but intense rainfall. The increased ability of soil to store and retain water makes grass- and cropland more resilient to drier summers, and prevents loss of agricultural land.

Agricultural drainage ditches and underdrains are common throughout the catchment. Wetland ecosystems (such as fens, marshes, wet woodland and open water) are key in regulating flows and water quality, but only account for 1.3% of the catchment area. Ponds, however, are a key feature of the landscape historically and many ponds have been restored through grant schemes. Focusing specifically on the low-lying zones around headwater streams which could naturally have been expected to be wetland habitats, 7% are neutral grassland, 2% open water and less than 1% fen/swamp habitats, with the vast majority being managed as improved grassland and arable land (40% and 34% respectively). This indicates a significantly reduced ability of the catchment to retain and regulate flows and water quality through naturally functioning headwater areas. Headwaters, due to their smaller size, are particularly vulnerable to climate change.

Woodlands are likely to be most affected by summer droughts, especially on clay soils, which could make them more susceptible to pests and change the species composition of woodlands and hedges. Wet woodlands could disappear faster as succession to dry woodlands is sped up. Drier summers will impact the species composition of the landscape, putting trees such as oak and willow at risk.

Natural habitats like this can act as buffers and could mitigate increased risk of diffuse pollution, as well as create additional retention areas. Woodlands, grassland in good condition and hedgerows increase infiltration and further regulate flows. More diverse, better connected habitats additionally provide better opportunities for pollinators, which is likely to benefit horticulture. Reducing artificial drainage, for example by blocking drainage channels could mitigate drought risks for woodland and wetland habitats. Retaining more water within the catchment will buffer high and low flows.

There are no abstractions within the Beult catchment for public water supply. The main abstractions are for irrigating agricultural and horticultural crops. However, the Beult contributes to a public water supply abstraction point on the main river Medway downstream at Teston, which in turn feeds Bewl Reservoir. The catchment is a drinking water safeguard zone, with pollution from pesticides impacting the use of water for public water supply. Drinking water within the Beult catchment is supplied by South East Water from their Water Resource Zones (WRZs) 6, 7 and 8. WRZs are areas that have their own supply network and mainly depend on local water sources, although transfer water between zones is possible as required. The southern part of the catchment is mainly covered by WRZ 7 which is supplied with water from Bewl Reservoir (to which the Beult contributes) and a number of local groundwater sources. The northern part of the catchment is covered by WRZ 6 where the water sources are predominantly boreholes in the chalk and greensand aquifers. WRZ 8 covers the extreme east of the catchment where supplies came from chalk groundwater sources. In all three WRZs, demand in a dry year is expected to be higher than available supply by 2025. Especially WRZ 7, where 47% of water are supplied from surface water, is expected to be significantly influenced by climate change (South East Water, 2019).

Sewerage systems in the Beult catchment are made up of nine small sewage treatment works each with a catchment serving an individual town or a group of villages. As with many parts of rural Kent, there are also numerous properties that are not connected to the sewerage network and depend on septic tanks for the disposal of wastewater. Private as well as public sewage treatment contributes to poor river health through increased nutrient input, with waste water treatment effluent contributing up to 75% of flow during low flows.

The main pressure on water supply systems is increasing population coupled with uncertainties about how household water use will change in response to water saving messages. Groundwater sources are expected to be relatively resilient to climate change as they are dependent on recharge that almost entirely occurs in winter months as a result of winter rainfall which is expected to increase.

Increasing the extent and condition of the natural assets identified above, such as healthy soils, wetland habitats and woodlands on a catchment scale will increase the resilience of the catchment to climate change. In turn, water resources will benefit from a more stable, cleaner supply that can respond better to weather extremes. Table 7 summarises key assets and their connection to water resources.

Credit: FlickrCC Natural England

Table 7. Important natural assets in the Beult Catchment and connected opportunities for using EbA measures to increase the resilience of water resources.

Natural Asset (baseline)	Impact of Climate Change	Impact on Water Resources	Opportunity for Ecosystem-based Adaptation
Soils: mostly heavy, slowly draining clay soils with no groundwater body	Hotter, drier summers dry out soils, Intense rainfall (runoff) Wetter winters leave areas waterlogged for longer	increased risk of polluting watercourses due to runoff Reduced availability of water for plant growth	Soil management to increase organic matter and improve structure can reduce runoff rates and
Streams and wetlands: Extensive surface stream network and ponds, few wetlands Main channel (SSSI)	Flows decrease in the summer, and low flows occur more often Change in species composition Further impact on SSSI already suffering from low flows and nutrient input	Reduced water availability Increased pollution due to runoff and low dilution capacity Increase in flashy flows due to low retention capacity	Restoration of headwater wetlands and floodplain wetlands and buffers Reconnection with floodplain Increased connectivity
Agricultural land: Mainly pasture and cropland, some horticulture	Increase in drought Increase in winter flooding	Loss of yield due to reduced growth Loss of quality due to lack of water Reduced period of accessibility Potential increase in pesticide use due to new pests emerging	Improved soil management to increase retention and infiltration capacity Increase in on farm water storage
Woodlands and hedgerows	Change in species composition	Reduced infiltration & retention in the landscape increasing flashy flows and flood risk if trees lost	Increase connectivity Wet woodland restoration Hedgerow restoration

Figure 62. Overview of different Ecosystem-based Adaptation options and where they can contribute to water resource in a landscape like the Beult catchment.

CASE STUDY – THE LITTLE STOUR & NAILBOURNE (KENTISH STOUR CATCHMENT)

The Little Stour, one of the 3 PROWATER pilot areas in South East England, is a tributary of the Great Stour Figure 63, draining the East Kent Chalk, with groundwater contributing approximately 80 % to river flow, and so is a good example of a groundwater dominated chalk river (Wood, Agnew and Petts, 2001). The Great Stour catchment covers an area of 1 081 km2, with an average annual rainfall of 754 mm (73 % of rainfall lost to ET). While the headwater is surface water dominated due to a greensand and clay geology, it flows across the East Kent Chalk for the lower part of its course.

