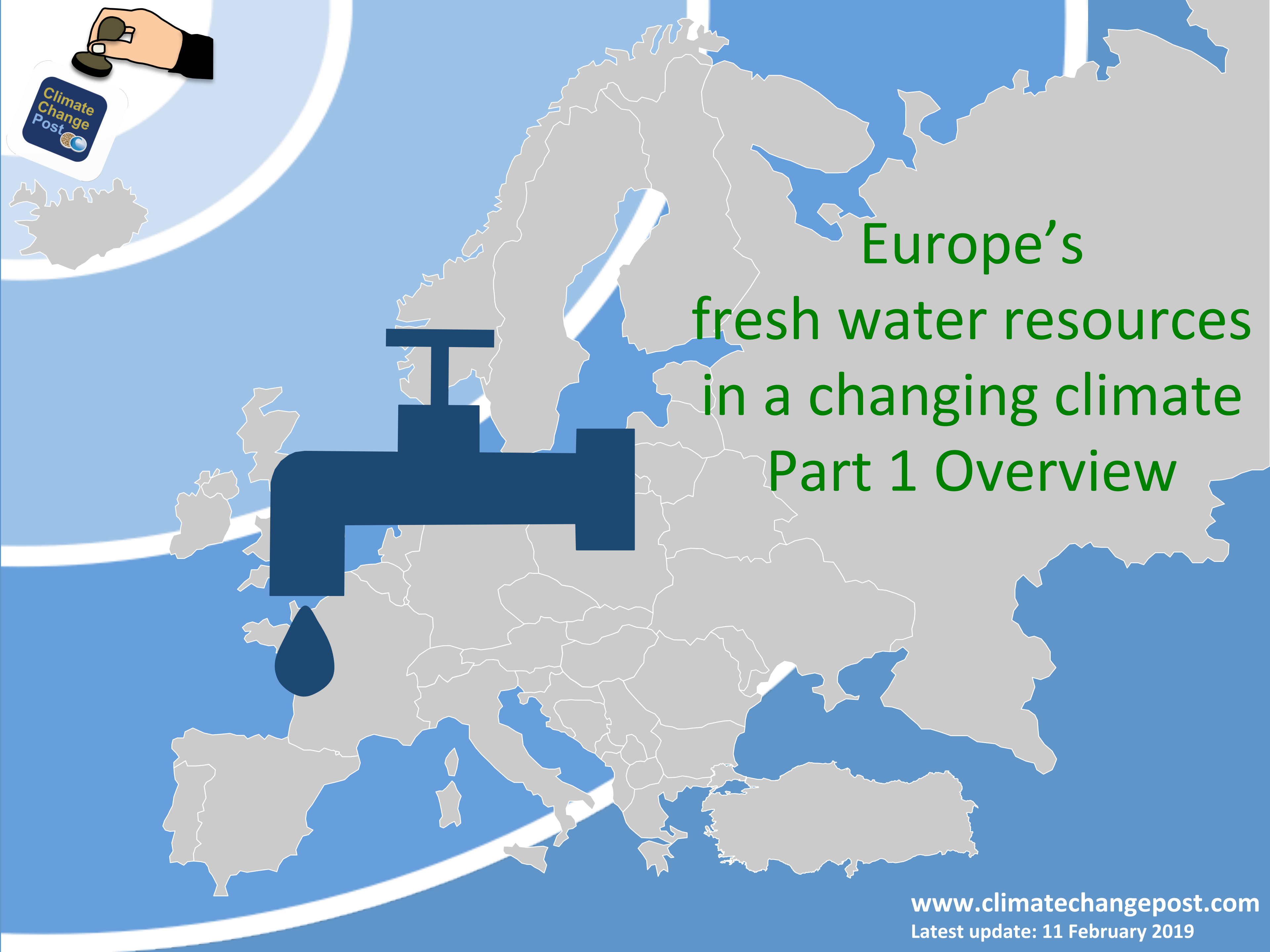


Europe's fresh water resources in a changing climate

Part 1 Overview

www.climatechangepost.com
Latest update: 11 February 2019

Fresh water resources

The global picture

Chronic water shortage:

People suffer from "chronic water shortage" if they have access to less than 1,000 m^3 fresh water per person per year

Present-day populations living within watersheds exposed to water scarcity: 1.6 – 2.4 billion people (25% - 39% of global population)

Population growth increases pressure on water resources:
By 2050, the effects of population increases alone mean that 3.1 - 4.3 billion people (37% - 53 %) will be living in watersheds exposed to water scarcity

Climate change increases pressure on water resources:
More people will see an increase in exposure to water scarcity than a decrease

Globally, by 2050, moderate scenario of climate change:

- more water scarcity for 0.5 to 3.9 billion people
- less water scarcity for 0.1 to 2.7 billion people

Source:
Gosling and Arnell (2016)

Fresh water resources

The risk of drought increases mainly in southern Europe. For southern and eastern Europe the increasing risk from climate change would be amplified by an increase in water withdrawals. Water shortages due to extended droughts will also affect tourism flows, especially in southeast Mediterranean where the maximum demand coincides with the minimum availability of water resources.

Key issues with respect to the vulnerability of fresh water resources are:

- maintenance of critical river flows during dry conditions;
- impact of longer and increased frequency of droughts on water supply;
- uncertainty in replenishment rate of aquifers;
- potential salinity increases in borehole and river-mouth abstraction points as a consequence of rising sea-levels and/or storm surges;
- an increase in the demand for water for irrigation, garden watering, industry (especially food and drink) and households.

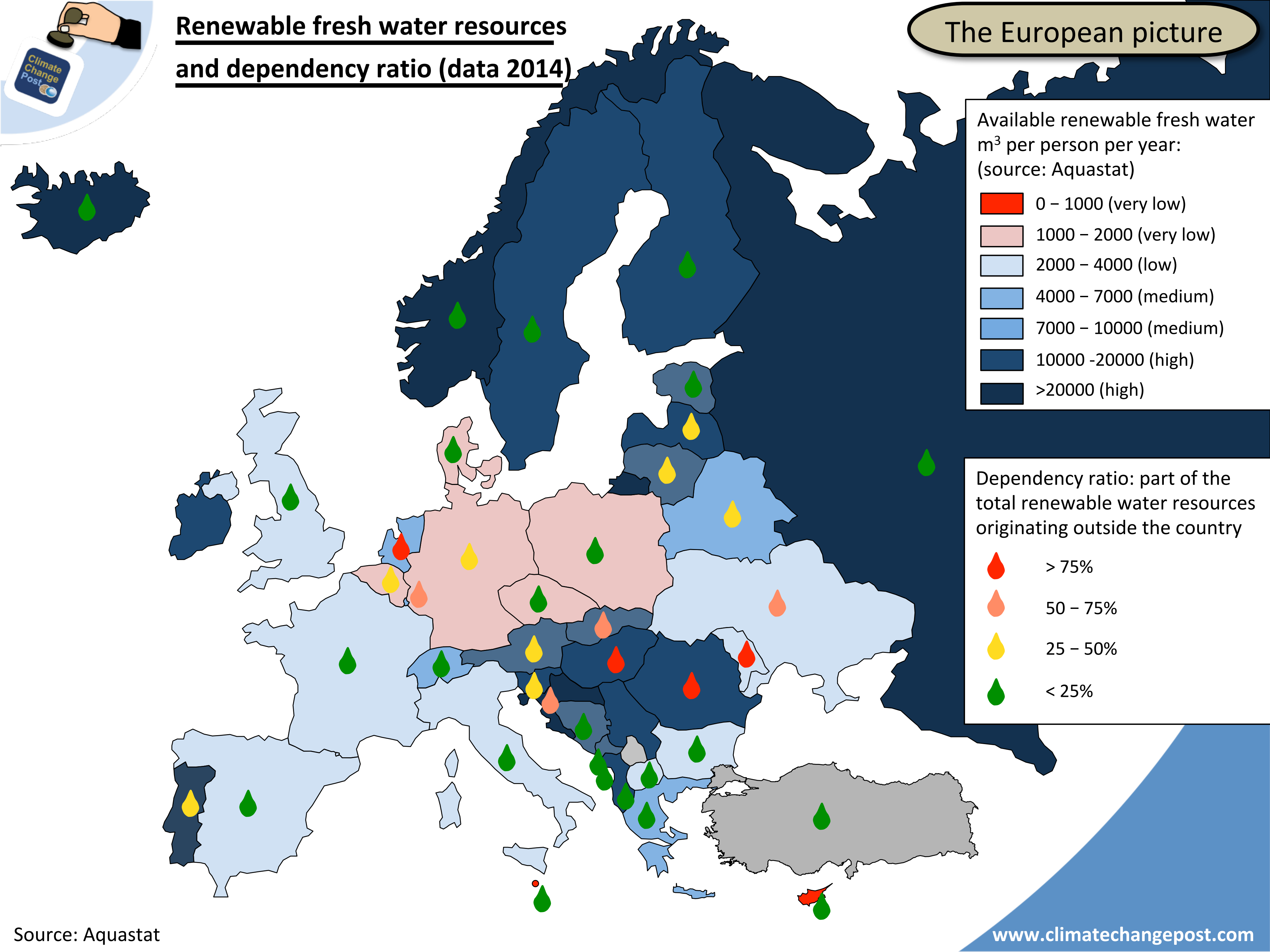
Renewable fresh water resources

It is unsustainable in the long run to use more freshwater from resources than can replenished by nature. The fresh water that can be replenished is 'renewable'.

