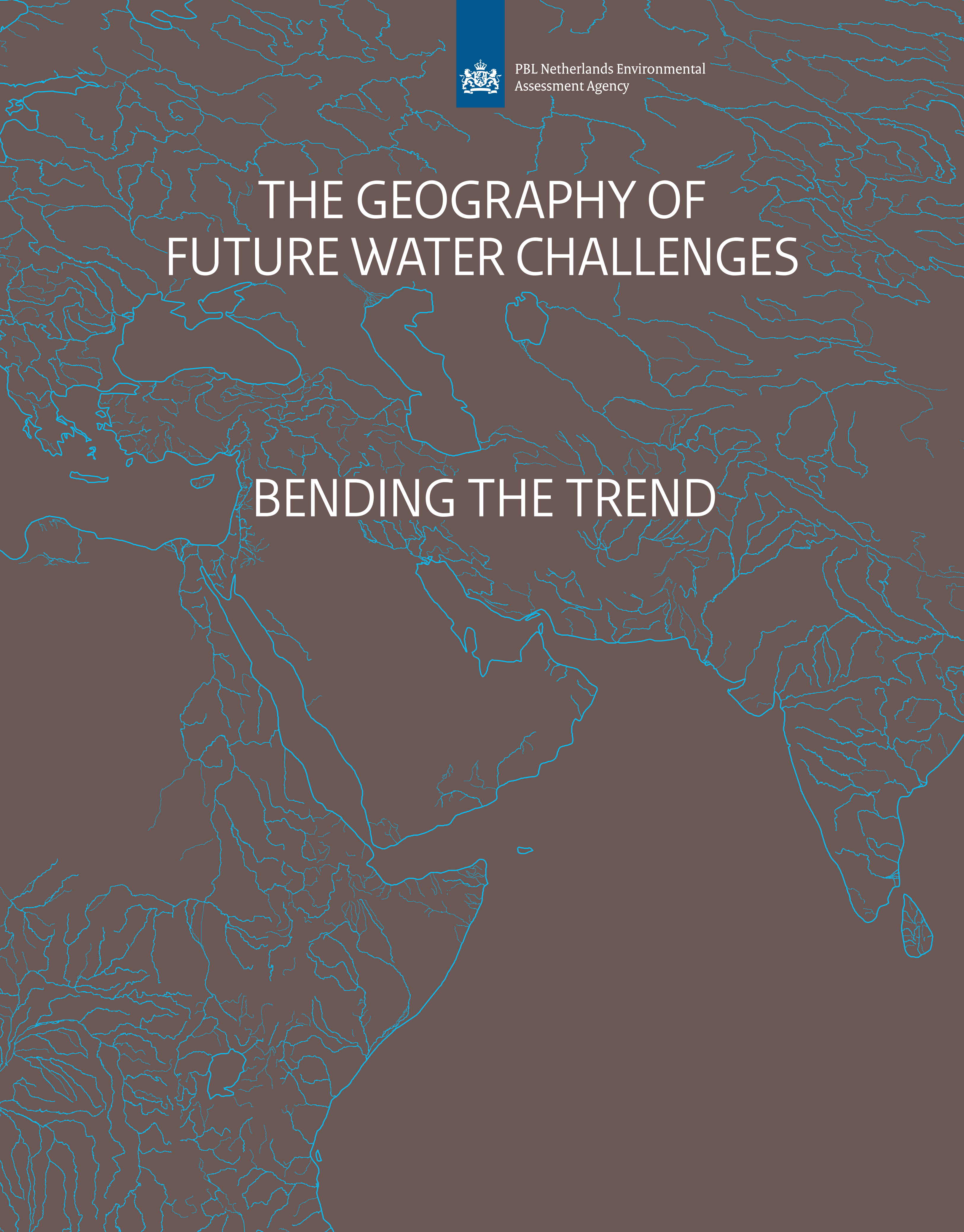
PBL Netherlands Environmental
Assessment Agency



THE GEOGRAPHY OF FUTURE WATER CHALLENGES

BENDING THE TREND

The Geography of Future Water Challenges
Bending the Trend

THE GEOGRAPHY OF FUTURE WATER CHALLENGES

BENDING THE TREND

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FOREWORD

Water security is a matter of life and death for the world. People are not only causing water-related risks and stresses, they are also negatively affected by them — in many cases exacerbated by climate change. Since the publication of *The Geography of Future Water Challenges* in 2018, events of extreme flooding, drought, wildfires and tropical storms have increasingly disrupted societies and ecosystems around the world. Without the urgently needed, collective and effective responses, water- and climate-related disasters are projected to get worse.

This follow-up study, requested by the Dutch Ministry of Infrastructure and Water Management, shows that we can bend the trend of increasing water- and climate-related stresses, as presented in the 2018 report. Captured in infographics and focused on high ambition future pathways, in particular, an overview is given of what could be achieved with concrete measures in four hotspot landscapes: river basins, deltas and coasts, dryland regions and cities. Results show that we can strongly reduce flood risks, subsidence, the negative effects of new dams, and the risks of migration and conflict, while improving crop production and water-use efficiency in agriculture, households and industries, often in combination with restoring ecosystem quality, strengthening biodiversity and reducing social inequities. On the other hand, the already existing industry, infrastructure, dams and the projected level of nutrient emissions will continue to decrease water security and hamper ecological restoration of freshwater ecosystems.

The interrelated global water, climate change and biodiversity crises show that current value systems, policies and economic practices are not suitable for bending the trend. It is clear, now more than ever, that water needs to be at the top of everyone's agenda, from local actors to global organisations and from public to private enterprises around the world. Fundamental transitions in the way we use our water resources, produce our food and energy and protect ourselves against flooding are needed, if we are to find our way out of the interdependent ecological, economic and social crises. Acknowledgement of the value of water as a human right and global common good, and recognition of the increasing water-related stresses in all its dimensions and on all scales, can form the basis for building coalitions, bridging interests, overcoming lock-inns and creating a shared, inclusive, resilient and sustainable future.

Extensive future pathways and global targets are available for the development of policy on reducing greenhouse gas emissions, but for water security and reducing climate risks these are still lacking. Climate change, population growth and economic development will not wait and the world is already facing a huge adaptation deficit. The urgency to take action and achieve transformation is high and the coming decades will be critical in bending the trend. We hope that the perspectives and turnarounds presented in this study will help to increase awareness, add insights into *what* could be achieved and *how*, and help build a common agenda for water security for all.

Marko Hekkert,
Director-General of PBL Netherlands Environmental Assessment Agency

Henk Ovink,
Special Envoy for International Water Affairs for the Kingdom of the Netherlands

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SETTING THE SCENE

WATER, ESSENTIAL FOR LIFE

The worldwide degradation of natural resources is one of the major societal challenges. Water is one of the most important resources for humankind. It is a prerequisite for life on our planet an cuts across many social, economic and environmental activities.

Water brings life, but also can be disruptive in the way of pollution, flooding and drought. The United Nations defines water security as: 'The capacity of a population to safe-guard sustainable access to adequate quantities of and acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability.'

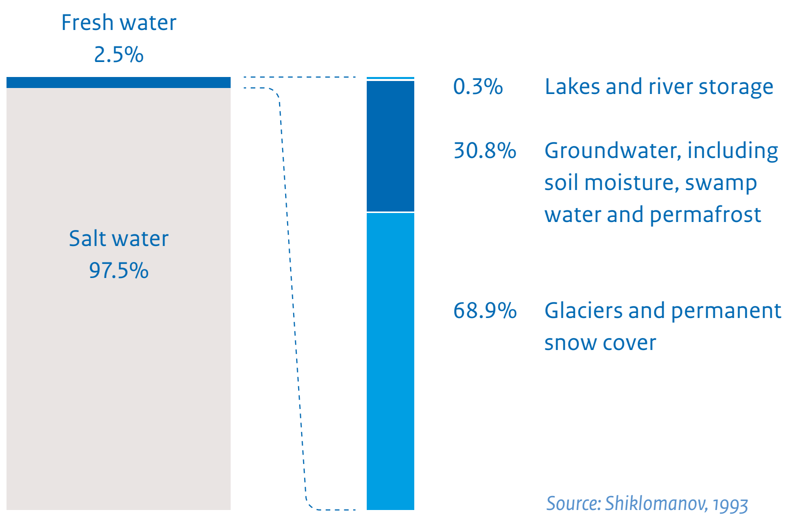
Water security is related to three water-related challenges:

1. water scarcity (too little water),
2. water pollution (dirty water) and
3. flood risk (too much water).

Today and in the coming decades, these challenges and their impact on people's daily lives are increasing due to population growth, economic development, increased agricultural production and climate change, in turn affecting water availability, sea level rise and weather patterns.