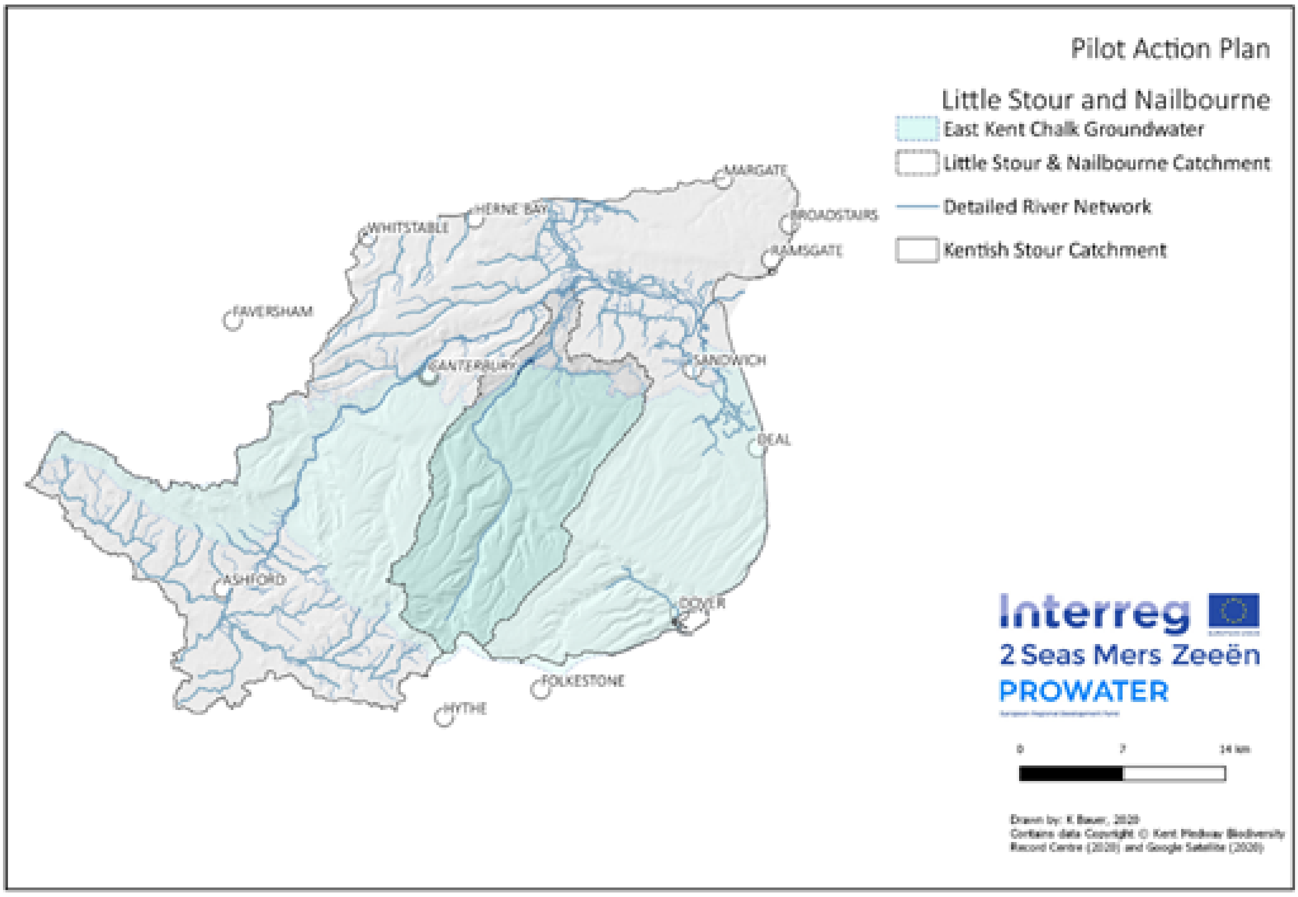


Figure 63. The Little Stour and Nailbourne Catchments are part of the Kentish Stour catchment, which overlies the East Kent Chalk aquifer.

The effective rainfall in the Little Stour catchment, i.e. the proportion that recharges the groundwater body and contributes to streamflow, comes to approximately 316 mm per year (BGS, 2008). The channel of the Little Stour has been heavily modified and straightened in the past. Low flows are an issue in the catchment, but groundwater flooding also presents a key concern to communities.

Over the decades between 2000 and 2019, the average annual volume of total freshwater resources across the catchment (based on the Environment Agency's effective rainfall data) amounted to 302.4 million m3/year. Assuming abstraction of 20% of the annual freshwater available is the limit before a catchment becomes water stressed (based on the thresholds provided by the Water Exploitation Index, where 20% exploitation indicate water stress and 40 % serious water stress), this leaves 60.3 million m3 of water available for human use in the catchment per year.

Abstraction for public water supply is impacting levels in the groundwater body, leading to low flows in the Little Stour already. By 2050, abstraction will be reduced by 30 000 -100 000 m3/ day due to environmental protection and climate change (EA, 2020 – Environmental Ambition Document). The East Kent Chalk is an important source for drinking water and across the whole Stour catchment all water abstractions for public water supply, which make the vast majority of abstractions, are from the chalk aquifer. The remainder are mainly for agriculture and industry and comprise both groundwater and surface water abstractions with the latter mainly focused within the low-lying marshes in the North East of the catchment. Southern Water (SW), Affinity Water (AW) and South East Water (SEW) each serve part of the Little Stour and Nailbourne catchment although SEW are only responsible for a small area to the west of the upper Nailbourne and their main local abstraction is from boreholes at Kingston. SW has the largest abstraction in the sub-catchment, this is from a highly productive borehole with extensive adits (underground channels increasing yield of water) and is situated between Adisham and Wingham and is vulnerable to groundwater drought and nitrate input. Nitrate and pathogens are common issues across the catchment and, in the case of nitrate, often due to historic inputs that are still travelling through the chalk.

Climate change will decrease recharge to the chalk, which could lower flows in the Little Stour and Nailbourne and lead to less water being available for abstraction. The Great Stour catchment overall is likely to have higher winter flows (10%) (Prudhomme et al., 2012) and lower summer and autumn flows while the Little Stour could behave slightly differently and be more resilient to dry summers as a higher proportion of its flow comes from groundwater sources. Low flows however, could increase or at least remain stable (Prudhomme et al., 2012). The chalk aquifer itself could experience reduced recharge by the 2050s by 4 - 37% in the future (Mansour and Hughes, 2014). Models for a high emissions scenario for Little Bucket Farm, a groundwater borehole in the Little Stour, show a decrease in groundwater levels in almost all scenarios, except for February, which could experience an increase in recharge one in four years. Levels could be 1.43 metres lower over the year (median), with reductions of more than 3.7 metres in spring possible every one in four years.

Higher temperatures and drier weather impact soil organic matter. On steep slopes, intense rainfall events increase erosion risk, in turn increasing runoff and associated pollution. The main soil types in the Little Stour catchment are shallow lime-rich soils over chalk, which are potentially particularly vulnerable to loss of soil organic matter even under permanent grassland (Emmett et al 2010). While the main part of the catchment is overlying the chalk aquifer, hilltops especially in the south of the catchment are covered by superficial clay deposits which limit recharge. These deposits enhance runoff and where they meet the underlying chalk – often on chalk slopes with thin soils. Erosion risk is increased on the more permeable soils in the catchment especially on the steep slopes (>3 degrees), but they are less vulnerable to compaction. This is exacerbated where poor land management practices leave the soil bare. Leaching of nutrients and pesticides to groundwater is a particular problem and already impacts the drinking water supply. **Introducing attenuation features on slopes, buffer strips and improving soil management can support levels of organic matter and improved soil structure, reduce runoff and in turn improve water quality draining to the aquifer.**

Large parts of the catchment could turn from good to moderate or poor agricultural quality due to drought risk. Soil moisture already is a limiting factor on yields and decreasing organic matter increases drought risk, especially on the shallow soils over chalk. The area will become less suited to agriculture as it is today, with new crops such as vines, maize and olives being more suited to the expected climate in 2080. Soil management measures will also increase the resilience of agriculture.

Land cover change, especially from arable to grassland or grassland to forest could impact recharge across the catchment. Recharge modelling comparing different scenarios of land use change for the Stour showed decreased recharge if 50% of grassland was converted to arable land, and highest reductions from conversion of grassland or arable to forest. Conversion of arable land to grassland resulted in increased recharge, with smaller impacts from conversion of forest to arable and forest to grass (Mansour and Hughes, 2014). **Chalk grassland is relatively resilient to climate change impacts, and healthy areas already exist across the catchment and could be expanded to increase connectivity and protect recharge quantity and quality.**

Adapting management of the landscape presents a range of opportunities to increase resilience to the impacts of climate change. Soil management measures such as cover crops or reduced tillage can improve soil health and organic matter, especially in locations at higher risk such as slopes and thin soils. Conversion of coniferous forests on deep soils, or change to chalk grassland, could increase recharge and improve quality of water draining to the aquifer. Finally, restoring the main river channel to increase diversity and naturalise flows enhances natural function of the channel and supports the ecosystem in low flows while also creating higher retention capacity in the channel.