The total renewable freshwater resource of a country is the total annual volume of river run-off and groundwater recharge, plus the total volume of actual flow of rivers coming from neighbouring countries. This resource is supplemented by water stored in lakes, reservoirs, icecaps and fossil groundwater.

Dividing the total renewable freshwater resource by the number of inhabitants leads to water availability per capita. This is an annual data and does not reflect seasonal variations.

Thirteen countries have less than 5,000 m^3 of water per person per year. The Mediterranean islands of Malta and Cyprus and some densely populated countries in central and north-western Europe have the lowest water availability per capita. Nordic countries generally have the highest water resources per capita.

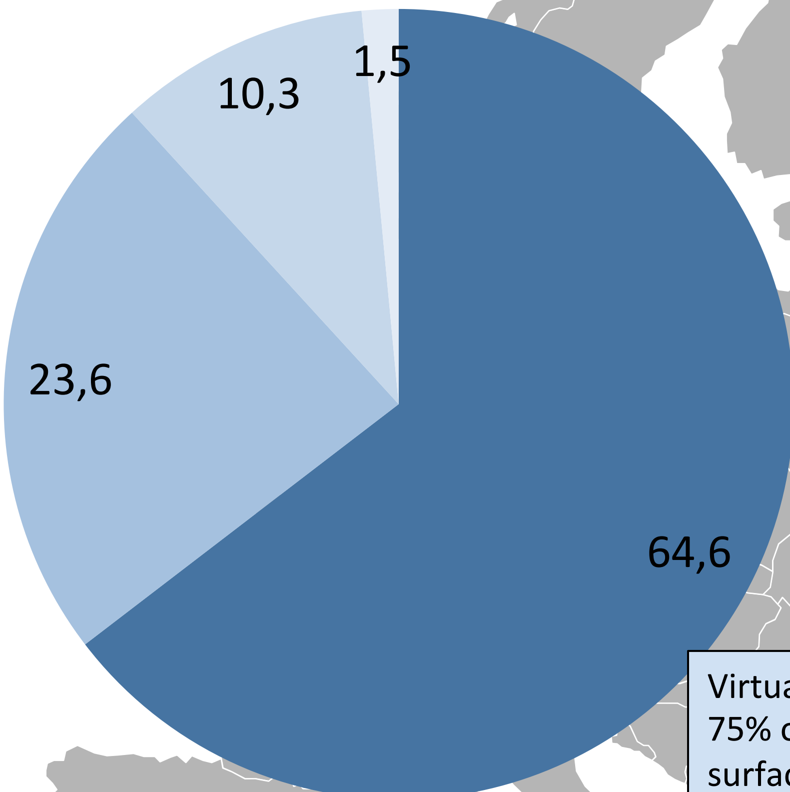


Renewable fresh water resources
and dependency ratio (data 2014)
The European picture
Climate Change Post
Available renewable fresh water
m³ per person per year:
(source: Aquastat)
0 – 1000 (very low)
1000 – 2000 (very low)
2000 – 4000 (low)
4000 – 7000 (medium)
7000 – 10000 (medium)
10000 -20000 (high)
>20000 (high)
Dependency ratio: part of the
total renewable water resources
originating outside the country
> 75%
50 – 75%
25 – 50%
< 25%
Source: Aquastat
www.climatechangepost.com

What renewable fresh water resources do Europeans use?

The European picture

Freshwater abstraction by source in 2015 (%)



Virtually all abstraction for energy production and more than 75% of that abstracted for industry and agriculture comes from surface sources. For agriculture, however, groundwater's role as a source is probably underestimated due to illegal abstraction from wells. Groundwater is the predominant source (about 55%) for public water supply due to its generally higher quality than surface water. In addition, in some locations it provides a more reliable supply than surface water in the summer months.

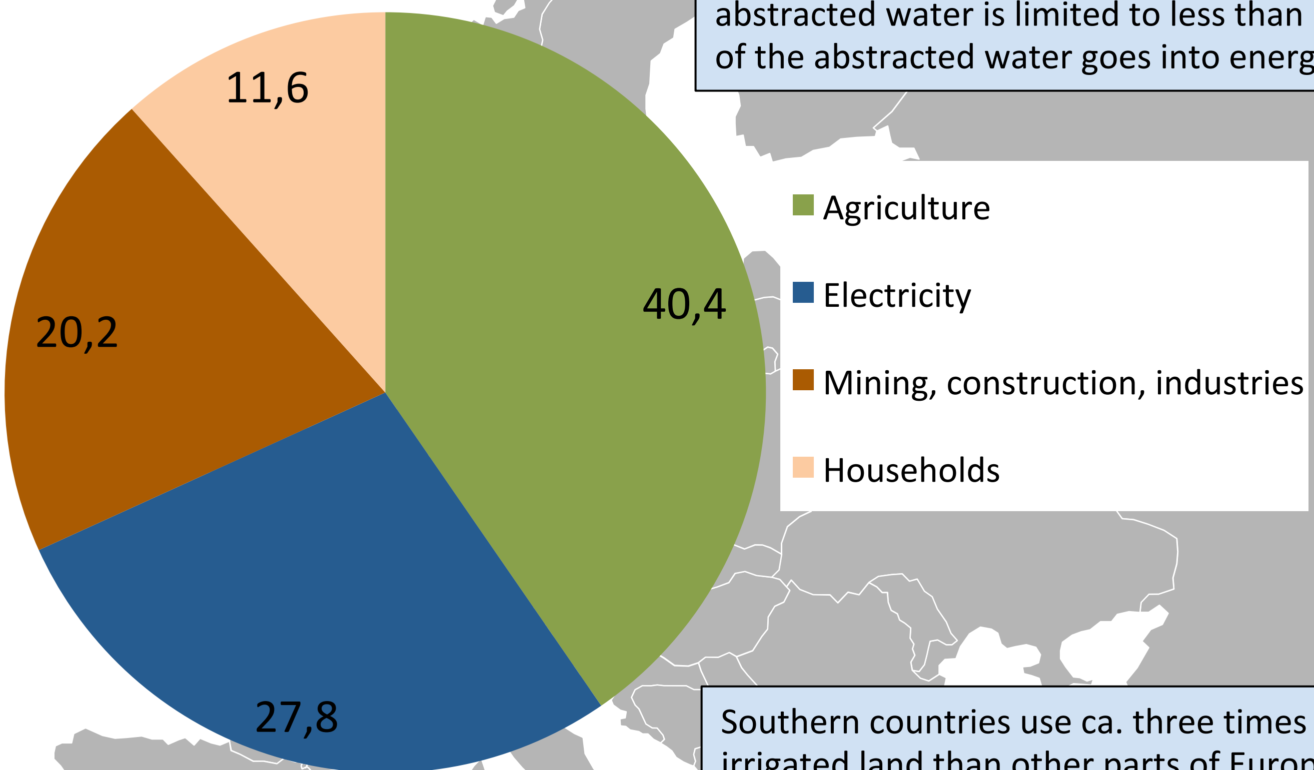
Source: EEA

For what sectors are Europe's fresh water resources being used?

The European picture

Large differences exist across the continent. In Malta, Cyprus and Turkey, for example, almost 80% of the abstracted water is used for agriculture. In the central and northern countries (Austria, Belgium, Denmark, Germany, Ireland, Luxembourg, Netherlands, UK, and Scandinavia), agricultural use of the abstracted water is limited to less than 5%, while more than 50% of the abstracted water goes into energy production.