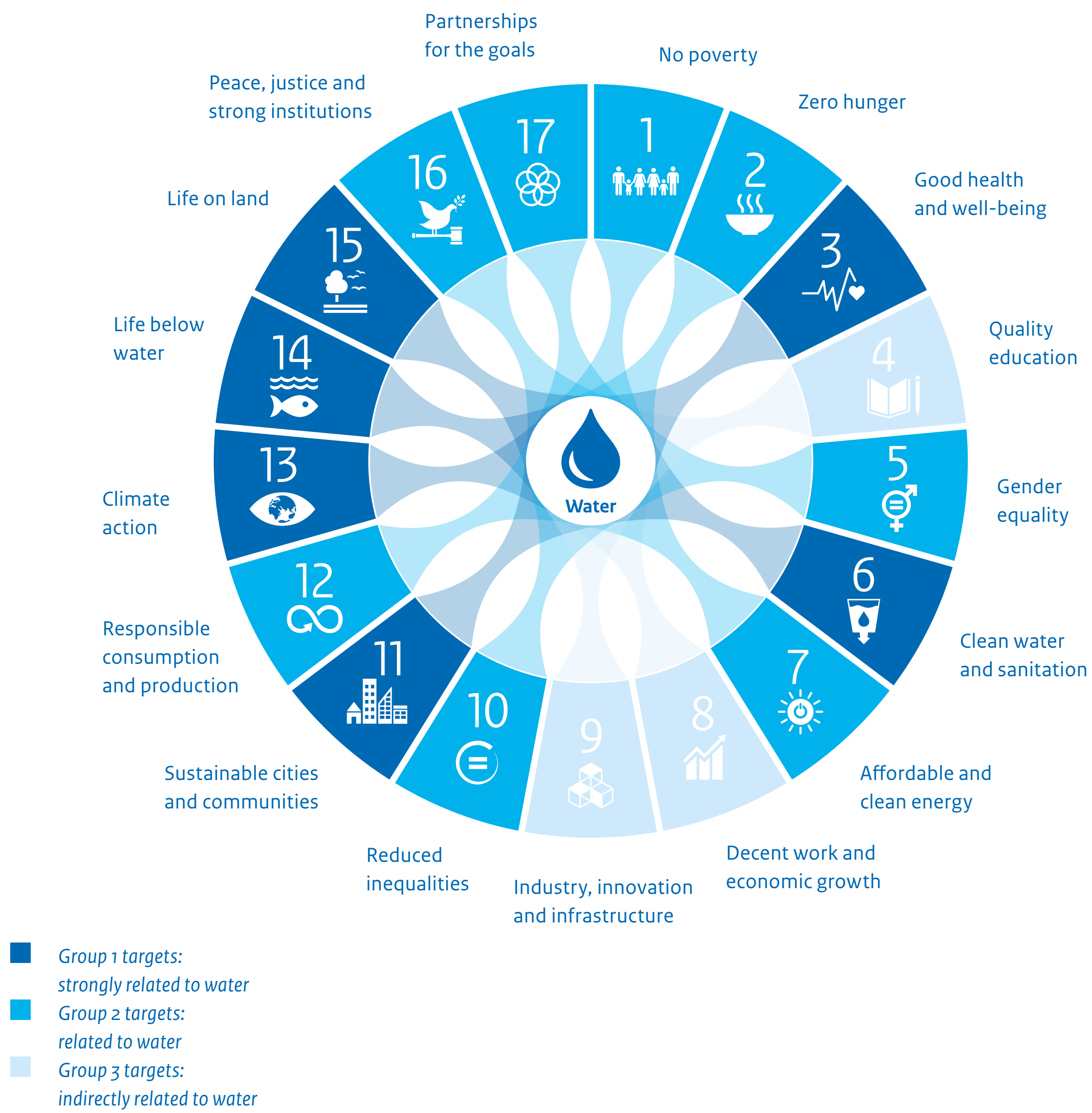
Water, critical for sustainable development
Water cuts across many social, economic and environmental activities and interventions, and thus is linked to many Sustainable Development Goals (SDGs) such as human health and well-being, clean water and sanitation, food production, sustainable cities and communities, climate adaptation, and the quality of ecosystems. Sustainable development, therefore, cannot be achieved without improving water management and reducing water- and climate-related risks for people, economy and ecosystems.

Fresh water: a precious resource
Only 2.5% of the water on earth is fresh water; about 70% of which is stored in ice, 30.8% in groundwater systems, and 0.3% is directly available in rivers and lakes.



Source: Shiklomanov, 1993

All Sustainable Development Goals are linked to water



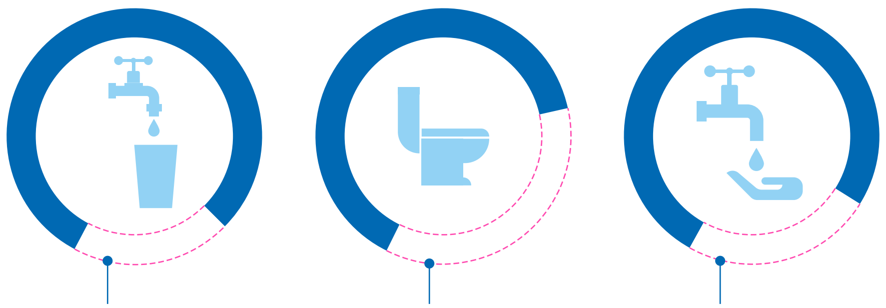
Source: PBL

RISKS ARE STILL HIGH

In their most recent overview, in 2022, the IPCC concluded that the increasing climate risks require urgent attention and climate adaptation efforts worldwide, and that transformational approaches are needed yet hardly found.

The proportion of the global population using safely managed drinking water services increased from 70% in 2015 to 74% in 2020. For safely managed sanitation services, this increased from 47% to 54%, over the same period. The number of deaths in 2021 due to polluted water and lack of sanitation was still high, however, at around 800,000. This has a negative impact on achieving the Sustainable Development Goal (SDG3) 'Good Health and Well-being' and also means that the targets related to SDG6 'Clean Water and Sanitation' will not be achieved by 2030 (UN, 2022).

No access to clean water or sanitation (2030)



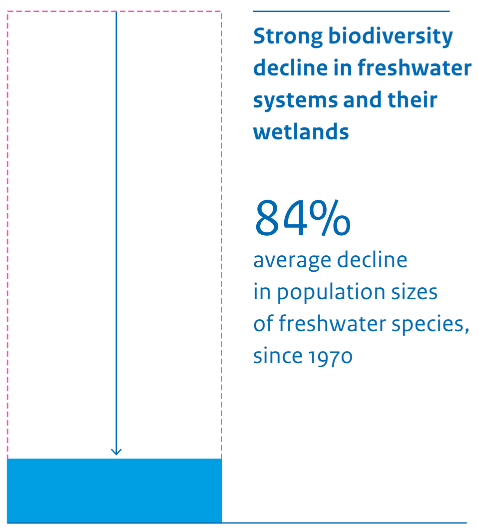
1.6 billion people will lack safely managed drinking water

2.8 billion people will lack safely managed sanitation

1.9 billion people will lack basic hygiene

Source: United Nations, 2022

More than half of the key biodiversity areas of the world are unprotected (UN, 2022) and the biodiversity of freshwater ecosystems has declined far more than that of all other ecosystems in the world (WWF, 2021).



Strong biodiversity decline in freshwater systems and their wetlands

84% average decline in population sizes of freshwater species, since 1970

Source: WWF, 2022

Selection of main conclusions of IPCC 2022 ***Impacts, Vulnerability and Adaptation***

- Further global warming will cause unavoidable increases in multiple climate hazards and presents multiple risks to ecosystems and humans.
- Current unsustainable development patterns are increasing exposure of ecosystems and people to climate hazards.
- The level of risk will depend on concurrent near-term trends in mitigation efforts, level of socio-economic development, exposure, vulnerability, and adaptation.
- Continued and accelerating sea level rise will encroach on coastal settlements and infrastructure, and lead to submergence and loss of low-lying coastal ecosystems. If trends in exposed areas continue, this will exacerbate the impacts.
- Vulnerability is higher in areas with poverty, governance challenges and limited access to basic services and resources, violent conflict and high levels of climate-sensitive livelihoods.
- The increasing climate risks require urgent attention and efforts in climate adaptation worldwide.
- There is negligible evidence that existing responses are adequate to reduce climate risk. Transformational approaches are needed to tackle complex challenges across sectors and scales, but are hardly found.