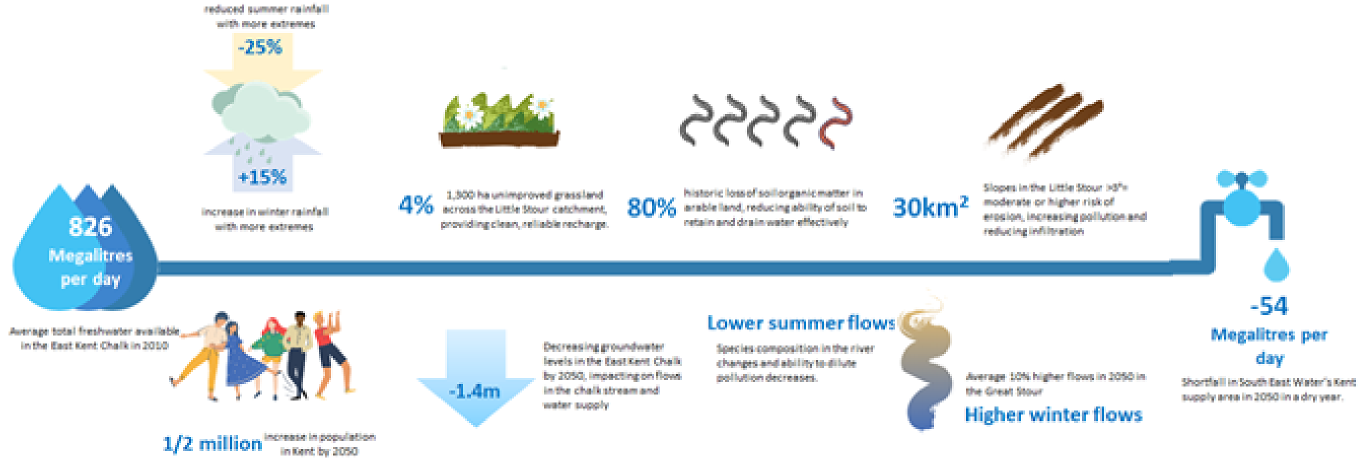


Figure 64. A summary of pressures from climate change, degradation of natural capital and demand on the supply demand balance for the Stour area.

Figure 65. Overview of different Ecosystem-based adaptation options and where they can contribute to water resource in a landscape like the East Kent Chalk catchments.

CASE STUDY – THE NETE CATCHMENT (CAMPINE REGION, FLANDERS)

The Scheldt basin has a total area of 21 000 km² situated in three different countries. The main part of the Scheldt basin is situated in Flanders and the Nete basin is one of the 9 sub-basins of the Scheldt River. The Nete basin, with a total surface of 1 673 km², has an average population density of 180 inhabitants/km² and a total length of 2 224 km of streams. The main part of the basin is situated in the province of Antwerp, close to the Dutch border.

Figure 66. The Nete catchment situated in the Flemish Region.

The mean average annual precipitation generates approximately 1500 million m³ per year. The average annual flow at the basin endpoint is about 388 million m³ (approx. 12 m³/s) with relative low variation over the years (1990-2000). The flow variation on a daily basis can vary significantly due to heavy rainfall run-off, sewage overflow events, industrial discharges and dam control (agriculture and traditional water mills). The basin is crossed by 165 km of canals that have distributed infiltration and seepage interference with the basin. The estimated canal seepage and irrigation losses are estimated between 75 and 110 million m³ per year. The estimated effective groundwater abstractions for the whole basin are about 71 million m³ but are licensed up to 120 million m³. Abstractions for drinking water production are licensed up to 80 million m³. The actual abstraction is estimated to be about 40 million m³. Industrial discharges range around 110 million m³ per year of which over 50 % can be ascribed to sewage treatment plant effluents. The sewage treatment plant investments of the 90's re-enabled macrophyte growth by their effect on the turbidity-levels as suspended solids are very efficiently removed by the treatment plants. As the limiting factor of light disappeared and the nutrients levels remained, an abundance of macrophytes appeared. In periods of low flow with intensive growth, their massive presence influences flow resistance and water tables. Consequently, this may cause problems in subsequent periods of intense rainfall (e.g. summer storms).

The Nete basin has no cities with more than 50 000 inhabitants and has a relative low population density compared to the average of the Flemish region (350 inhabitants/km²). Nevertheless, there is significant urbanisation present. Spatially distributed urbanization spreads along the main exits roads from the town centres. Beside the increased runoff of water from roads and housetops, there is inflow of ditches and drainage-systems to the sewer infrastructure. This decreases treatment efficiency and sewage overflows during intense rainfall events and congestions during dry periods. Specifically, rainfall events that follow dry periods result in a significant load towards receiving surface waters. Artificial drainage of valleys, a loss of functional infiltration areas by urbanization, canalization of streams and the embankment and use of inundation areas has led to an increasing vulnerability for both desiccation and flood-events.

Soil-types in the Nete-basin

The Nete basin is a lowland river basin with a large percentage of alluvial plains (16.1%). The Nete basin has a fairly flat relief. The height within the Nete basin varies from 0 to ± 70 m TAW. The highest areas are located in the eastern part of the basin on the border with the Meuse basin. The sandy soil types originate from the last ice age when a permanent high-pressure area situated above the northern ice cap. The permanent and intensive winds that blew from the north brought along the deposition of large amounts of sand-particles. The relicts of these processes are still present in the form of parabolic land dunes. These land-dunes consequently brought about the main topographical variation within the flat basin. Historical flooding of the rivers has created wide and moist alluvial plains. Only a small percentage of these alluvial plains are in their original hydrological and ecological state. Most valleys have been embanked, drained and raised. The ongoing corrosion of natural floodplains has caused problematic flood risk downstream. Plain sand is the dominant soil type in the basin (85%). Looking at the soil-type distribution in detail we can see that almost 40% of the basin is characterised as moist or wet sand, of which a large proportion is drained for agriculture. The agricultural and horticultural sector occupies 32.8% of the area. Dairy farming is the dominant land use in the Nete basin with a relatively small amount of purely arable farms. But due to scale enlargement, the area of (permanent) grazing land is decreasing and replaced by fodder crops (maize). There is an increasing demand for irrigation due to more frequent droughts. Because there are abstraction bans from surface waters during low flow episodes, an increase in groundwater abstraction wells can be expected.

Impacts on water system

The Flanders Hydraulics Lab has modelled the 11 catchments in the Flemish Region using the MIKE 11 NAM module from DHI (De Boeck, Pereira et al. 2012). The NAM module of the MIKE 11 package is a lumped, conceptual rainfall-runoff model simulating overland flow, interflow and base flow. Although groundwater abstractions and irrigation can be considered in the NAM models, these aspects were not considered in the development of the catchment models for the Flemish Region. This can explain the difference between the modelled mean flow (18 m³/s) and the actual measured mean flow (approx. 12 m³/s) for the period 1990-2000. The catchment models were initially designed and calibrated for flood forecasting and are less suitable for low flow analysis. Nonetheless it is remarkable that the difference between modelled and measured flow is so high (6 m³/s - 33%). Due to gaps in the measured datasets, there is no long-term analysis of actual measured flows. Nonetheless, the modelled flows have been calibrated using actual flow data and show how large the patterns in flow variability actually are.