Water use in 2015 (%)



Southern countries use ca. three times more water per unit of irrigated land than other parts of Europe. The large amount of water dedicated to irrigation in the southern countries is problematic since most of these countries have been classified as water stressed, and face problems associated with groundwater over-abstraction such as aquifer depletion and salt water intrusion.

Source: EEA

Stress on renewable fresh water resources due to lower summer discharge

Europe's renewable freshwater resources are changing, due to land cover change, large-scale irrigation, the construction of reservoirs and dams, and changes in the hydrological cycle.

For instance, in winter, discharges of the rivers Rhine and Danube increase due to higher winter precipitation and earlier snowmelt, while summer discharge decreases due to lower snowmelt runoff from the Alps and increased evapotranspiration.

It is highly likely that climate change is amplifying the **north-south contrast of river runoff** in Europe:

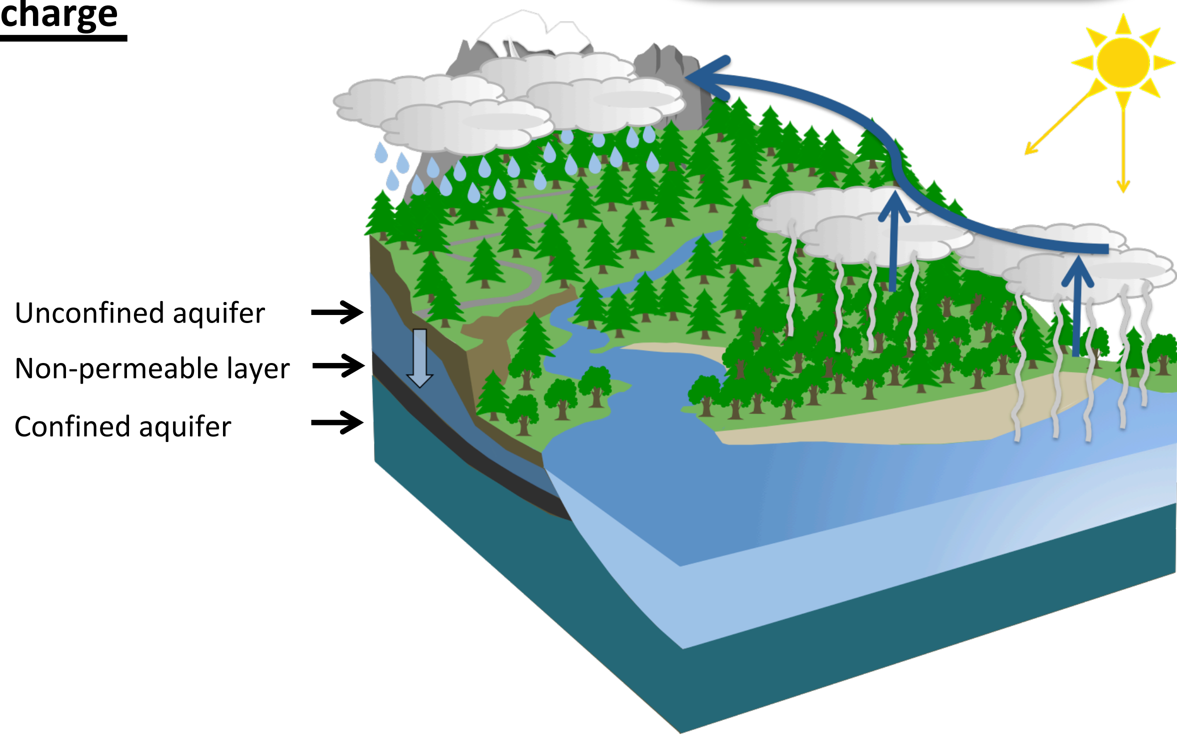
- As warming level increases, annual mean discharge of rivers increase in northern Europe and decrease in southern Europe. In central Europe, the transition region from a decrease to an increase, there is little change.
- Runoff of rivers and streams in in the Mediterranean region shows drying trends over the last half century. For Northern Europe, on the other hand, weak wetting trends have been observed.

Stress on renewable fresh water resources due to less groundwater recharge

The European picture

Groundwater recharge depends on the distribution, amount and timing of precipitation, evapotranspiration losses, snow cover thickness and snow melt characteristics, and land use/land cover.

The properties of the aquifer are also essential; small, shallow unconfined aquifers respond more rapidly to climate change, whereas larger and confined systems show a slower response.



It is highly likely that climate change is amplifying the **north-south contrast of groundwater recharge** in Europe:

- It is expected that in snow-dominated regions, warmer winters will cause snow melt and groundwater recharge and runoff to occur over longer periods and earlier in the year. Increased aquifer recharge will increase wintertime groundwater levels, whereas in spring and summer the groundwater levels may decrease with a warmer climate.
- Southern Europe will have less recharge overall and the region may become more water stressed than at present. Southern Spain is predicted to be among the worst affected regions in Europe, with almost total disappearance of recharge.

Stress on renewable fresh water resources

The European picture

Average annual runoff in Europe varies widely, from less than 25 mm in southeast Spain to more than 3000 mm on the west coast of Norway. Almost 20% of water resources are north of 60°N, while only 2% of people live there.

Climate change is going to make the distribution of water resources in Europe much more uneven than it is today: projections indicate that river discharge in northern Europe will increase throughout the year.

It is highly likely that climate change is amplifying the **north-south contrast of river runoff** in Europe

It is highly likely that climate change is amplifying the **north-south contrast of groundwater recharge** in Europe

More stress on limited groundwater resources in especially southern Europe

Increase non-sustainable use of groundwater reserves

Stress on renewable fresh water resources

More stress on limited groundwater resources in especially southern Europe

↓

Increase non-sustainable use of groundwater reserves

← **It's not just due to climate change!**

Water demand in the Greater Athens region has continued to grow at an excessive rate, driven by a growth of the urban region and the movement of people from city apartment blocks to houses with gardens on the fringes of the region. Agriculture accounts for approximately 80% of the region's water demand. Groundwater abstraction now exceeds recharge and the aquifer system is overexploited. As a result, the water level has declined significantly in wells and boreholes, driving a progressive deepening of those still operating. In addition, seasonal seawater now intrudes into the aquifer.

Dozens of drought stricken Greek islands in the Aegean are being forced to import greater amounts of water every year. The rapid development of Crete since 1980 has exerted strong pressures on many natural resources. Due to urbanization and the growth of agriculture and tourism industry, water demand in Crete has substantially increased by over 55% during the period 1985 – 2000.

Non-sustainable use of groundwater resources

Global:

Since 1960, irrigation has become more dependent on non-sustainable groundwater. Non-renewable groundwater abstraction globally contributed nearly 20% to the gross irrigation water demand in 2000, a more than threefold increase in size since the year 1960.

Europe:

For Europe, the contribution (%) of non-renewable groundwater abstraction to gross irrigation water demand was calculated for Italy (15%), Spain (7%), Turkey (7%) and Greece (2%) (Wada et al., 2012). Stress on limited groundwater resources in southern Europe will increase further as a result of increasing irrigation demand.

Substantial reductions in potential groundwater recharge are projected for the 21st century in southern Europe (Spain and northern Italy) whereas increases are consistently projected in northern Europe (Denmark, southern England, northern France).

Summary for Southern Europe

What does science tell us so far

- In the last century the Mediterranean basin has experienced up to 20 % reduction in precipitation.
- Owing to climate change alone, fresh water availability in the Mediterranean is likely to decrease substantially: by 2-15% for 2°C warming, among the largest decreases in the world, with significant increases in the length of meteorological dry spells and droughts.
- River flow will generally be reduced, and water levels in lakes and reservoirs will probably decline.
- Climate scenarios indicate that annual average runoff in southern Europe may decrease by 20-30 % at mid-century, and even up to 40-50 % in the second half of this century. Summer low flow may decrease much more.
- The seasonality of stream flows is very likely to change, with earlier declines of high flows from snow melt in spring, intensification of low flows in summer and greater and more irregular discharge in winter.
- In Greece and Turkey per-capita water availability may fall below 1,000 m^3 per year (the threshold generally accepted for severe water stress) for the first time in 2030. Critically low current water availability per capita in southeastern Spain may drop to below 500 m^3 per year in the future.
- The general increase in water scarcity as a consequence of climate change is enhanced by the increasing demand for irrigated agriculture to stabilize production and to maintain food security. Irrigation demands in the Mediterranean region are projected to increase between 4 and 18% by the end of the century due to climate change alone (for 2°C and 5°C warming, respectively). Population growth and increased demand may escalate these numbers to between 22 and 74%.