WATER-RELATED DISASTERS SINCE 2018

Since we published our first study in 2018, 1080 water- and climate-related disasters have been reported, globally. In four years' time — from 2018 to 2021 — droughts, river flooding events, landslides and tropical storms affected 275 million people and caused USD 444 billion in economic damage.

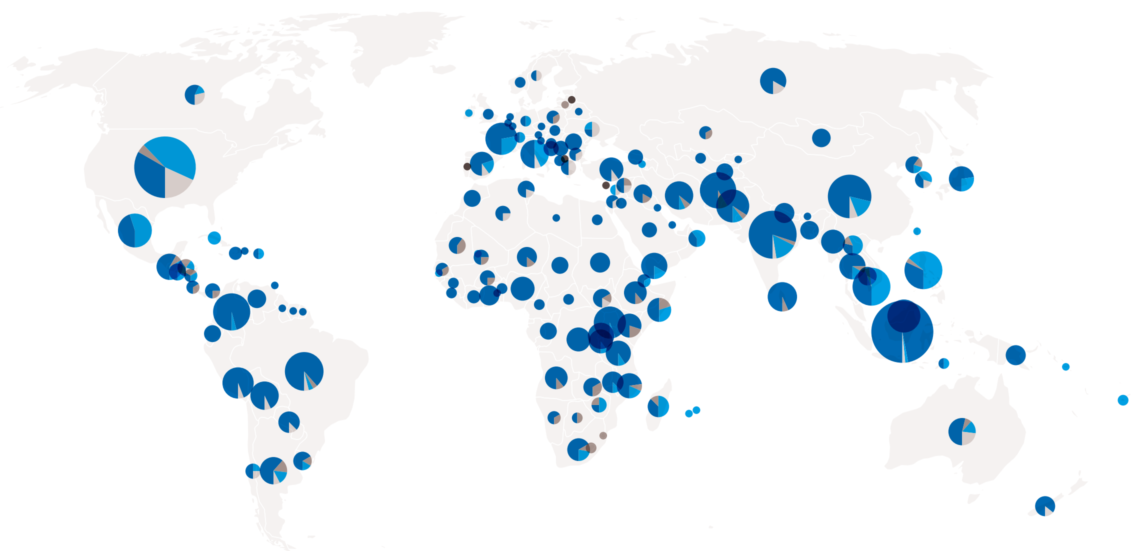
The number of water-related natural disasters, 2018–2021

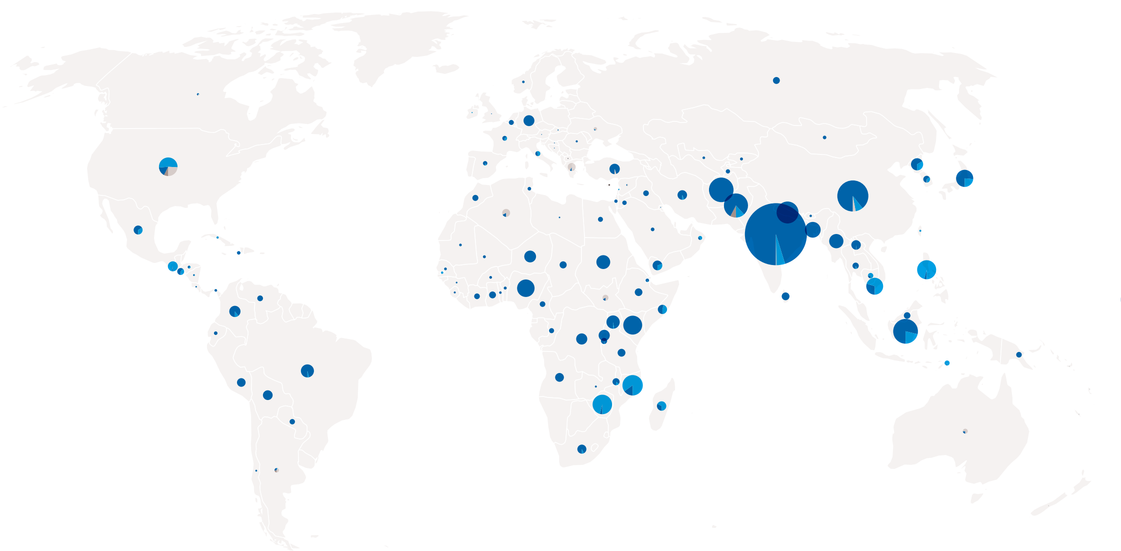
Floods
Droughts
Storms
Wildfires

40 disasters

5 disasters

Source: EM-DAT, CRED / UCLouvain, Brussels, Belgium – www.emdat.be (2022)





People killed by water-related natural disasters, 2018–2021

Floods
Droughts
Storms
Wildfires

6,000 people killed

600 people killed

Source: EM-DAT, CRED / UCLouvain, Brussels, Belgium – www.emdat.be (2022)

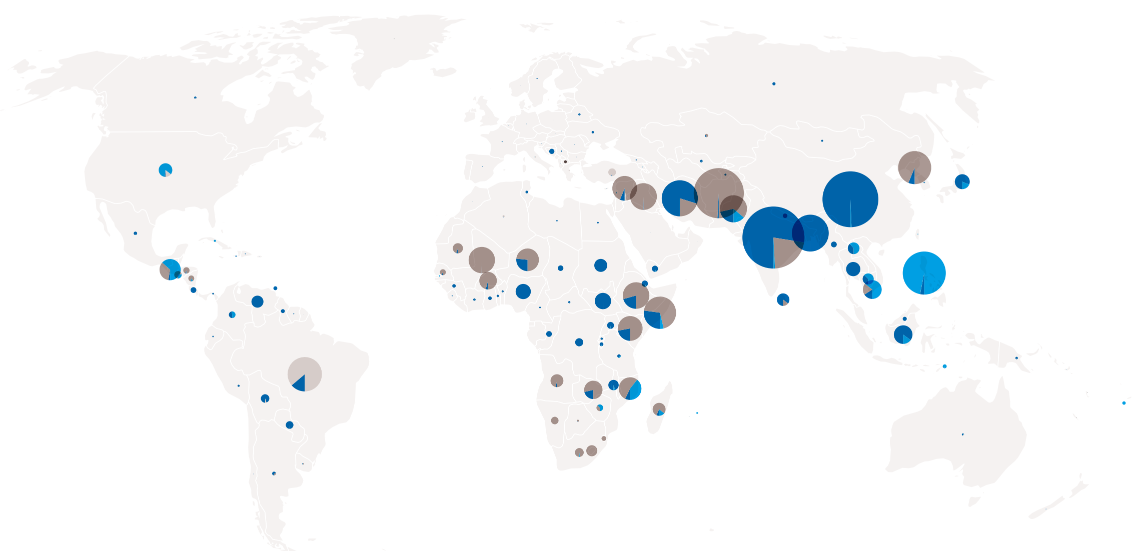
People affected by water-related natural disasters, 2018–2021

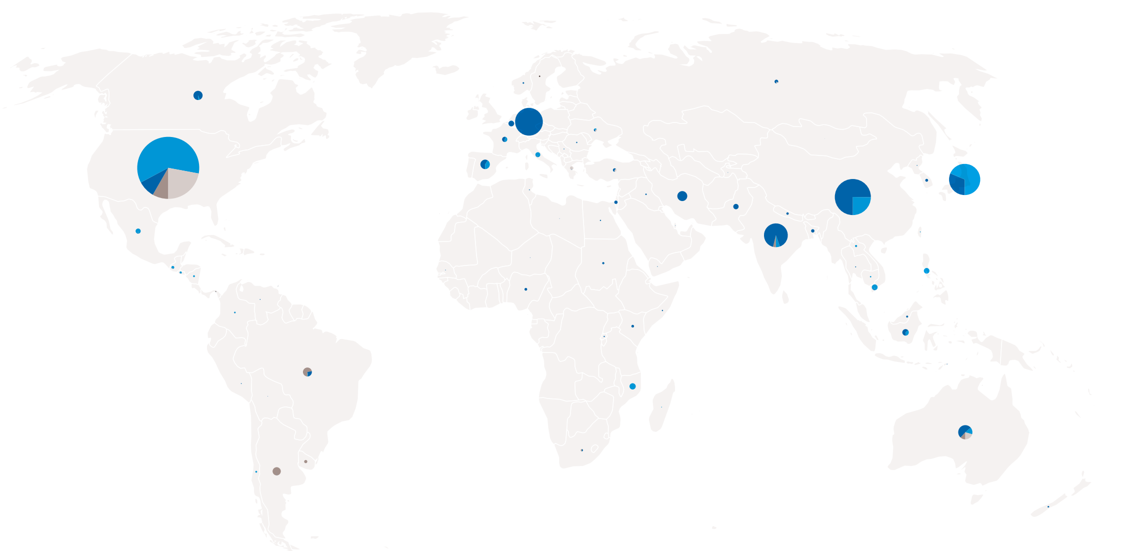
Floods
Droughts
Storms
Wildfires

25 million people affected

6 millon people affected

Source: EM-DAT, CRED / UCLouvain, Brussels, Belgium – www.emdat.be (2022)