Opportunities for restoration

We can see multiple problems. There is a high abstraction pressure on the groundwater system and a general decline in groundwater levels. This implies a shift from the natural base flow (seepage) to an effluent based base flow. To overcome additional demands and climate change challenges we need more infiltration and less drainage. The modelled river flow data shows that on an annual basis, there is plenty of water. If only we could retain and store 20% of the winter season peak flow volumes into the groundwater reservoir, summer water scarcity could be completely avoided (6 m³/s * 6 months = 100 million m³).

The Nete catchment has lost about 7% (21 mm) of its potential infiltration capacity, of which 4% (12 mm) from pine plantation canopy interception and 3% (9 mm) from soil sealing. This equals a volume of 35 million m³ (which would equal a virtual flow of 2.2 m³/s during six months). Also, less drainage could help to decrease peak flows. Current retention losses amount to an average decline in soil water content of 60 litre/m² (an average 14 cm drop in groundwater levels). Restoring groundwater levels to their natural historical regimes for the whole catchment would equal a volume of 100 million m³ (which would equal a virtual flow of 6.3 m³/s during 6 months).

The Nete catchment is one of the most natural catchments in the Flemish Region and has a relatively high share of Natura 2000 sites. Because the water quality has remained good, many rare and sensitive fish species can still be found in the Nete basin. In the past decades, many groundwater abstractions have been licensed. During normal years the abstraction pressure is relatively balanced. However, in recent years this balance tends to over abstraction. Groundwater levels are too low and there is less base-flow in the streams. Surface water abstractions have been prohibited to protect endangered species, but this is no fundamental solution. Different project aims to apply a broad range of EbA measures, which include forest conversion (conifer forest to deciduous forest and heathland), wetland restoration (e.g. agricultural water level management through weirs in drainage ditches), river re-meandering and soil quality improvement (e.g. increase of organic matter content). The implementation of these measures is slow but steady and most of the measures are driven by nature conservation objectives. The re-meandering projects are for example mainly initiates to overcome fish migration barriers.

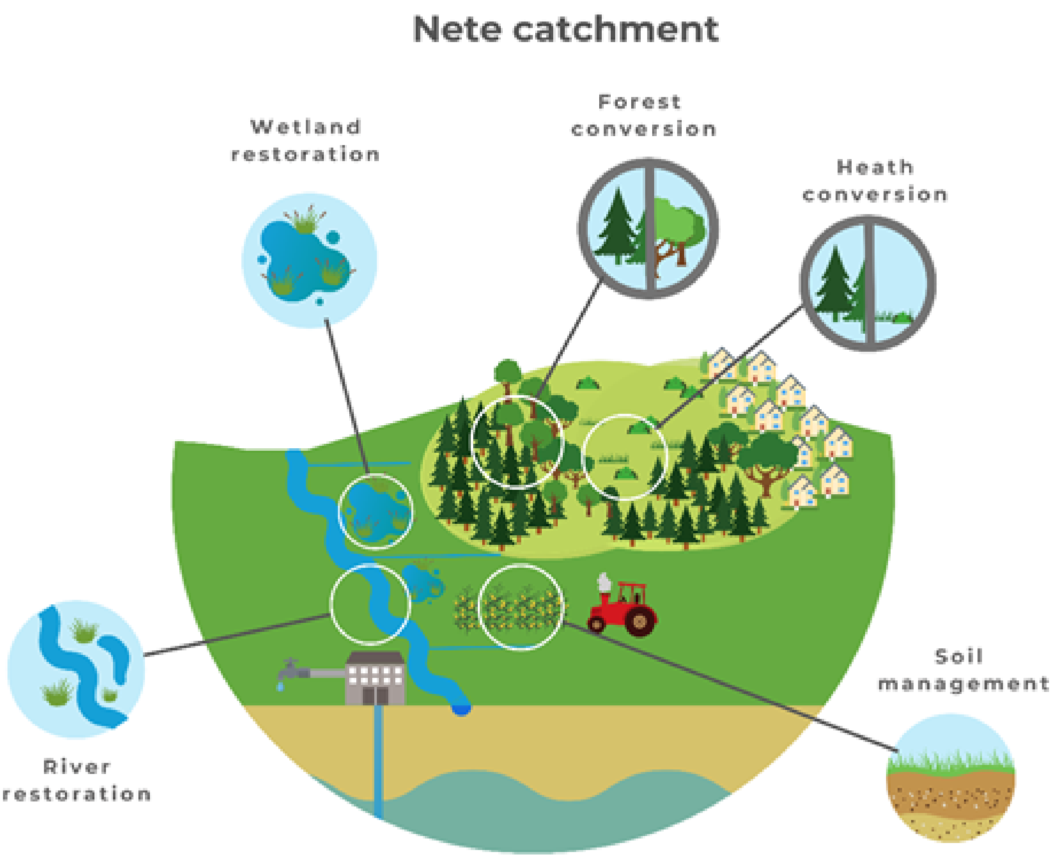
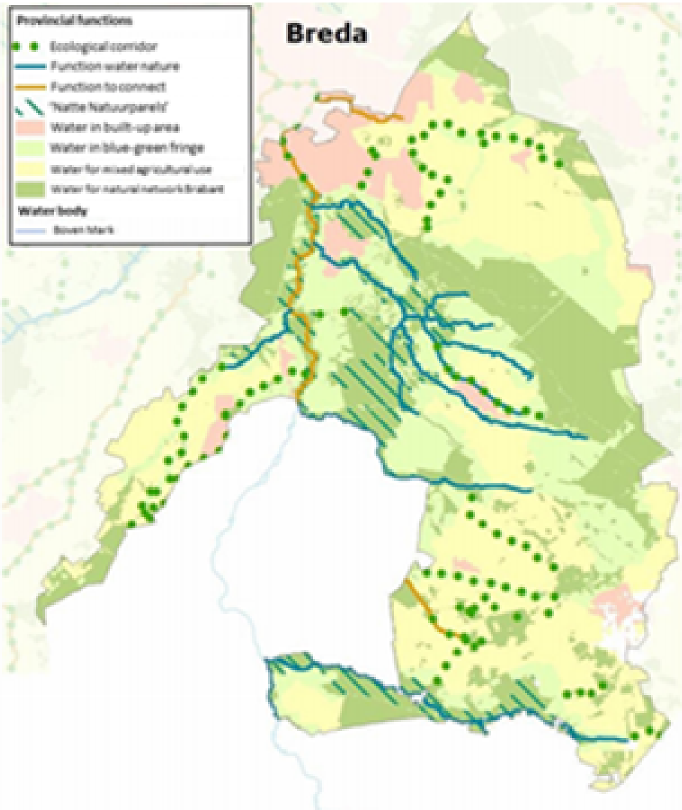


Figure 67. The Ecosystem-based Adaptation opportunities in the Nete catchment.

CASE STUDY – THE MARK CATCHMENT (NOORD-BRABANT, THE NETHERLANDS)

One of the catchments in the south of the Netherlands and a project site for the development of climate resilient water resources is the catchment of the “Boven Mark”. The Boven Mark originates in in Flanders and enters the Netherlands about 10 km south of the city of Breda (Noord-Brabant) Figure 68.