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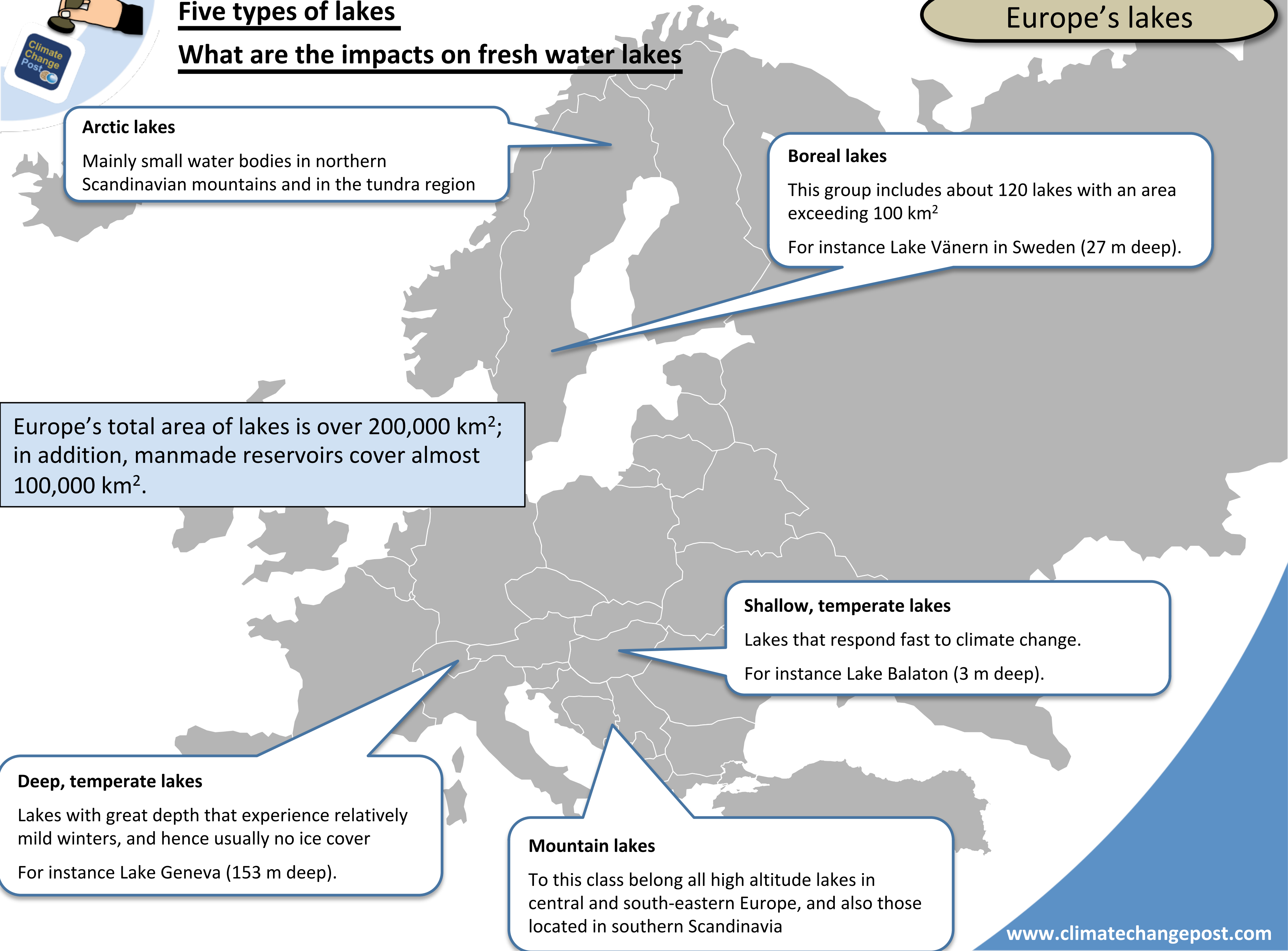
Five types of lakes

What are the impacts on fresh water lakes

Europe's lakes



Arctic lakes

Mainly small water bodies in northern Scandinavian mountains and in the tundra region

Boreal lakes

This group includes about 120 lakes with an area exceeding 100 km^2

For instance Lake Vänern in Sweden (27 m deep).

Europe's total area of lakes is over 200,000 km^2; in addition, manmade reservoirs cover almost 100,000 km^2.

Shallow, temperate lakes

Lakes that respond fast to climate change.

For instance Lake Balaton (3 m deep).

Deep, temperate lakes

Lakes with great depth that experience relatively mild winters, and hence usually no ice cover

For instance Lake Geneva (153 m deep).

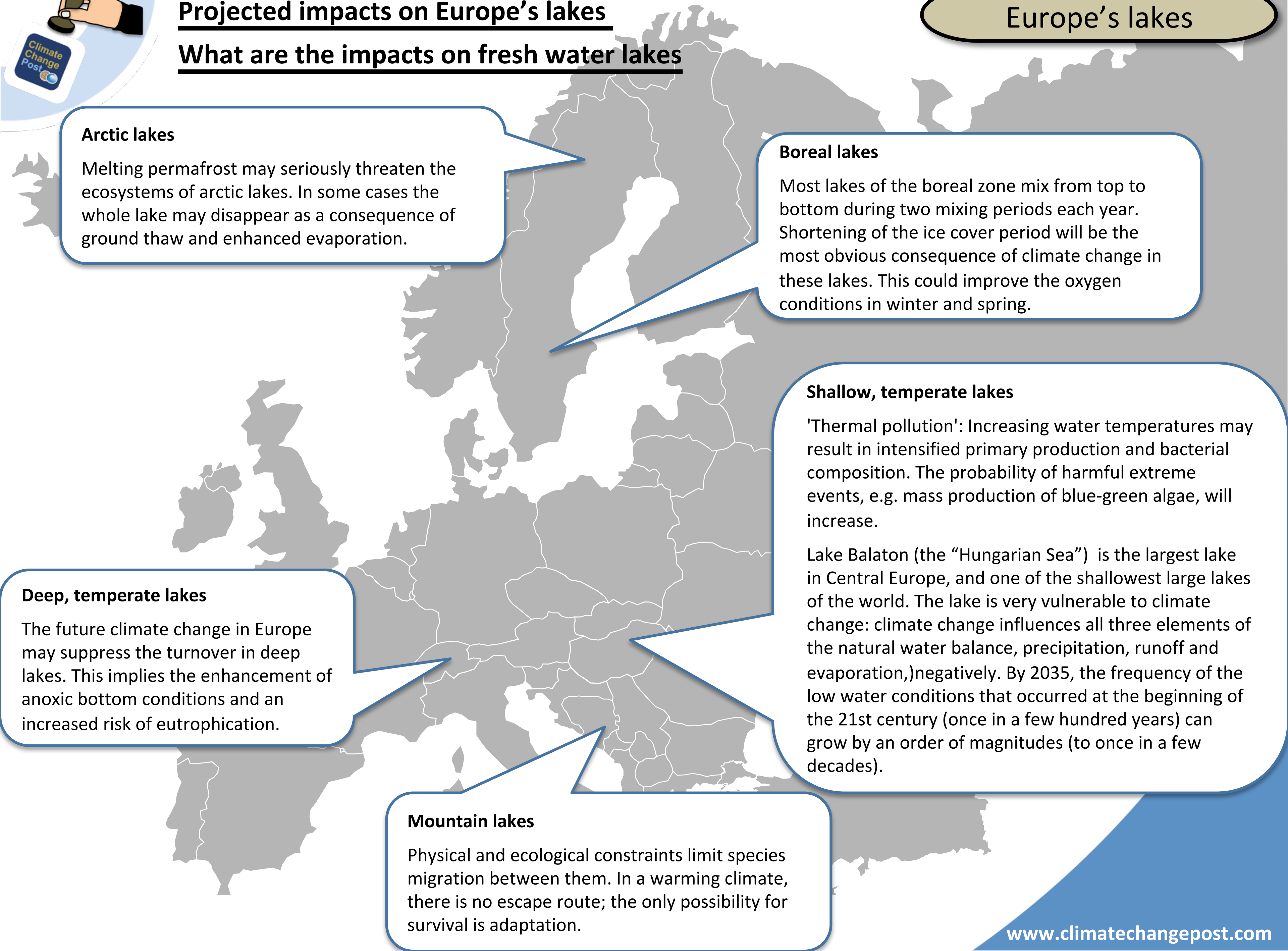
Mountain lakes

To this class belong all high altitude lakes in central and south-eastern Europe, and also those located in southern Scandinavia

Projected impacts on Europe's lakes

What are the impacts on fresh water lakes

Europe's lakes



Arctic lakes

Melting permafrost may seriously threaten the ecosystems of arctic lakes. In some cases the whole lake may disappear as a consequence of ground thaw and enhanced evaporation.