Economic damage from water-related natural disasters, 2018–2021

Floods
Droughts
Storms
Wildfires

USD 50 million in economic damage

USD 8 million economic damage

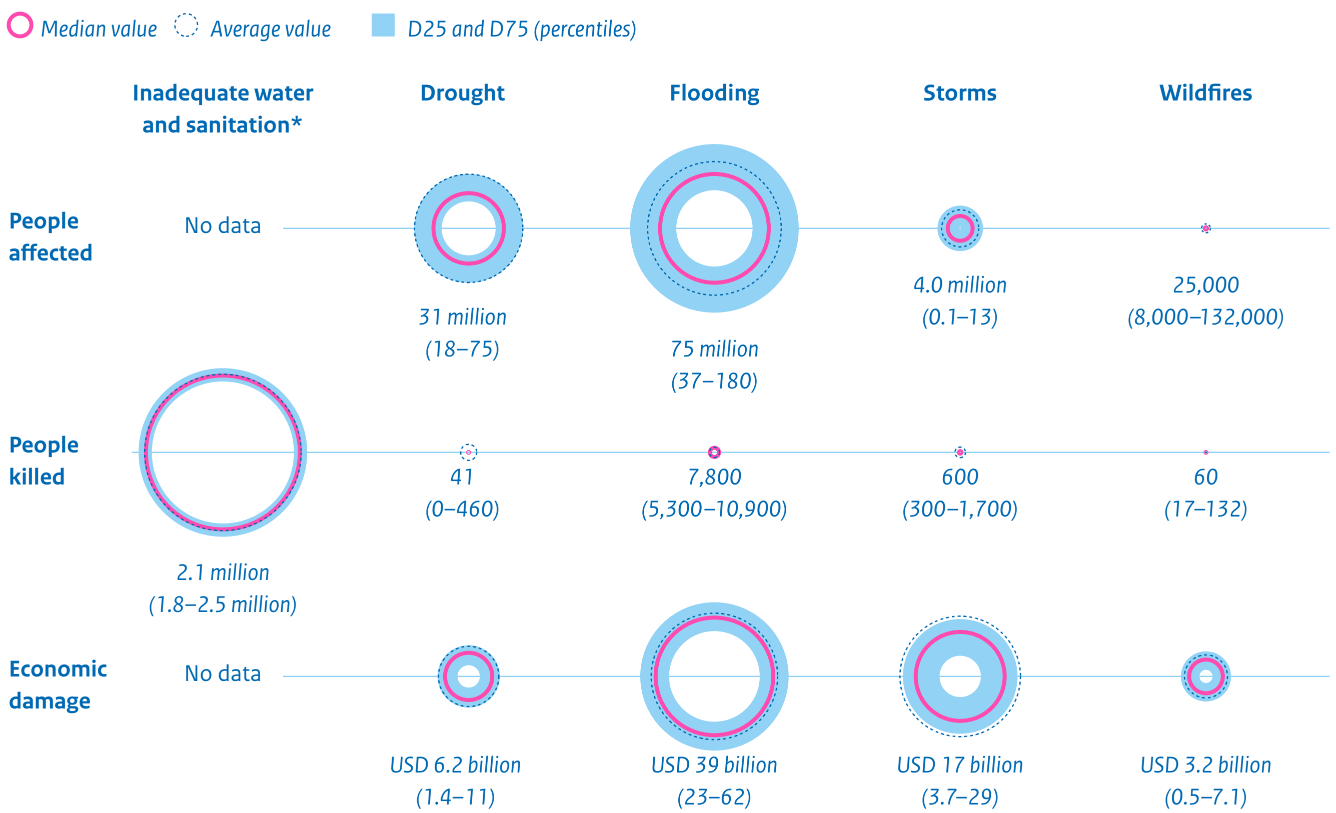
Source: EM-DAT, CRED / UCLouvain, Brussels, Belgium – www.emdat.be (2022)

THE UNEQUAL BURDEN OF WATER- AND CLIMATE-RELATED DISASTERS

Almost a million people die from water pollution, each year, and water- and climate-related weather extremes (drought, extreme rainfall, flooding, storm surges) kill thousands of people and cause billions of euros in economic damage.

The annual number of people affected by natural disasters, globally, between 1980 and 2021 was the highest for flooding events (including landslides), followed by storms and droughts. The number of deaths from diarrhoea and cholera far exceeded the number of people killed by natural disasters. Flooding and storms caused the greatest economic losses. The blue circles illustrate that the actual numbers vary strongly, from one year to the next.

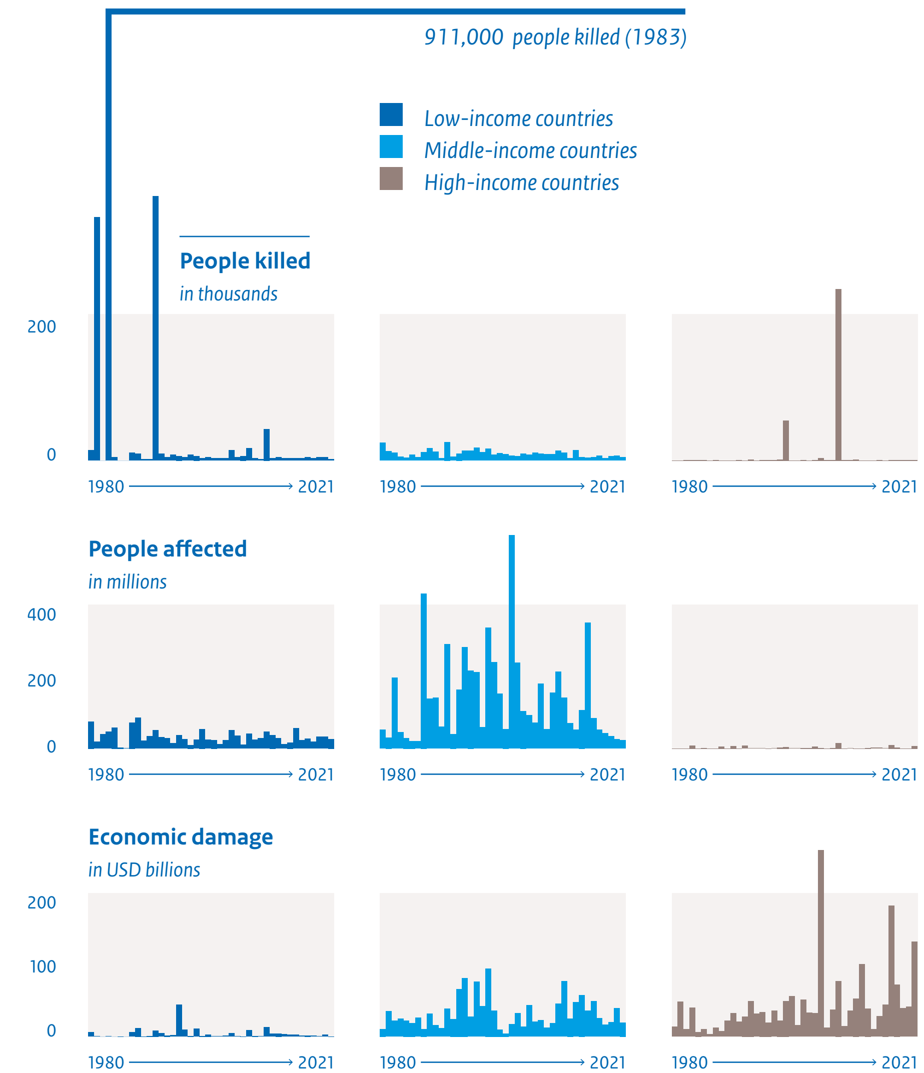
Annual impact from water-related disasters and diseases, globally, 1980–2021



*Source: IHME, 2019 (data 1990 - 2019)
Source: CRED

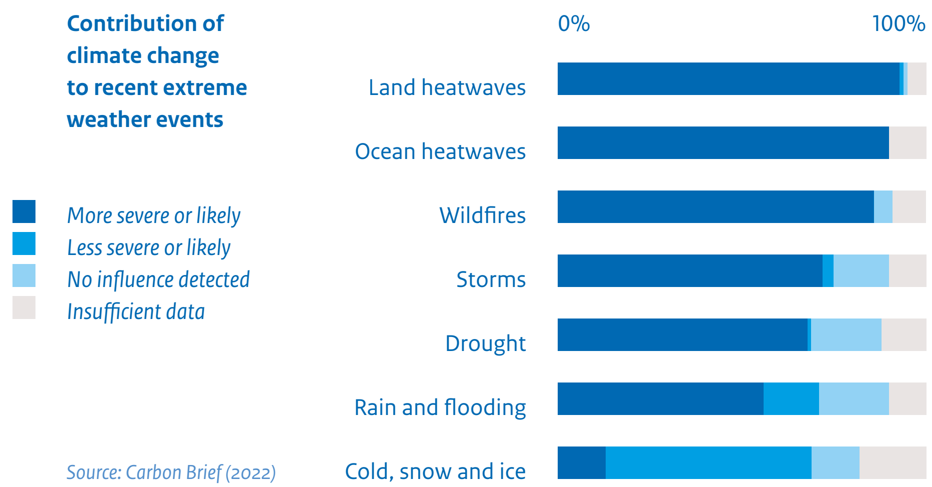
The number of people affected and killed by water- and climate-related disasters is relatively high for low- and middle-income countries. Economic losses are the greatest in high-income countries.