Characteristics Boven Mark	
Length (km)	14 (NL), 28 (BE)
Area Catchment (ha)	21,950 (NL)
Soiltype	Sand
Land usage	>50% agriculture
N2000	Ulvenhouts Forest
Drinkwater companies	Groundwater is abstracted near the city of Breda and from upper reaches Bavelse Leij and Merkske

Figure 68. Catchment area of the river Boven Mark and it’s characteristics in the Province of Noord-Brabant in the south of the Netherlands. ‘Natte Natuurparels’ definitie

The Boven Mark partly follows the border (3 km) between the Netherlands and Belgium and enters the Netherlands at the village Galder from which it moves northwards to end up in city waters (Singel) of Breda. The Dutch part of the waterbody consist of 3 km of border forming river and 11 km of river from the border up to Singels of Breda. The Dutch part of the river is characterized as a slow flowing river on sandy soil. In the 1960s, the river was canalised and three weirs were constructed. Since the 1990s, several restoration projects have been carried out including re-meandering the river and fish migration projects.

The Boven Mark has a yearly peak discharge of 23 m3/s and a spring discharge of circa 3.3 m3/s (table 1.). The annual peak discharge is about seven times higher than the spring discharge. The difference between peak discharge and spring discharge is considered large compared to a natural river discharge profile. The Boven Mark is thus known to have a strong peak-based discharge pattern. This results in dehydration of the upstream part of the river and limits the flood area for the storage of the peak discharge.

The Boven Mark is in the so called ‘Hogere Zandgronden’ in the Netherlands. The ‘Hogere Zandgronden’ are high-lying areas that have developed a surface of loose sand due to the absence of silt, mineral-rich river water and near groundwater. The supply of freshwater in the catchment of the Boven Mark is mostly dependent on precipitation.

Project Markdal river restoration

The project Markdal is working to restore the natural character of the river Boven Mark and the adjacent wetland. The aim of the project is to restore the natural waterflow and increase the groundwater level near the river.

At the time of writing the project has completed the concept design for the restoration of the Boven Mark and the final research questions are being worked out. Multiple measures are included in the project which will raise groundwater levels and limit flooding in agricultural and urban areas.

The measures include:

- Weir removal
- Re-meandering the channel
- Filling in drainage ditched and creating new river channels
- Implementing a level-controlled drainage system

Weir removal

The removal of weirs will result in structural changes in the water levels in Boven Mark. During winter and spring, the water level is expected to increase. During summer the concept design will result in lower water levels upstream from the two removed weirs and water level increase in the other sections.

Re-meandering the channel

The creation of new meanders will lower the groundwater level close to the river as groundwater levels rise as distances increase from the river.

Filling in drainage ditches and creating new river channels

At different locations in the project area waterways are filled in or new waterways are dug. Especially in the surrounding nature area, waterways are filled to increase groundwater levels. At other locations new channels are suggested to ensure the drainage of upstream areas.

Level-controlled drainage systems

Level-controlled drainage systems are included in the concept design to mitigate the increase of flood damage to agricultural fields. The implementation of this drainage system will result in lower groundwater levels during wet periods.

Expected outcomes

It is expected that this project will raise groundwater levels (GHG, GVG and GLG) within the Boven Mark. Where new meanders are dug and were the level-controlled drainage is implemented, this leads to lowering of the groundwater levels (GHG, GVG and GLG). Although, the GLG is barely influenced by the water level regulated drainage. Figure 70 shows the calculated changes in GHG as result of the measures in the concept design of the Markdal.

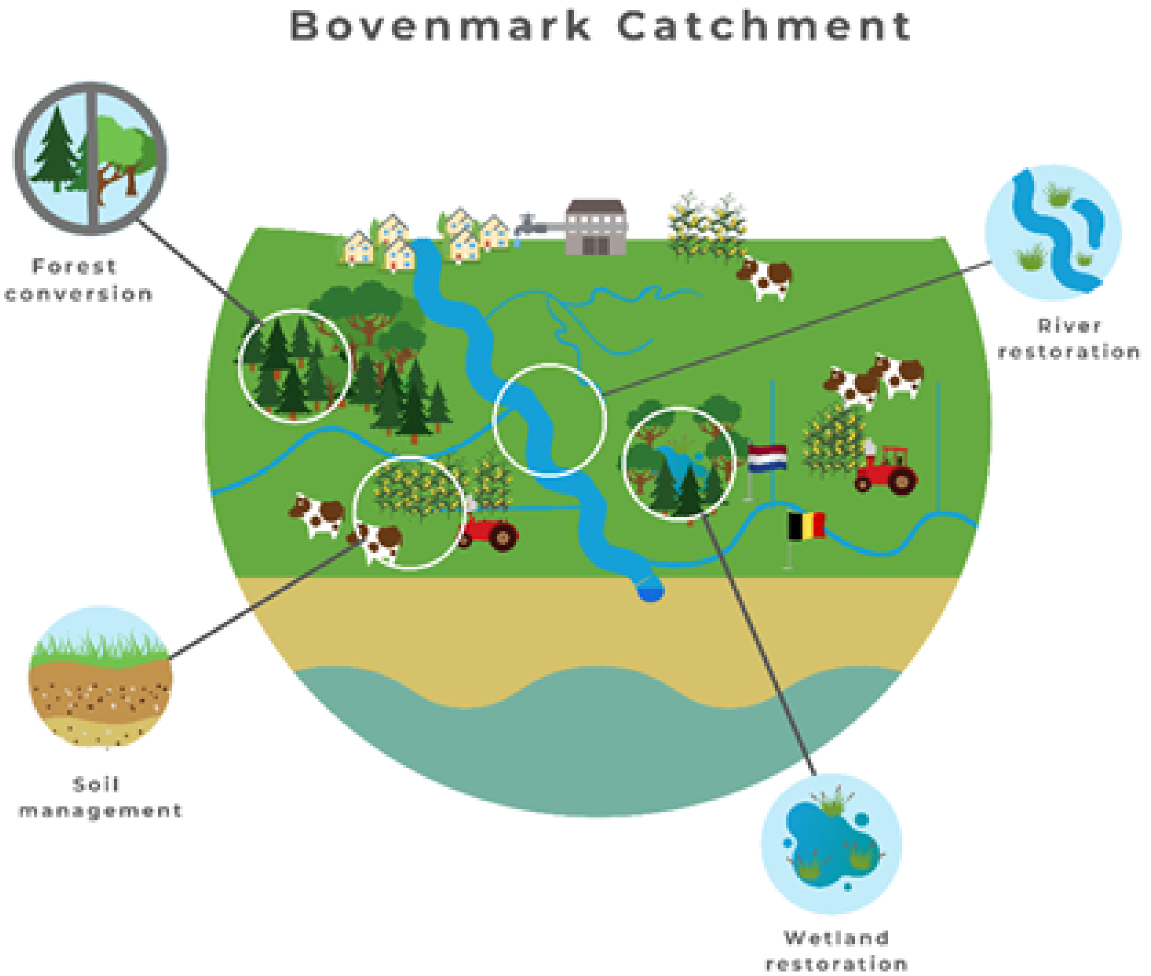


Figure 69. The Ecosystem-based adaptation opportunities in the Bovenmark catchment.

Project Bodem UP

Bodem UP is a program in which farmers and advisors work together on the jigsaw of profitable yields and preferable ecosystem functioning to among others reduce nitrate leaching into the groundwaters. Participation includes three or four farm visits a year. During which soil and feed samples are discussed, soil profiles are dug to evaluate soil structure and biological activity, and differences in chemical composition within a field can be analyzed using a handheld soil scanner. Based upon the outcomes of these visits the farmer and ZLTO-advisor choice a best practice measure to increase soil functioning. Examples of measures taking are: balanced fertilization instead of standard fertilization, promote catch and cover crops, reduce tillage and alleviate soil compaction. Currently, over 500 farmers in the province of Noord-Brabant are taking measures as part of BodemUP!