Boreal lakes

Most lakes of the boreal zone mix from top to bottom during two mixing periods each year. Shortening of the ice cover period will be the most obvious consequence of climate change in these lakes. This could improve the oxygen conditions in winter and spring.

Shallow, temperate lakes

'Thermal pollution': Increasing water temperatures may result in intensified primary production and bacterial composition. The probability of harmful extreme events, e.g. mass production of blue-green algae, will increase.

Lake Balaton (the "Hungarian Sea") is the largest lake in Central Europe, and one of the shallowest large lakes of the world. The lake is very vulnerable to climate change: climate change influences all three elements of the natural water balance, precipitation, runoff and evaporation,)negatively. By 2035, the frequency of the low water conditions that occurred at the beginning of the 21st century (once in a few hundred years) can grow by an order of magnitudes (to once in a few decades).

Deep, temperate lakes

The future climate change in Europe may suppress the turnover in deep lakes. This implies the enhancement of anoxic bottom conditions and an increased risk of eutrophication.

Mountain lakes

Physical and ecological constraints limit species migration between them. In a warming climate, there is no escape route; the only possibility for survival is adaptation.

The Alps: the ‘water towers’ of Europe

Pure glacial- and snowmelt-dominated regimes are found in the heart of the Alps.

These regimes are mainly controlled by the storage of precipitation as snow and ice during the cold months. Lowest flows occur between December and February, highest flows during spring and summer.

Glacial regimes, in particular, show a consistent behaviour with a melting season shifted by a week earlier, an increase of 29% in the snowmelt volume, and an enhanced contribution of the glacier to the total stream flow of corresponding catchments.

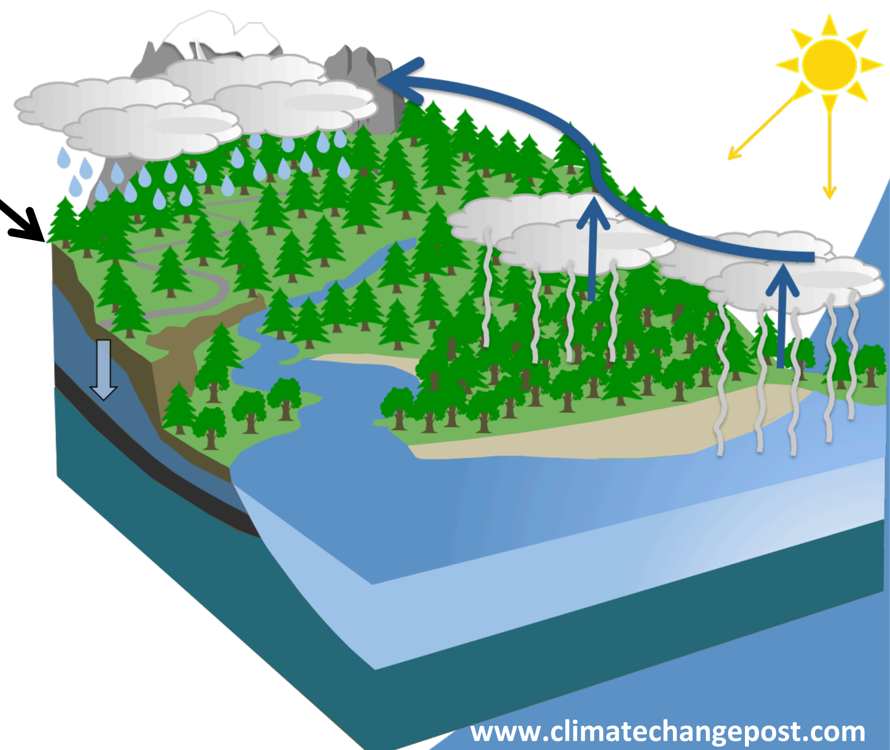
Observed: Winter droughts have become **less severe** (winter discharge increased): drought durations have decreased by an average of 25 days over 1961–2005.

Mixed snowmelt–rainfall regimes are found in pre-alpine regions.

These regimes exhibit two low flow seasons: during the winter when part of the precipitation is stored as snowpack, and during the summer due to a combination of earlier snowpack shortage, lack of precipitation and high evapotranspiration. For these regimes, high flows are mainly driven by snowmelt during the spring and by abundant precipitation in autumn.

Analysis of satellite data from the 1980s and early 1990s shows that lowlands around the Alps experience about 3–4 weeks less snow cover than they did historically.

Observed: Winter droughts seem to have become **more severe**. Over the last decades, hydrologic regime of Alpine rivers (Austria, France, Germany, Italy, Slovenia and Switzerland) show a consistent shift toward an earlier start of snowmelt flow.



Source:
Bard et al. (2015); Eisenreich (2005)

Future projections around the Alps

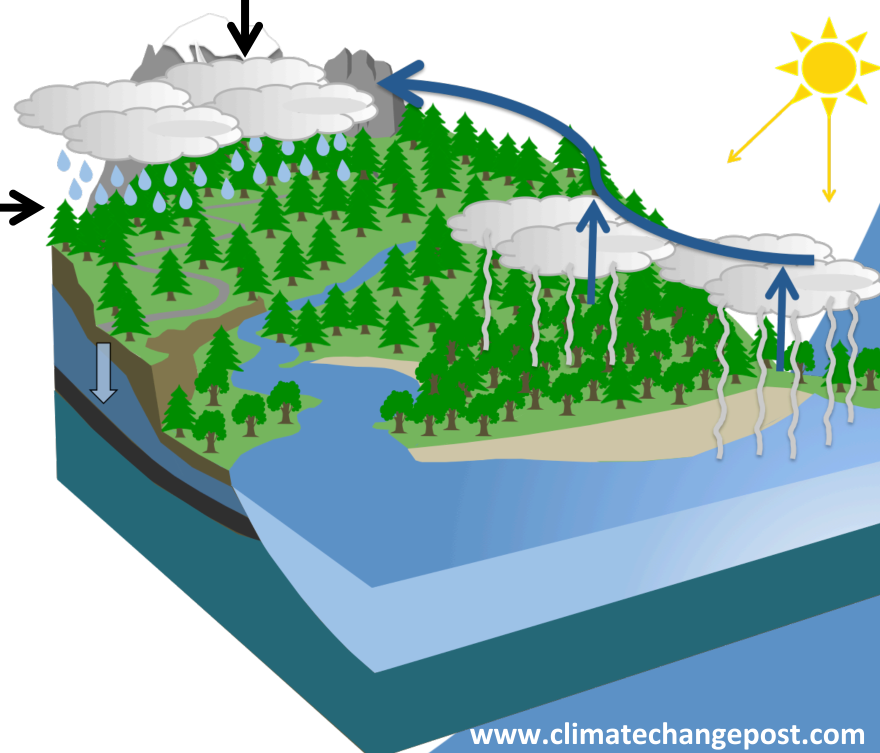
Observed: Winter droughts have become less severe (winter discharge increased): drought durations have decreased by an average of 25 days over 1961–2005.

Whether the observed trends are linked to climate change or to climate decadal variability remains an open question. The trends do agree, however, with moderate and high-end climate change scenarios that indicate that Alpine rivers winter discharge increases while the seasonal discharge peak in spring occurs earlier and the summer discharge decreases.

A sharp decline is projected for summer runoff in river basins such as the Rhine and the Rhone. This implies a higher probability of drought at the end of the summer.