In the 2022 report by the Lancet Countdown on health and climate change, experts conclude that 84% of global economic losses due to climate-related extreme events in 2021 affected the richest countries. The population of the poorest countries suffered the most, however, since in these countries almost none of the losses were insured.



Source: CRED
Data corrected for population growth / economic growth during this period

Contribution of climate change to recent extreme weather events



Source: Carbon Brief (2022)

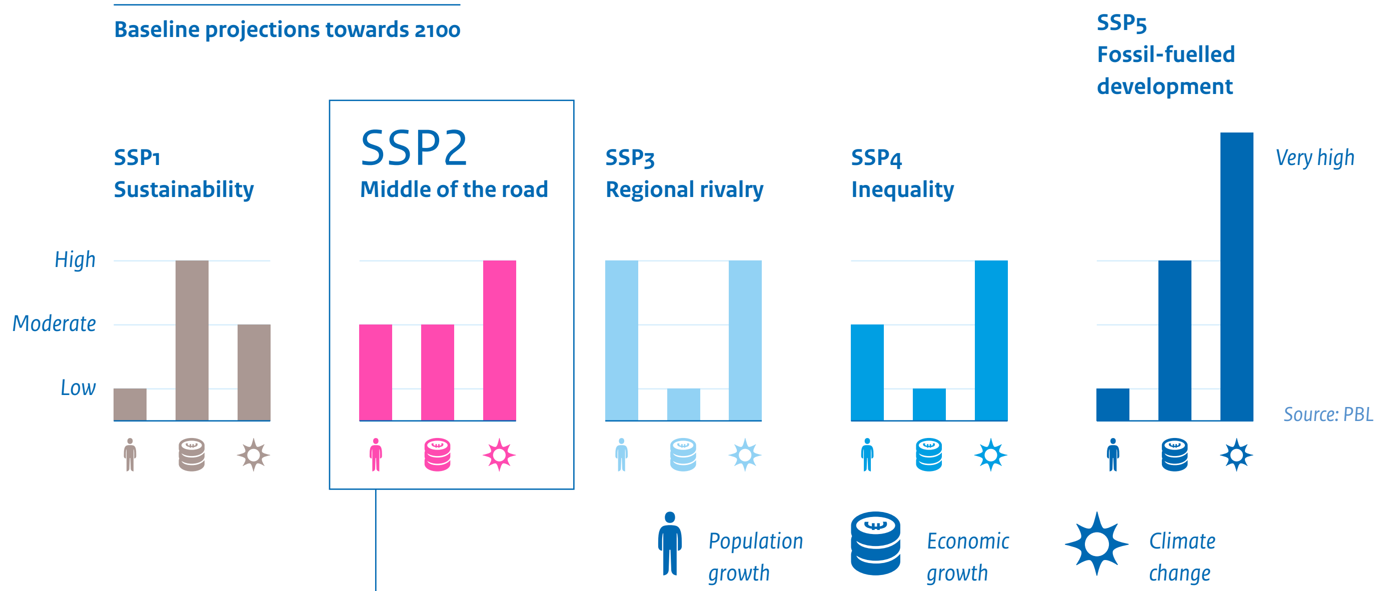
The time series in the graphs above, corrected for changes in population and economic growth, do not show a trend of changes in the global, annual number of people affected or killed by water-related disasters, or in the economic damage caused by these disasters, in the 1980–2021 period. Climate change is, however, already manifest in extreme weather events across the globe: the likelihood and intensity of most extreme weather events have increased in recent years due to climate change.

THE PRESSURES ON WATER SYSTEMS WILL FURTHER INCREASE

The pressures on water ecosystems will increase the next decades. We use the Business-as-usual pathway SSP2 in combination with RCP6.0 as a baseline for future socio-economic and climate change developments

The scientific community has developed five shared socio-economic pathways (SSPs) to explore the future. These pathways are narratives without climate policies that broadly outline the characteristics of a possible global future, in terms of population growth, economic and technological development, global collaboration and urbanisation. These five pathways result in a range of challenges for mitigation (reducing greenhouse gas emissions), adaptation (adjusting to climate change), water security, food security, biodiversity conservation and social equality.

Baseline projections towards 2100



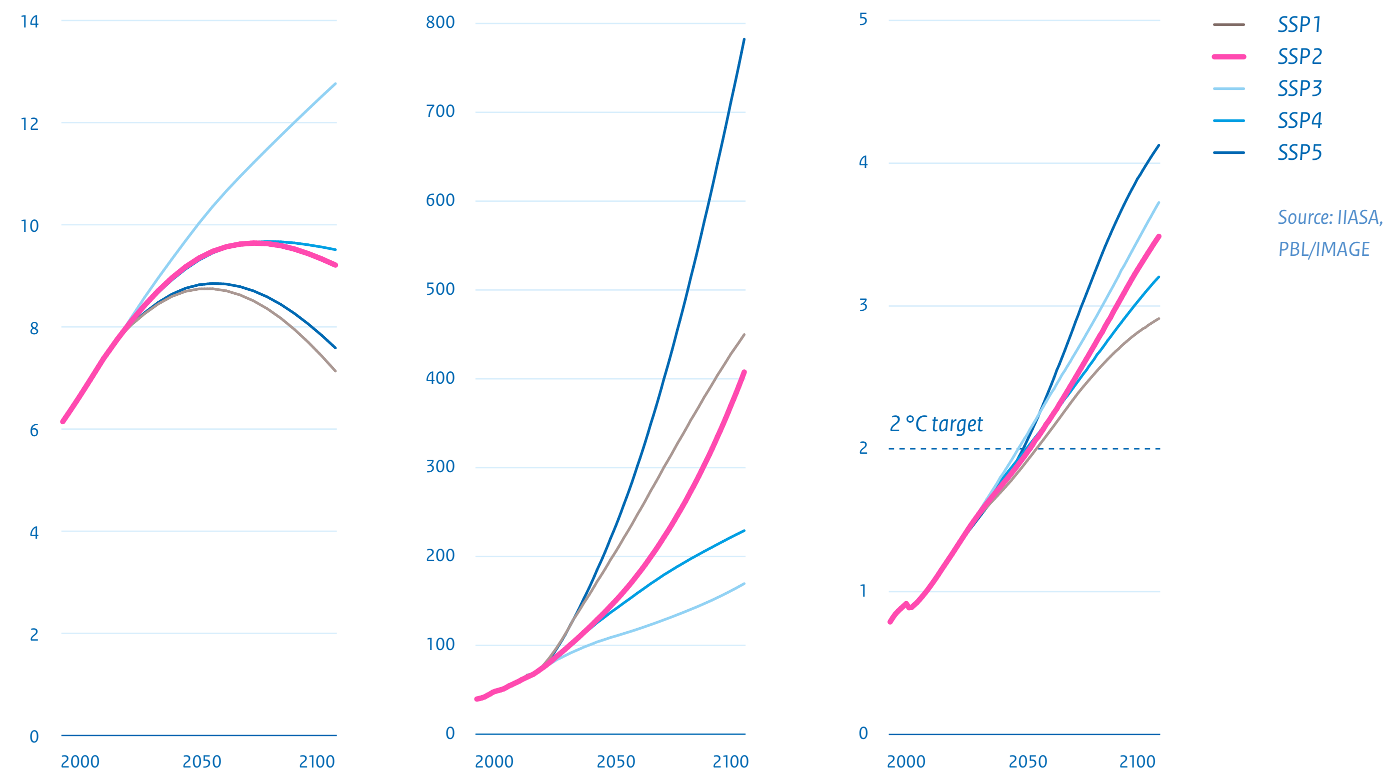
The Business-as-usual scenario — the socio-economic SSP2 scenario, in combination with the climate change scenario RCP6.0 — is our starting point to explore potential future solutions. The SSP2 pathway reflects a middle-of-the-road socio-economic and mitigation development. The RCP6.0 climate change scenario projects a temperature increase of close to 3 °C by 2070 and 3.7 °C by 2100.
This combination, thus, reflects a situation in which the Paris Agreement's target of a maximum global temperature increase of 1.5 °C or 2 °C will not be achieved, and realising the water and climate adaptation challenges will be more complicated than along more successful mitigation pathways (SSP1). Likewise, the impacts of pathways with more population and/or economic growth and more global warming will result in more severe impacts (SSPs 3, 4, 5).