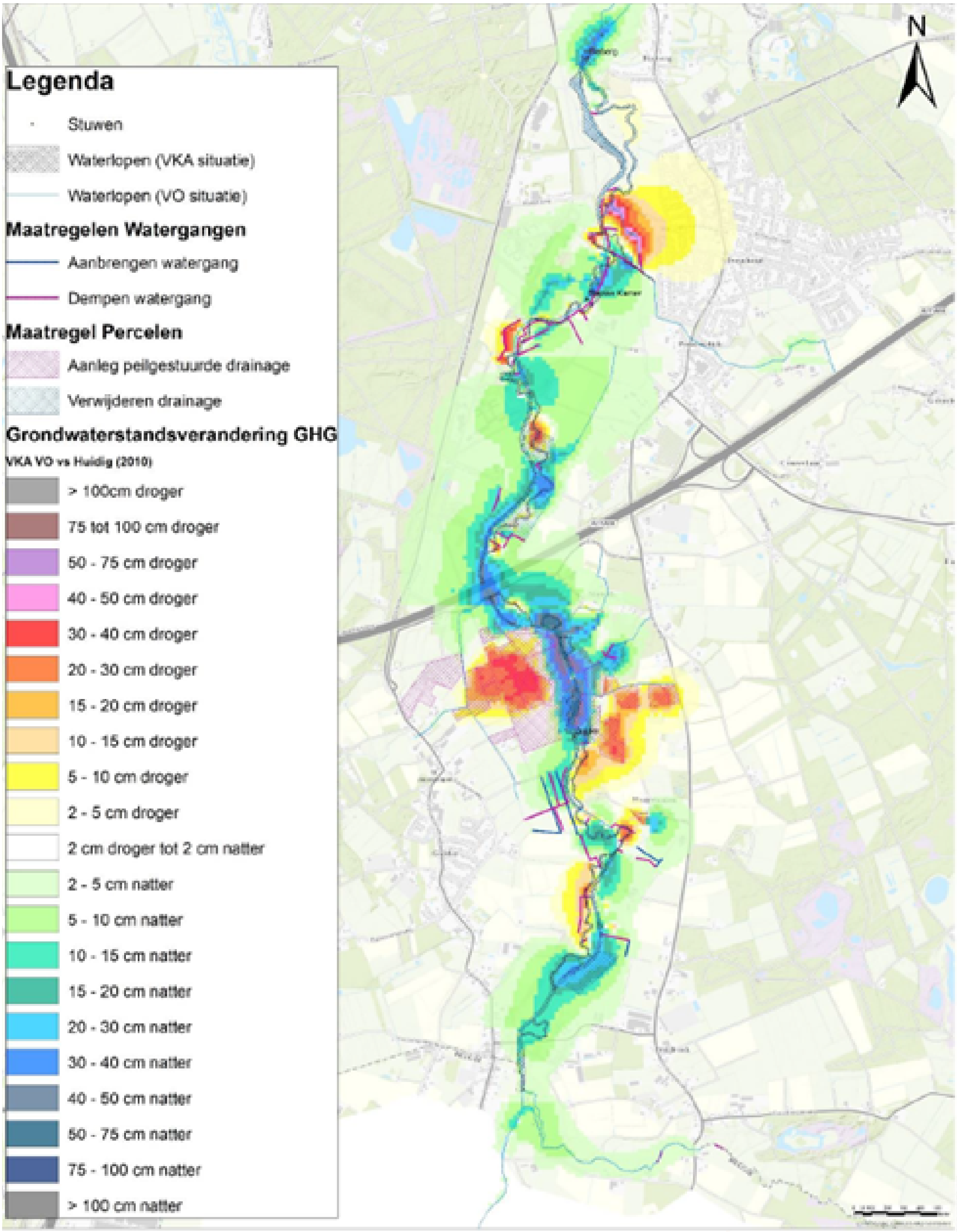


Figure 70. Expected changes in groundwater level (GHG) as result of the measures of the concept design of the project Markdal

CALL TO ACTION

Climate projections for northern Europe show less precipitation in summer and increasingly erratic rainfall leading to a greater risk of both flooding and droughts. These changes put increasing pressure on water supplies alongside population growth and increasing demand for water from industry and individuals. Sustainable management of water starts at the top of the catchment. While water industry resource management traditionally focuses on the optimal allocation of available water resources through supply infrastructure and demand management, PROWATER looks into opportunities to increase water availability through Ecosystem-based Adaptations (EbA). These are a type of Nature-based Solution designed specifically to reduce vulnerability and build resilience to climate change (IUCN). This report outlines the challenges facing water resources and advocates the use of EbA to work alongside more traditional resource management techniques. We need to mitigate the historic changes we have incurred and increase the resilience of our landscapes and habitats and provide practical solutions to the increasing issue of water scarcity that we face now and in the coming years. If we are committed to a future with clean and plentiful water for all we need to fund EbA schemes that promote a system where the landscape stores, cleans and delivers good quality water for us. Funding measures such as wetland creation, river restoration, conversion of conifer plantations to natural habitats and good agricultural soil management allows the natural movement of water through the landscape. This provides a steady supply of clean water for use by both people and the environment. The added benefits of EbA measures are that once you begin to consider the environment as an integrated system, outcomes do not stand alone. Measures to support water resources also benefit recreation, local economies, carbon storage and biodiversity.

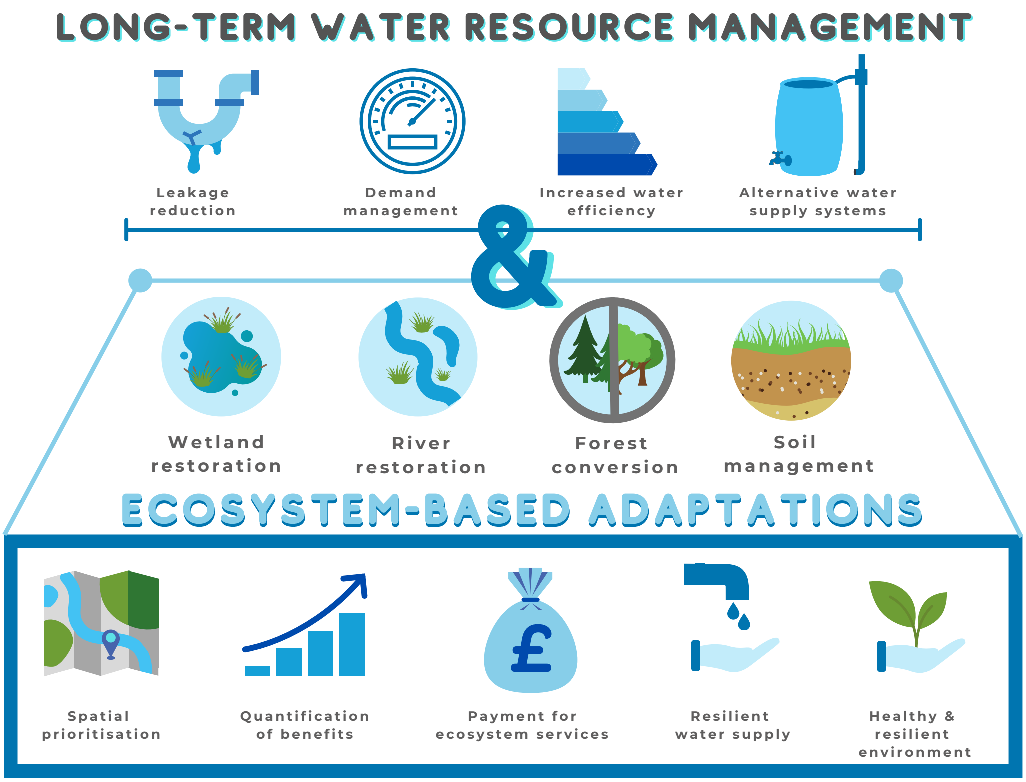


Figure 71. Long-term water resource management vision integrated into the Interreg 2 Seas PROWATER project (PROWATER).