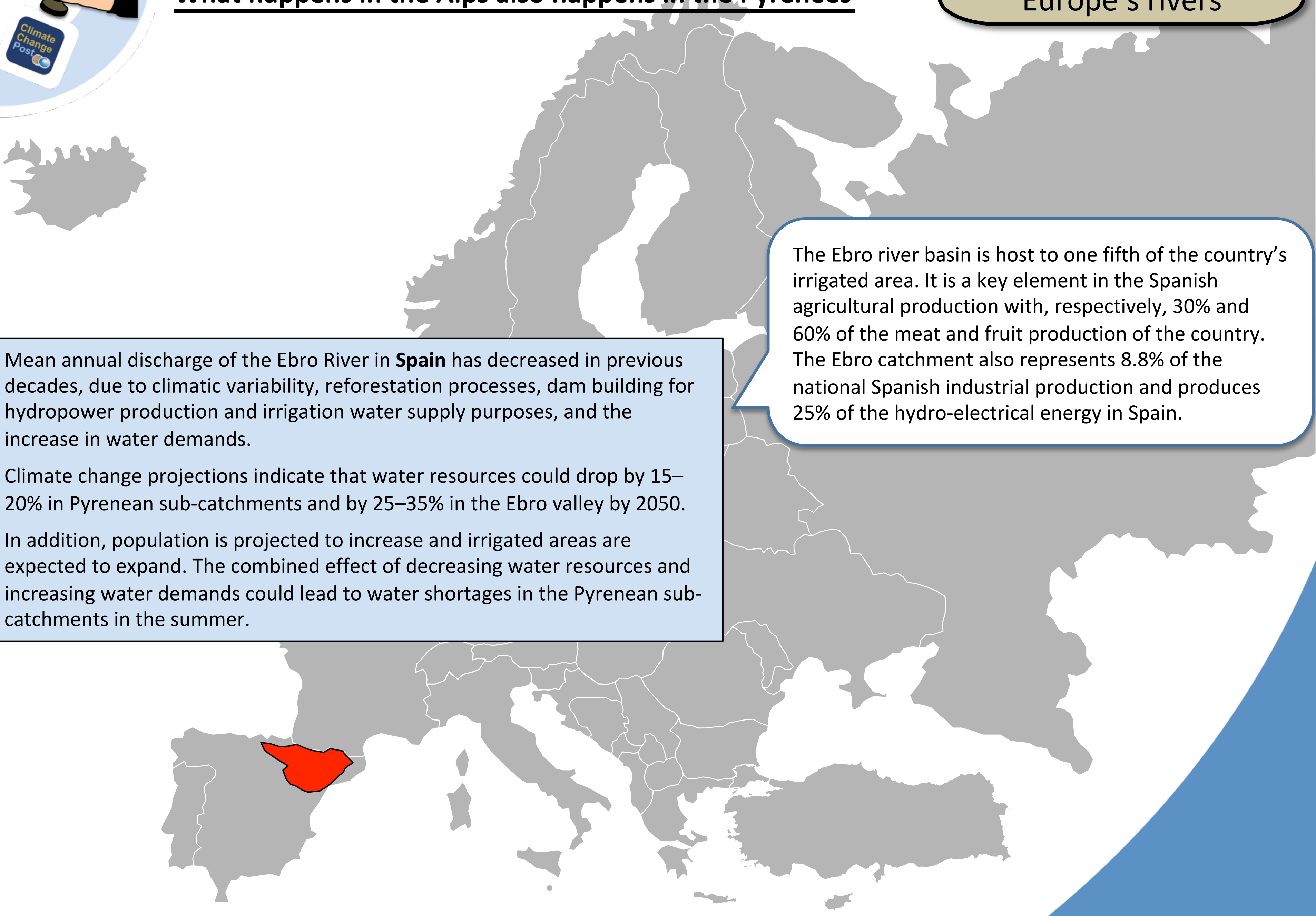
Dry river beds are a rare occurrence in the northern Alps because glacier meltwater ensures a minimum discharge in rivers during warm and dry periods of the summer, even when snowmelt no longer contributes to runoff. In the future, however, with glaciers rapidly retreating, glacial meltwater will no longer substantially contribute to runoff.

For the Rhone a reduction of summer discharge is projected of 50% to 75% by 2100 compared to 1961–1990. In some years, the Rhone may dry up partially or completely towards the end of the summer and into the early fall.



What happens in the Alps also happens in the Pyrenees

Europe’s rivers



Mean annual discharge of the Ebro River in **Spain** has decreased in previous decades, due to climatic variability, reforestation processes, dam building for hydropower production and irrigation water supply purposes, and the increase in water demands.

Climate change projections indicate that water resources could drop by 15–20% in Pyrenean sub-catchments and by 25–35% in the Ebro valley by 2050.

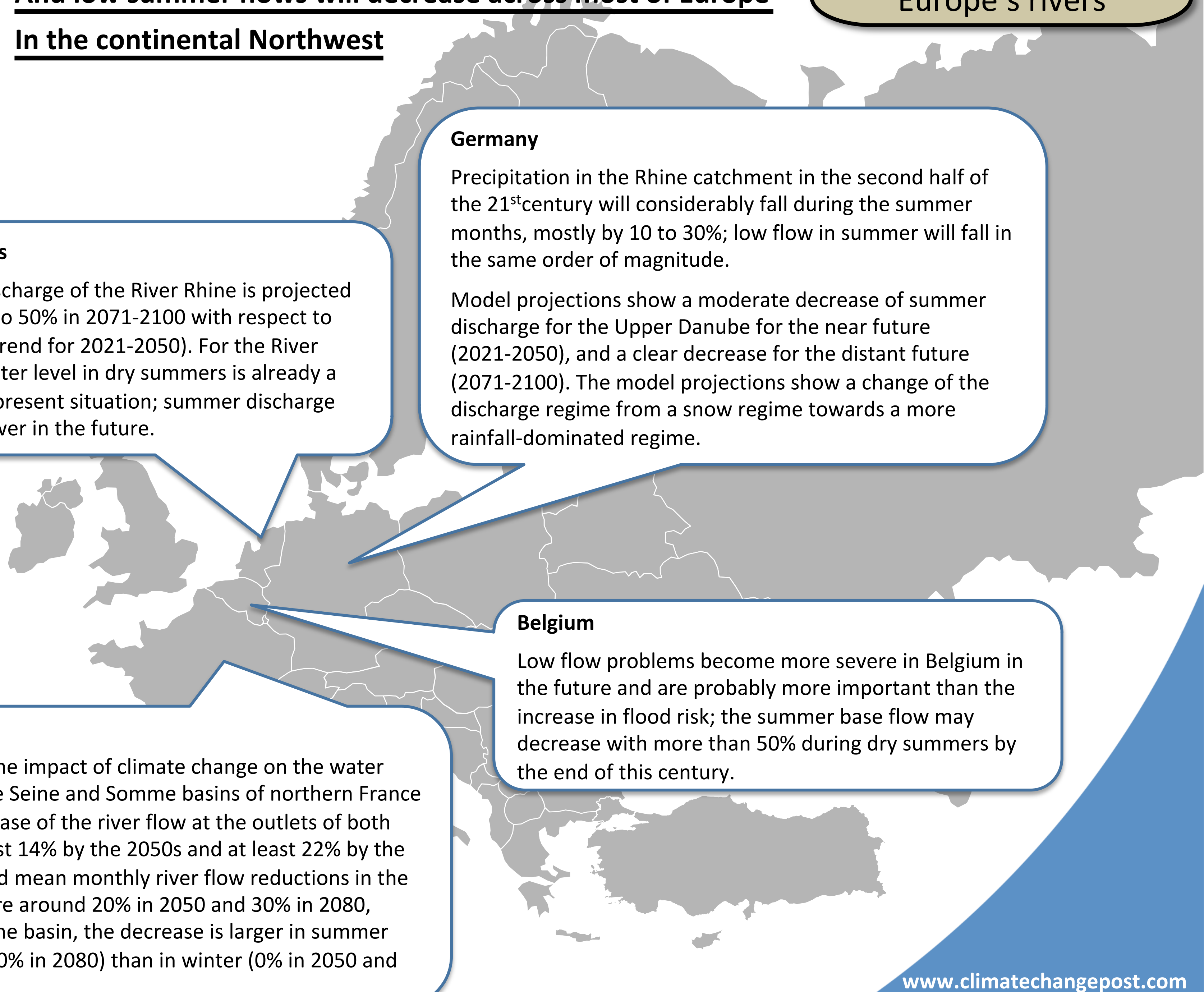
In addition, population is projected to increase and irrigated areas are expected to expand. The combined effect of decreasing water resources and increasing water demands could lead to water shortages in the Pyrenean sub-catchments in the summer.

The Ebro river basin is host to one fifth of the country’s irrigated area. It is a key element in the Spanish agricultural production with, respectively, 30% and 60% of the meat and fruit production of the country. The Ebro catchment also represents 8.8% of the national Spanish industrial production and produces 25% of the hydro-electrical energy in Spain.

Europe's rivers

And low summer flows will decrease across most of Europe

In the continental Northwest



The Netherlands

Low summer discharge of the River Rhine is projected to decrease up to 50% in 2071-2100 with respect to 1961-1990 (no trend for 2021-2050). For the River Meuse a low water level in dry summers is already a problem in the present situation; summer discharge may be even lower in the future.