Shared socio-economic pathways
Under the SSP2 pathway, the population growth from 7 billion people today to around 9 billion people by 2070, and the projected further economic development will strongly increase the use of and pressure on the water resources and aquatic ecosystems. This will increase the challenge to adapt, as shown in PBL's *Geography of Future Water Challenges* (2018) and confirmed by IPCC 2022.

Global population
in billion people

Global GDP
in USD_{2005} trillion, per year

Global temperature change
in °C, compared to pre-industrial levels

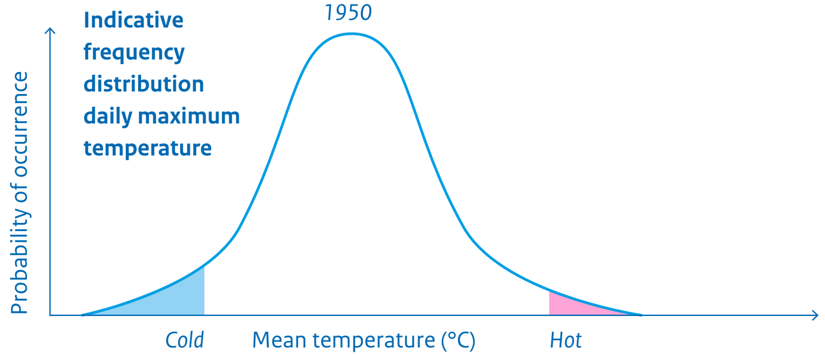


THE CLIMATE IS CHANGING AND SO IS THE LIKELIHOOD OF EXTREMES

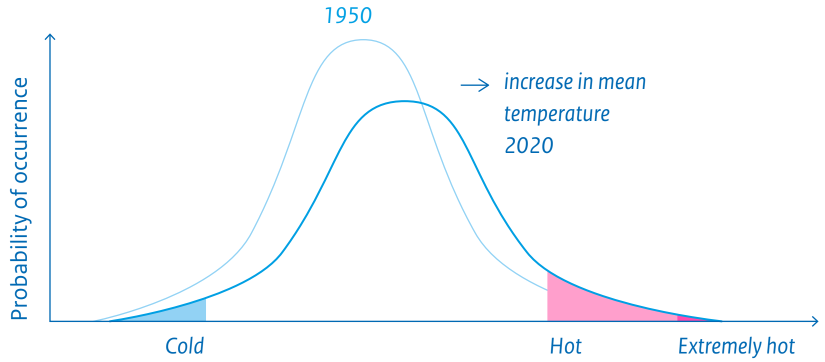
The curve describing the probability of occurrence of daily maximum temperatures looks like a bell. The bell curve is both shifting to higher temperatures and changing in shape. Days with an annual mean temperature are occurring less often while the likelihood of extremely hot temperatures is increasing rapidly.

Shift in mean conditions, stronger shift of extremes

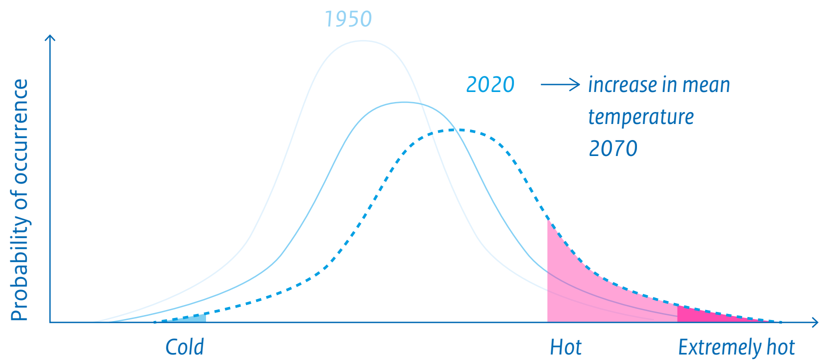
Climate change includes both gradual changes, such as in average temperature, precipitation patterns and sea level rise, and changes in weather extremes, such as heatwaves, droughts, flooding events and storm surges.



Long-term NASA measurements show a fundamental change in the frequency distribution of the global daily temperature over the 1950–2020 period, with a lower probability of average temperatures and a higher probability of extreme values. If this trend continues towards 2100, extreme events are expected to occur more often than they are today.



The populations, economies and ecosystems of the future, thus, will face an increase in the frequency and intensity of extreme weather conditions and higher risks of disaster. Increased efforts in adequate climate adaptation will be needed to reduce current and future disaster risks (PBL, 2018; IPCC, 2022).



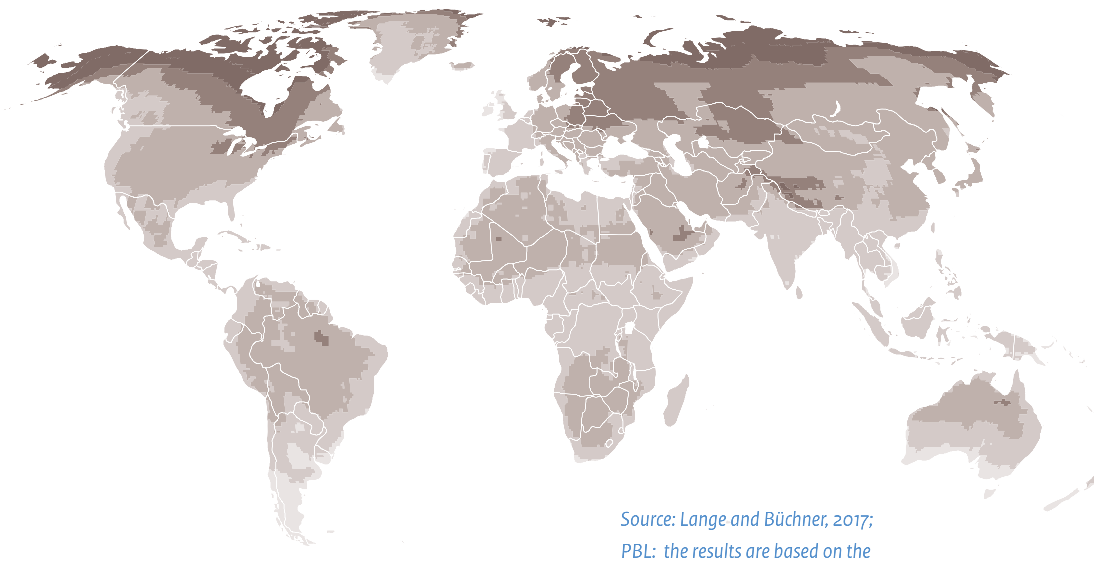
Source: PBL

Change in temperature 2020–2070

Under the RCP6.0 climate scenario, global average temperature is projected to increase by over 2 °C by 2070, with large regional differences. Global warming is relatively strong in the northern regions.