REFERENCES

Acreman, M. et al. (2020) 'Protected areas and freshwater biodiversity: a novel systematic review distils eight lessons for effective conservation', Conservation Letters, 13(1). doi: 10.1111/conl.12684.

Acreman, M. C. and McCartney, M. P. (2009) 'Hydrological Impacts in and around Wetlands', in The Wetlands Handbook, p. 24.

Baguis, P. et al. (2010) 'Climate change scenarios for precipitation and potential evapotranspiration over central Belgium.', Theoretical and Applied Climatology 99(3-4): 286.

Bannister, N. (2007) The cultural heritage of woodlands in the South East With reference to the.

Basche, A. and DeLonge, M. (2019) 'Comparing infiltration rates in soils managed with conventional and alternative farming methods: a meta-analysis', PLoS ONE, p. 22. doi: 10.1101/603696.

Bastos, A. et al. (2020) 'Direct and seasonal legacy effects of the 2018 heat wave and drought on European ecosystem productivity', Science Advances. American Association for the Advancement of Science, 6(24), p. eaba2724. doi: 10.1126/sciadv.aba2724.

Bertassello, L. E. et al. (2018) 'Wetlandscape Fractal Topography', Geophysical Research Letters, 45(14), pp. 6983–6991. doi: 10.1029/2018GL079094.

BGS (2008) 'The Chalk aquifer of the North Downs', Research Report, p. 73.

BGS (2019) Current UK groundwater use | Groundwater resources in the UK | Water resources and groundwater | British Geological Survey (BGS), BGS.ac.uk.

Boardman, J., Evans, R. and Ford, J. (2003) 'Muddy floods on the South Downs, southern England: Problem and responses', Environmental Science and Policy. Elsevier BV, 6(1), pp. 69–83. doi: 10.1016/S1462-9011(02)00125-9.

Boukhris, O. E. F., Willems, P. and Vanneuville, W. (2009) The impact of climate change on the hydrology in highly urbanised Belgian areas, Water and Urban Development Paradigms. Edited by J. Feyen, K. Shannon, and M. Neville. Boca Raton: Crc Press-Taylor & Francis Group.

Brouwers, J. et al. (2009) Hoofdstuk 11: Klimaatverandering en Waterhuishouding (pp. 283-304) in: Van Steertegem M. (red.), Milieuverkenning 2030, Vlaamse Milieumaatschappij, Aalst.

Brouwers, J. et al. (2015) 'MIRA Klimaatrapport 2015', p. 152.

Brown, I. et al. (2016) UK Climate Change Risk Assessment Evidence Report: Chapter 3, Natural Environment and Natural Assets.

Coördinatiecommissie Integraal Waterbeleid (2018) Evaluatierapport droogte 2017. Available at: https://www.integraalwaterbeleid.be/nl/publicaties/afbeeldingen/evaluatierapport-droogte-2017/view.

Coördinatiecommissie Integraal Waterbeleid (2019) Evaluatierapport waterschaarste en droogte 2018.

Coördinatiecommissie Integraal Waterbeleid (2020) Evaluatierapport waterschaarste en droogte 2019.

Copernicus Land Monitoring Service (2018) 'CLC 2018 Land Cover'. CLC. Available at: https://land.copernicus.eu/pan-european/corine-land-cover/clc2018 (Accessed: 18 September 2020).

Decleer, K. et al. (2016) 'Mapping wetland loss and restoration potential in Flanders (Belgium): An ecosystem service perspective', Ecology and Society, 21(4). doi: 10.5751/ES-08964-210446.

Department for Environment Food and Rural Affairs (2020) Defra Statistics: Agricultural Facts, England Regional Profiles.

Devon Wildlife Trust (no date) Culm grassland natural flood management. Available at: https://www.devonwildlifetrust.org/what-we-do/our-projects/culm-grassland-natural-flood-management-project (Accessed: 6 November 2020).

EEA (no date) European Environment Agency (2020), Use of freshwater resources in Europe. Available at: https://www.eea.europa.eu/data-and-maps/indicators/use-of-freshwater-resources-3/assessment-4.

Environment Agency (2018) Climate change impacts and adaptation Chair's foreword.

Environment Agency (2019a) 'The state of the environment : soil', (June), p. 22.

Environment Agency (2019b) 'The state of the environment: soil', (June), p. 22. Available at: www.gov.uk/environment-agency.

Environment Agency (2020a) 'Meeting our future water needs: a national framework for water resources', (March). Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/872760/Appendix_1_Modelling_approach_and_assumptions_made.pdf.

Environment Agency (2020b) 'Meeting our future water needs: a national framework for water resources', (March).

FAO (2003) Soil Compaction - an unnecessary form of land degradation. Available at: http://www.fao.org/ag/ca/doc/Soil_compaction.pdf (Accessed: 15 November 2014).

Fung, F. et al. (2018) 'UKCP18 Factsheet: Precipitation', Met Office Hadley Centre, Exeter, pp. 1–8.

Group Wetland Ecosystem Research (2020) 'Tamar 2000 Support Project: Wetland Phase I report'.

Hayhow DB et al. (2019) State of Nature.

Hess, T. M. et al. (2010) 'Estimating the impact of rural land management changes on catchment runoff generation in England and Wales', Hydrological Processes. Wiley, p. n/a-n/a. doi: 10.1002/hyp.7598.

HR Wallingford (2015) Updated projections for water availability for the UK.

Hydrological Summary for the United Kingdom (2018).

Jackson, C. R., Bloomfield, J. P. and Mackay, J. D. (2015a) 'Evidence for changes in historic and future groundwater levels in the UK', Progress in Physical Geography: Earth and Environment. SAGE Publications Ltd, 39(1), pp. 49–67. doi: 10.1177/0309133314550668.

Jackson, C. R., Bloomfield, J. P. and Mackay, J. D. (2015b) 'Evidence for changes in historic and future groundwater levels in the UK', Progress in Physical Geography: Earth and Environment. SAGE Publications Ltd, 39(1), pp. 49–67. doi: 10.1177/0309133314550668.

Keay, C. A. et al. (2013) 'SP1104 the Impact of climate change on the capability of land for agriculture as defined by the Agricultural Land Classification', Final Report for DEFRA Project SP1104, p. 138.

Kent Nature Partnership (2020) Biodiversity Strategy 2018 to 2044. Available at: https://democracy.kent.gov.uk/documents/s89509/Item 14 - Appendix 1 - Kent Biodiversity Strategy Final Draft Feb 2019.pdf (Accessed: 8 September 2020).

Kovats et al. (2014) European Environment Agency. Available at: http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap23_FINAL.pdf (Accessed: 18 September 2020).

Kowalski, M. et al. (2011) Written by.

Lammar, P. and Hens, L. (2005) 'Health and Mobility in Flanders (Belgium)', in Environmental Health Impacts of Transport and Mobility, pp. 199–222. Available at: http://dx.doi.org/10.1007/1-4020-4307-4_15.