Germany

Precipitation in the Rhine catchment in the second half of the 21st century will considerably fall during the summer months, mostly by 10 to 30%; low flow in summer will fall in the same order of magnitude.

Model projections show a moderate decrease of summer discharge for the Upper Danube for the near future (2021-2050), and a clear decrease for the distant future (2071-2100). The model projections show a change of the discharge regime from a snow regime towards a more rainfall-dominated regime.

Belgium

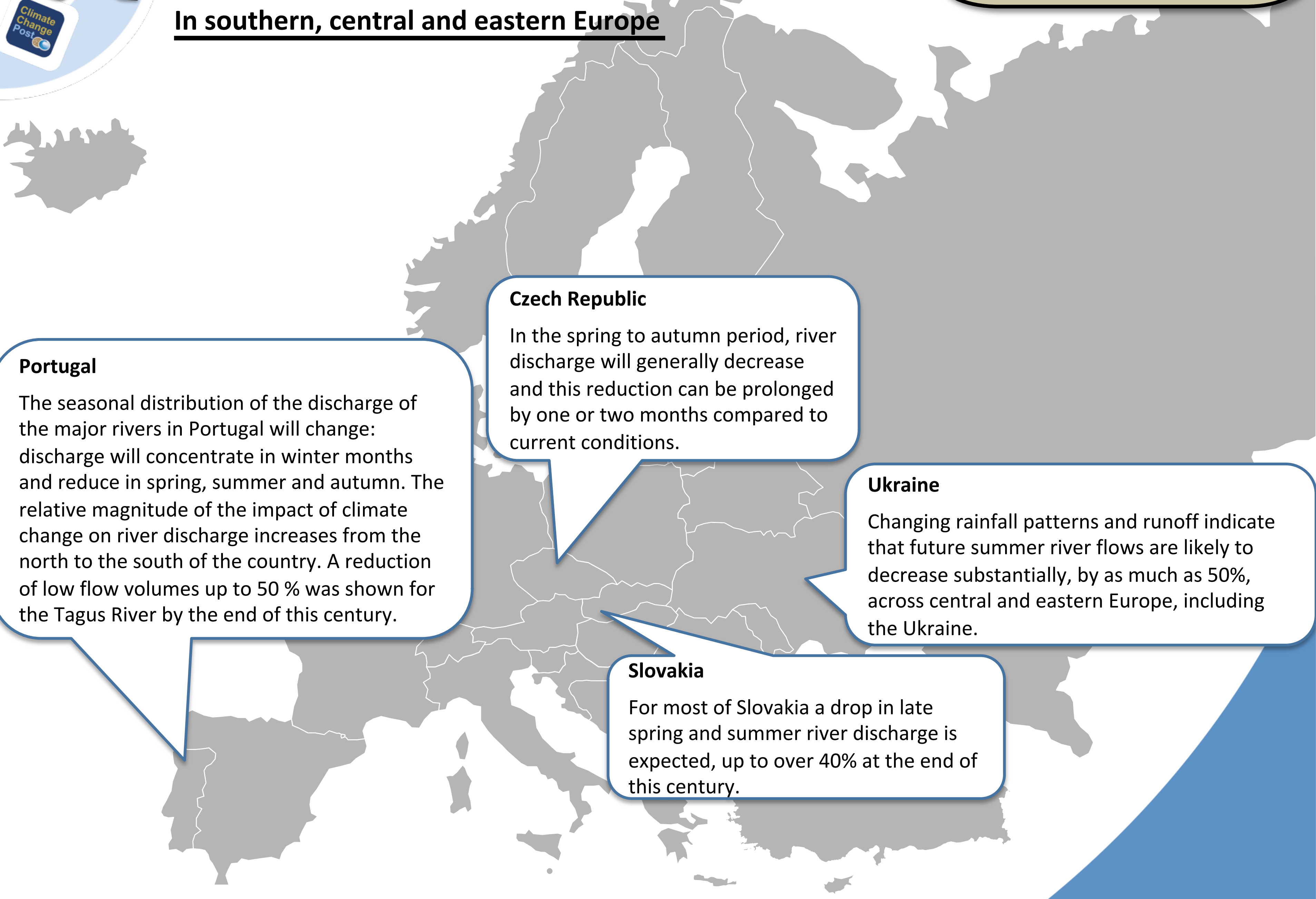
Low flow problems become more severe in Belgium in the future and are probably more important than the increase in flood risk; the summer base flow may decrease with more than 50% during dry summers by the end of this century.

France

Projections of the impact of climate change on the water resources of the Seine and Somme basins of northern France showed a decrease of the river flow at the outlets of both basins by at least 14% by the 2050s and at least 22% by the 2080s. Projected mean monthly river flow reductions in the Somme basin are around 20% in 2050 and 30% in 2080, while in the Seine basin, the decrease is larger in summer (30% in 2050, 40% in 2080) than in winter (0% in 2050 and 15% in 2080).

And low summer flows will decrease across most of Europe

In southern, central and eastern Europe



Portugal

The seasonal distribution of the discharge of the major rivers in Portugal will change: discharge will concentrate in winter months and reduce in spring, summer and autumn. The relative magnitude of the impact of climate change on river discharge increases from the north to the south of the country. A reduction of low flow volumes up to 50 % was shown for the Tagus River by the end of this century.

Czech Republic

In the spring to autumn period, river discharge will generally decrease and this reduction can be prolonged by one or two months compared to current conditions.

Ukraine

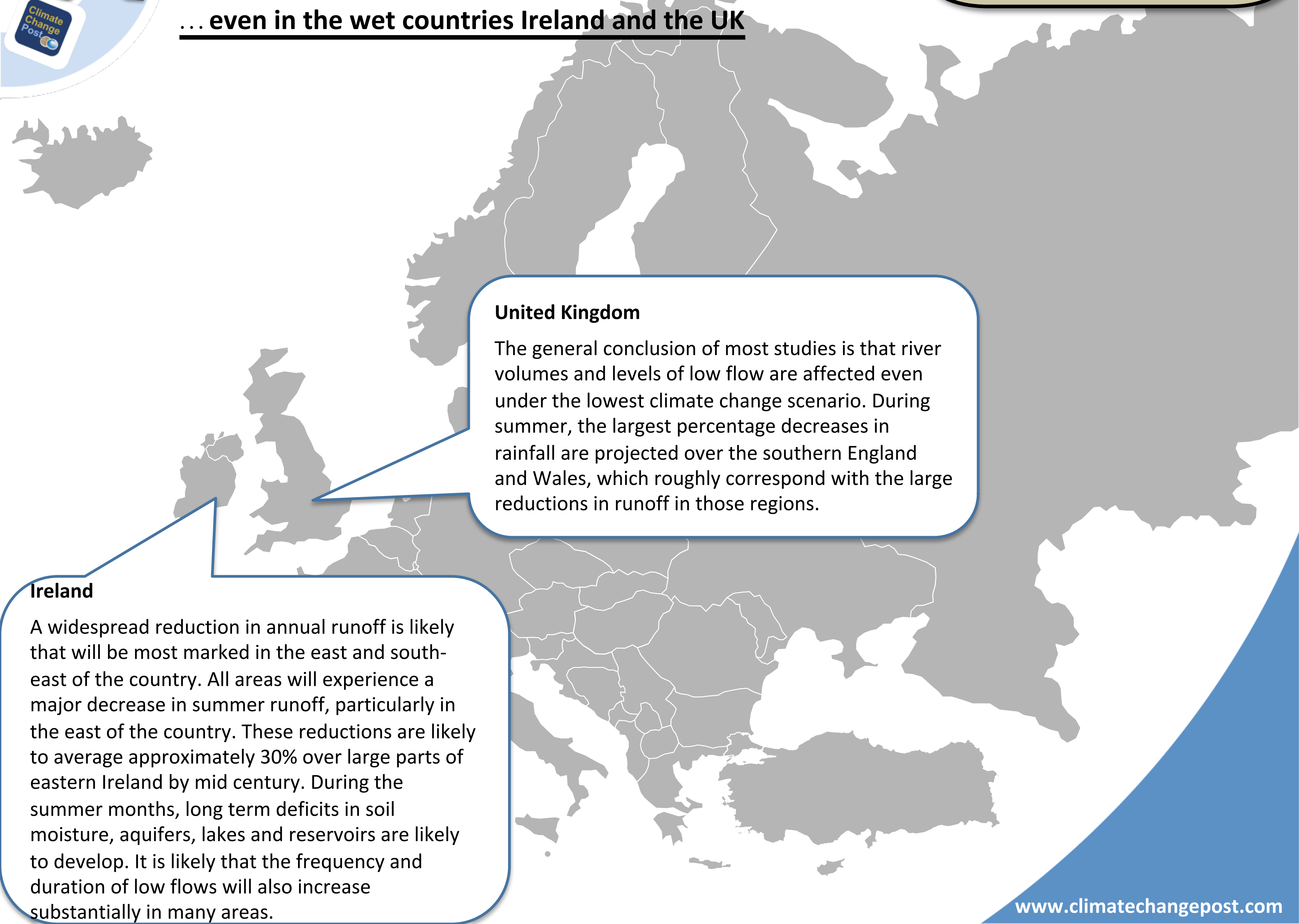
Changing rainfall patterns and runoff indicate that future summer river flows are likely to decrease substantially, by as much as 50%, across central and eastern Europe, including the Ukraine.