degrees Celsius

- < 1
- 1 – 1.5
- 1.5 – 2
- 2 – 2.5
- > 2.5



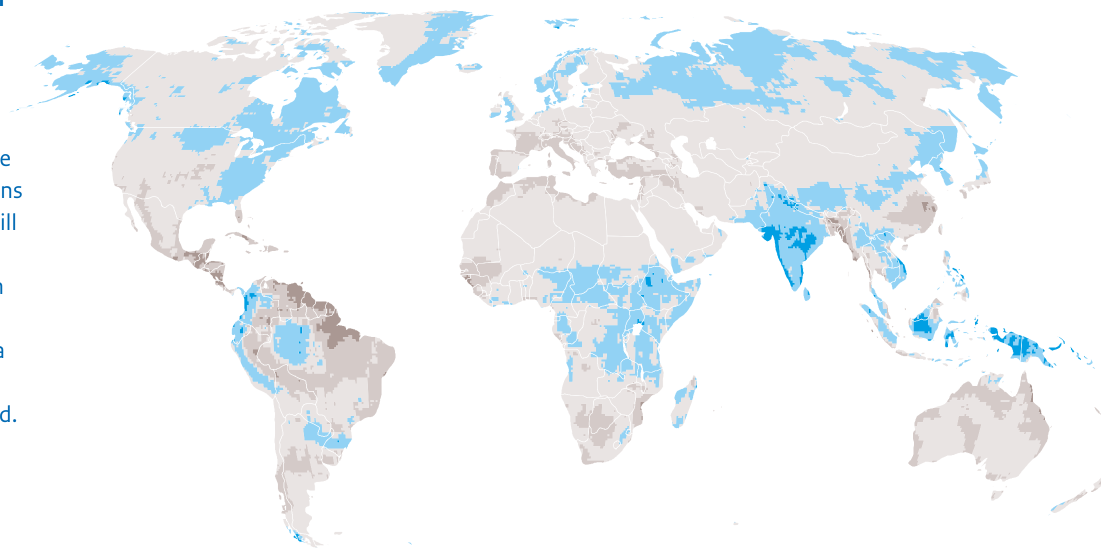
Source: Lange and Büchner, 2017; PBL: the results are based on the projections of 4 climate models

Change in precipitation 2020–2070

Under the RCP6.0 climate scenario, in general, the net result of changing temperature and precipitation patterns is that most dry areas will become dryer and wet areas wetter, apart from dryland regions in East Africa and southern Asia where an increase in precipitation is projected.

mm/day

- < -0.5
- -0.5 – -0.1
- -0.1 – 0.1
- 0.1 – 0.5
- > 0.5



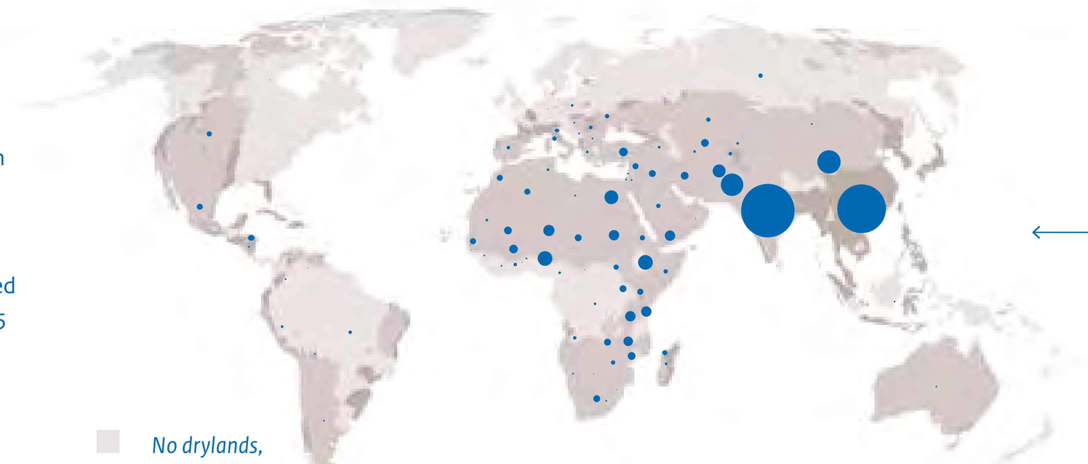
Source: Lange and Büchner, 2017; PBL: the results are based on the projections of 4 climate models

REDUCING RISKS: FOUR HOTSPOT LANDSCAPES

In *The Geography of Future Water Challenges* (2018), we identified four hotspot landscapes, with clusters of water- and climate-related challenges. We use these hotspot landscapes to explore future pathways for tackling these challenges.

Drylands and water-stressed areas

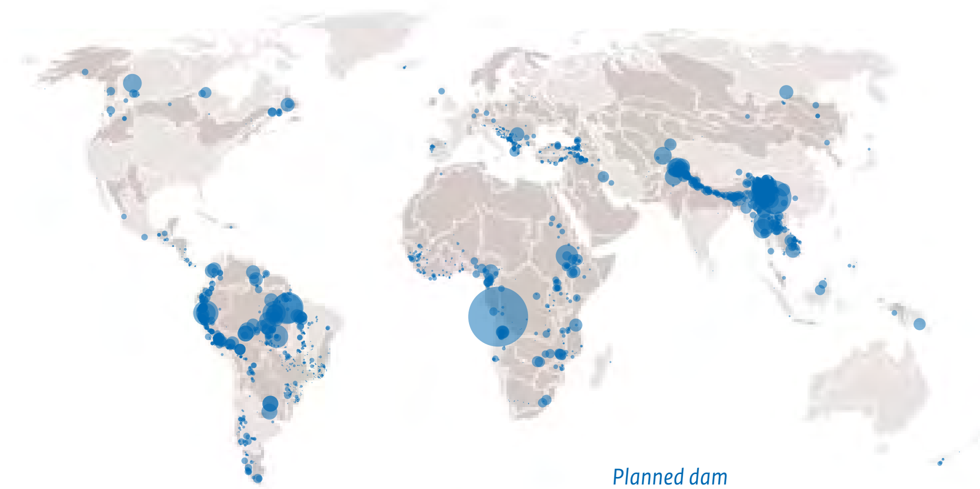
The global dryland population is projected to increase from around 2.8 billion today to 4 billion by 2070. The rural dryland population is projected to remain steady at around 1.5 billion. Changes are projected to be most dramatic in Sub-Saharan Africa, with a 40% increase in rural population and a tripling urban dryland population. Here, increased water stress and crop yield gaps may increase migration and the risk of conflict.



No drylands, no water stress
Drylands
Water stress outside drylands
Rural population 2050
Source: PBL/IMAGE

Transboundary river basins

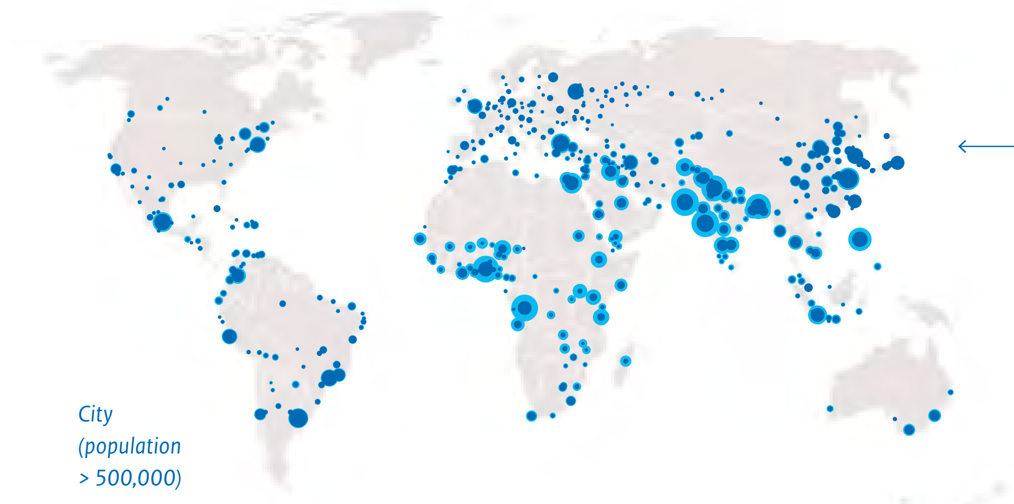
The currently planned 3700 large new dams for hydropower and irrigation will further reduce freshwater biodiversity and sediment flows to deltas and coasts. These dams in combination with increasing water demand and water pollution will increase the pressure on transboundary collaboration in river basins.