Louette, G. et al. (2011) 'Bridging the gap between the Natura 2000 regional conservation status and local conservation objectives', Journal for Nature Conservation, 19(4), pp. 224–235. doi: https://doi.org/10.1016/j.jnc.2011.02.001.

Lowe, J. A. et al. (2018) UKCP18 National Climate Projections.

Mainstone, C., Hall, R. and Diack, I. (2016) A narrative for conserving freshwater and wetland habitats in England.

Mansour, M. and Hughes, A. G. (2014) Land use, climate change and water availability: preliminary modelling of impacts of climate change and land use change on groundwater recharge for England and Wales.

Mansour, M. M. and Hughes, A. G. (2017) Summary of results for national scale recharge modelling under conditions of predicted climate change.

Masante, D. et al. (2020) 'Drought in Europe', JRC European Drought Observatory.

'Meeting our future water needs: a national framework for water resources' (2020), (March).

Met Office Hadley Centre (2018a) UKCP18 Probabilistic Climate Projections. Centre for Environmental Data Analysis, date of citation. Available at: https://catalogue.ceda.ac.uk/uuid/9842e395f2d04f48a177c3550756bf98?search_url=%2F%253Fq%253Dukcp18%26sort_by%253D (Accessed: 25 September 2020).

Met Office Hadley Centre (2018b) UKCP18 Probabilistic Climate Projections. Centre for Environmental Data Analysis, date of citation.

MIRA (2018) Bebouwde oppervlakte. Available at: https://www.milieurapport.be/milieuthemas/bodem/bodembedekking-gebruik/bebouwde-oppervlakte.

MIRA (2020) (no date) Waterverbruik. Available at: https://www.milieurapport.be/milieuthemas/waterkwantiteit/waterverbruik-beschikbaarheid/waterverbruik (Accessed: 13 November 2020).

Mitsch, W. J. and Gosselink, J. G. (2000) Wetlands. 3rd editio. New York: John Wiley & Sons.

Morris, J. et al. (2016) 'Cost of soil degradation in England and Wales: an ecosystems approach EnvEcon 2016'.

National Audit Office (2020) 'Water supply and demand management', Department for Environment Food and Rural Affairs, (March 2020).

National River Flow Archive (no date) Station Data for 40005 - Beult at Stilebridge. Available at: https://nrfa.ceh.ac.uk/data/station/info/40005 (Accessed: 15 September 2020).

Natural England (2009) Environmental impacts of land management - NERR030.

Poelmans, L. et al. (2010) 'Assessing the relative impact of urban expansion and climate change on high flows in a small catchment in Flanders (Belgium).', Land Use Policy., 12, p. 2010.

PROWATER (no date). Available at: https://www.pro-water.eu/overview (Accessed: 3 December 2020).

Prudhomme, C. et al. (2012) Future flows and Groundwater Levels-SC090016. Available at: www.ceh.a (Accessed: 15 September 2020).

Rekenhof (2014) Bescherming en herstel van de grondwatervoorraden - Grondwatervergunningen, grondwaterheffing en steun voor grijswaterprojecten - Verslag van het Rekenhof aan het Vlaams Parlement. Brussel.

Staes, J. and Meire, P. (2013) 'Overzichtsrapport van mogelijke aanpassingen aan het Vlaams ecologisch netwerk in relatie tot klimaatverandering', IWT/SBO onderzoeksproject CcASPAR: Valorisatierapport 4, Universiteit antwerpen, Onderzoeksgroep Ecosysteembeheer.

Van Steertegem, M. (no date) MIRA-T 2008 Indicatorrapport (2009) Marleen Van Steertegem (eindred.), Milieurapport Vlaanderen, Vlaamse Milieumaatschappij.

Strong, C. et al. (no date) ACHIEVING ABUNDANCE: UNDERSTANDING THE COST OF A SUSTAINABLE WATER FUTURE. Available at: www.wri.org/ (Accessed: 18 September 2020).

Tabari, H., Taye, M. T. and Willems, P. (2015) Actualisatie en verfijning klimaatscenario's tot 2100 voor Vlaanderen – Nieuwe modelprojecties voor Ukkel op basis van globale klimaatmodellen (CMIP5), studie uitgevoerd in opdracht van de Afdeling Operationeel Waterbeheer van de Vlaamse Milieumaatschappi.

Trémolet, S. et al. (2019) Investing in Nature for European. London.

Verstraeten, G. (2013) Conversion of deciduous forests to spruce plantations and back: evaluation of interacting effects on soil, forest floor, earthworm and understorey communities. Ghent University. doi: 10.1021/ac301764q.

VMM (2019) Grondwaterwinning. Available at: https://www.milieurapport.be/milieuthemas/waterkwantiteit/waterverbruik-beschikbaarheid/grondwaterwinning (Accessed: 29 October 2020).

VMM (2020a) Indicator bevoorrading leidingwater. Available at: https://www.vmm.be/data/leidingwater-beschikbaarheid/indicator_bevoorrading_leidingwater/view (Accessed: 24 November 2020).

VMM (2020b) Uitwerking van een reactief afwegingskader voor prioritair watergebruik tijdens waterschaarste. Tussentijds rapport. Documentref.: VMM/S004X/201119/2.0. Datum 26/10/2020.

VMM, SCK and De Watergroep (2020a) Actuele grondwaterstandindicator. Available at: https://www.dov.vlaanderen.be/page/actuele-grondwaterstandindicator.

VMM, SCK and De Watergroep (2020b) Historische gondwaterstandindicator. Available at: https://www.dov.vlaanderen.be/page/historische-grondwaterstandindicator.

Vrebos, D. et al. (2017) 'ECOPLAN-SE: Ruimtelijke analyse van ecosysteemdiensten in Vlaanderen, een Q-GIS plugin, Versie 1.0'. Antwerpen: Universiteit Antwerpen, p. 132.

Water Resources South East (2020) 'Future water resource requirements for South East England', (March), pp. 1–27.

Water UK (no date) Water and health. Available at: https://www.water.org.uk/advice-for-customers/water-and-health/ (Accessed: 6 November 2020).

Watts, G. et al. (2015) 'Climate change and water in the UK – past changes and future prospects', Progress in Physical Geography: Earth and Environment. SAGE Publications Ltd, 39(1), pp. 6–28. doi: 10.1177/0309133314542957.

West Country Water Resources (2020) 'Initial Resource Position March 2020', (March).

Wetland Vision (2008) Wetland Vision. Available at: http://ousewashes.org.uk/biodiversity/wetland-vision/ (Accessed: 18 September 2020).

Willems, P. et al. (2010) 'Climate change impact on hydrological extremes along rivers and urban drainage systems. Final report. Final report for Belgian Science Policy Office - Programme Science for a Sustainable Development, K.U.Leuven - Hydraulics Section & Royal Meteorological '.

Wood, P. J., Agnew, M. D. and Petts, G. E. (2001) Hydro-ecological variability within a groundwater dominated stream.
Woodland Trust (2011) The State of the UK's Forests, Woods and Trees: Perspectives from the sector.

World Resource Institute (no date) Aqueduct Water Risk Atlas. Available at: https://wri.org/applications/aqueduct/water-risk-atlas/#/?advanced=false&basemap=hydro&indicator=w_awr_def_tot_cat&lat=30&lng=-80&mapMode=view&month=1&opacity=0.5&ponderation=DEF&predefined=false&projection=absolute&scenario=optimistic&scope=baseline&time (Accessed: 18 September 2020).

WWF (no date) Water for wildlife, tackling drought and unsustainable abstraction.