Slovakia

For most of Slovakia a drop in late spring and summer river discharge is expected, up to over 40% at the end of this century.

And low summer flows will decrease across most of Europe

… even in the wet countries Ireland and the UK



United Kingdom

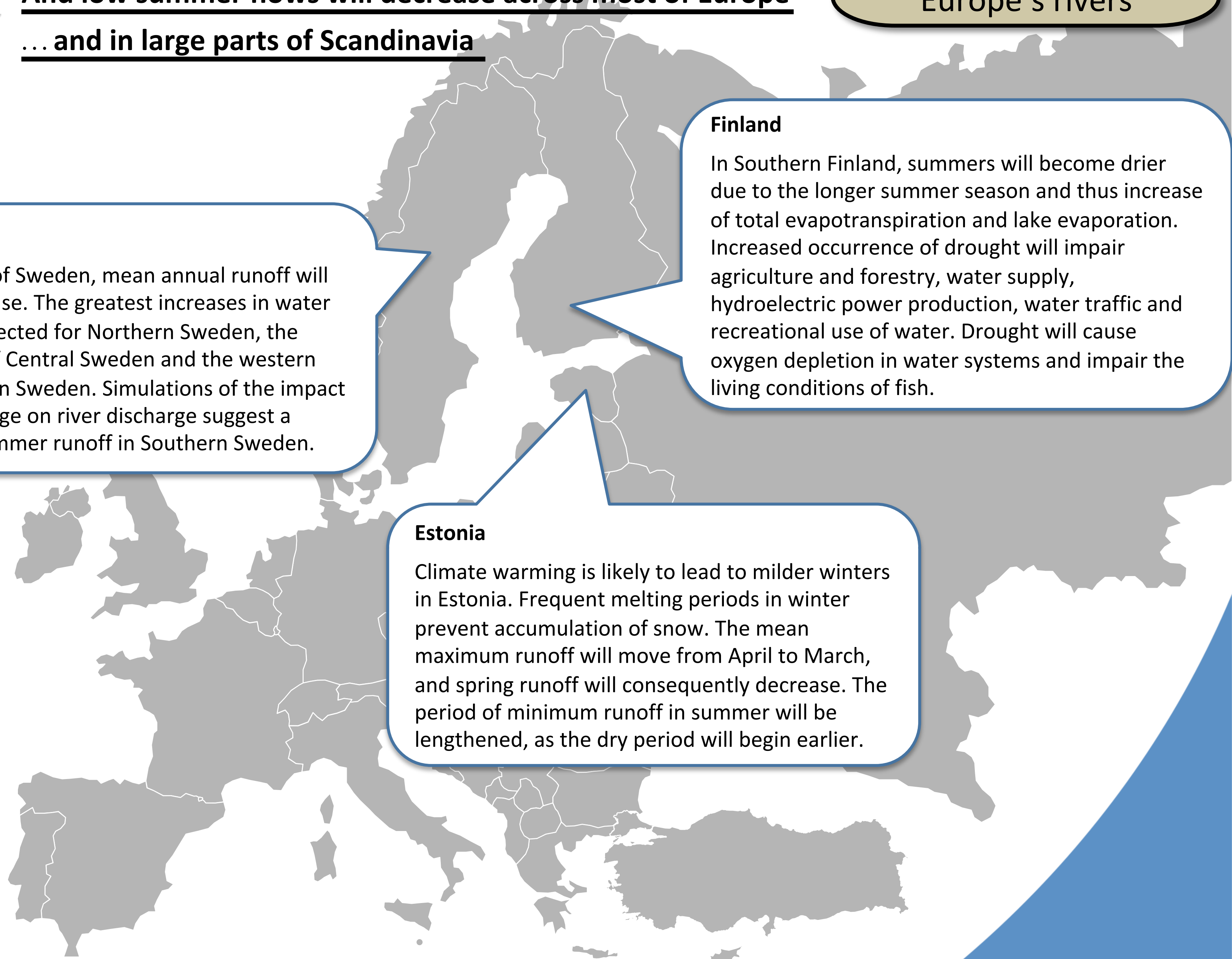
The general conclusion of most studies is that river volumes and levels of low flow are affected even under the lowest climate change scenario. During summer, the largest percentage decreases in rainfall are projected over the southern England and Wales, which roughly correspond with the large reductions in runoff in those regions.

Ireland

A widespread reduction in annual runoff is likely that will be most marked in the east and south-east of the country. All areas will experience a major decrease in summer runoff, particularly in the east of the country. These reductions are likely to average approximately 30% over large parts of eastern Ireland by mid century. During the summer months, long term deficits in soil moisture, aquifers, lakes and reservoirs are likely to develop. It is likely that the frequency and duration of low flows will also increase substantially in many areas.

And low summer flows will decrease across most of Europe

… and in large parts of Scandinavia



Sweden

For the whole of Sweden, mean annual runoff will probably increase. The greatest increases in water supply are projected for Northern Sweden, the western part of Central Sweden and the western part of Southern Sweden. Simulations of the impact of climate change on river discharge suggest a decrease of summer runoff in Southern Sweden.

Finland

In Southern Finland, summers will become drier due to the longer summer season and thus increase of total evapotranspiration and lake evaporation. Increased occurrence of drought will impair agriculture and forestry, water supply, hydroelectric power production, water traffic and recreational use of water. Drought will cause oxygen depletion in water systems and impair the living conditions of fish.

Estonia

Climate warming is likely to lead to milder winters in Estonia. Frequent melting periods in winter prevent accumulation of snow. The mean maximum runoff will move from April to March, and spring runoff will consequently decrease. The period of minimum runoff in summer will be lengthened, as the dry period will begin earlier.

Water quality is under stress

Main problem lakes: higher temperatures

Observed:

Lake summer surface water temperatures are warming significantly, with a mean trend of 0.34°C per decade over the period 1985-2009, across 235 globally distributed lakes. In Northern Europe, lakes were warming significantly faster than the global average.

Projected:

As a result, projections indicate a 20% increase in algal blooms and a 5% increase in toxic blooms over the next century in lakes globally. Increased evaporation associated with warming can lead to declines in lake water level, with implications for water security, substantial economic consequences, and in some cases, complete ecosystem loss.

Deep subalpine lakes in Europe are experiencing a decrease in the frequency of winter full turnover and an intensification of thermal stability. As a result, hypolimnetic oxygen concentrations are decreasing and nutrients are accumulating in bottom water, with effects on the whole ecosystem functioning.

Water quality is under stress

Main problem rivers: less dilution pollution

Declining river flows decrease their dilution capacity, resulting in increased concentrations of effluents from point sources. In addition, rising water temperatures decrease oxygen solubility and concentrations and increase the toxicity of pollutants (e.g. heavy metals and organophosphates) to fish and other freshwater species. Freshwater organisms might also experience increased stress due to lower summer flows that decrease available habitats and the exceedances of critical water temperature thresholds.

Water quality is under stress

Main problem groundwater: salt intrusion

The European picture

Reduced groundwater level increases the risk of contamination mainly from sea water intrusion in coastal aquifers. Besides, changes in river flow affect connected aquifers: reduced minimum flow, for instance, can lead to higher riverine concentration in wastewater effluents as waters are less diluted posing a risk to groundwater, with possible consequences for aquifers. Also, the effect of climate change on air temperature and river temperatures may influence groundwater temperatures and dissolved oxygen concentrations. Because many biogeochemical processes in groundwater are temperature dependent, climate-induced changes that affect groundwater temperature may negatively affect the quality of groundwater.

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