Planned dam (capacity in MW)
10,000
Transboundary river basin
Source: PBL

Cities

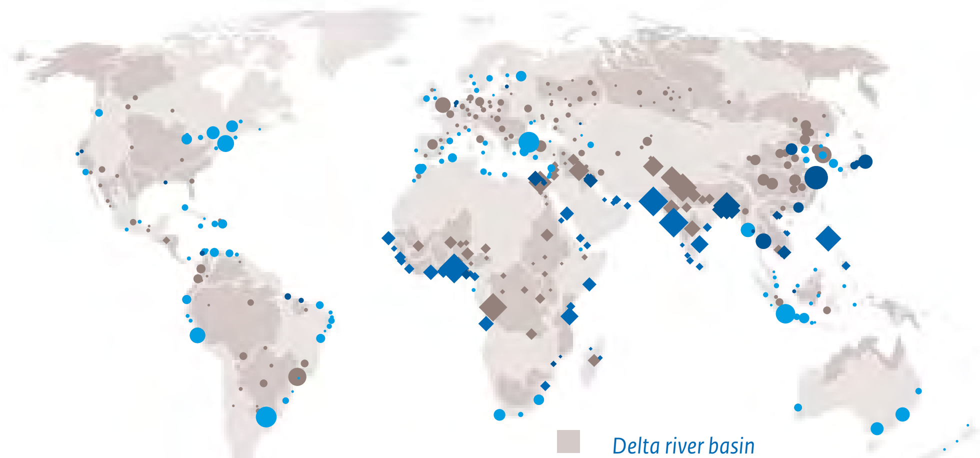
By 2070, approximately 70% of the world's population is projected to live in cities. The global urban area is expected to expand by more than 70%, not only in riparian and coastal areas and deltas, but also in water-stressed regions, such as drylands. The strong growth of cities, especially in Asia and Sub-Saharan Africa, will challenge the provision of water supply and reduction in water pollution. Reducing the inequity between the formal city and informal settlements with respect to water services and water- and climate-related risks will be a major undertaking.



City (population > 500,000)
2010
2050
Source: PBL

Deltas and coasts

Population growth and economic development will increase the challenges of coping with sea level rise. By 2070, flood risk hotspots are projected for densely populated deltas and coastal zones in especially China, Southeast Asia, South Asia and Sub-Saharan Africa. Coastal zones and deltas are heavily influenced by upstream developments, such as dam construction affecting water and sediment flows, and upstream water use and water polluting emissions, affecting both water quantity and quality.

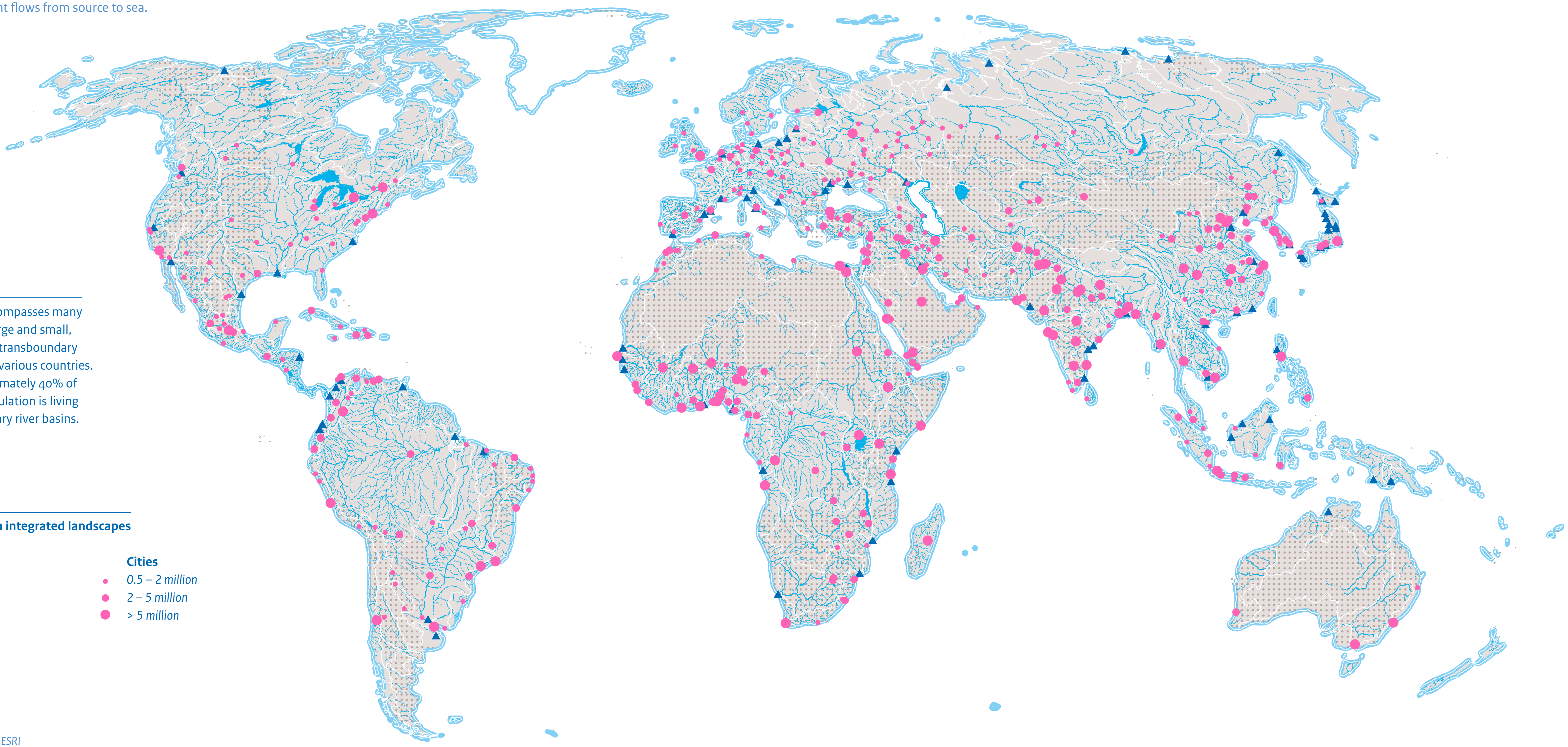


Delta river basin
Delta city
Coastal city
River city
Rapidly growing cities
Source: PBL

RIVER BASINS AS INTEGRATING LANDSCAPE

All drylands are part of river basins, which are linked to deltas and coastal zones. Rivers, therefore, connect all hotspot landscapes through water and sediment flows from source to sea.

The world encompasses many river basins, large and small, many of them transboundary and shared by various countries. Today, approximately 40% of the global population is living in transboundary river basins.



River basins in integrated landscapes

River basin

Deltas and coast

Major delta

Dryland regions

Rivers and lakes

Cities

0.5 – 2 million

2 – 5 million

> 5 million

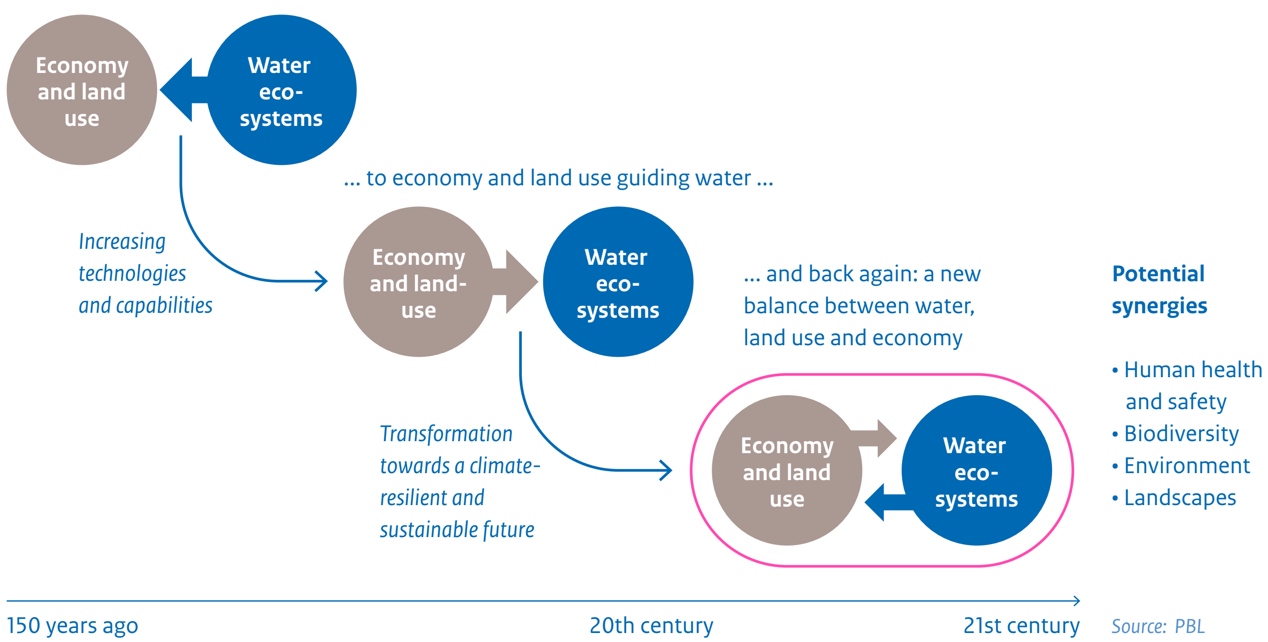
Source: PBL; DCW ESRI

BENDING THE TREND: EXPLORING WATER AND CLIMATE ADAPTATION PATHWAYS

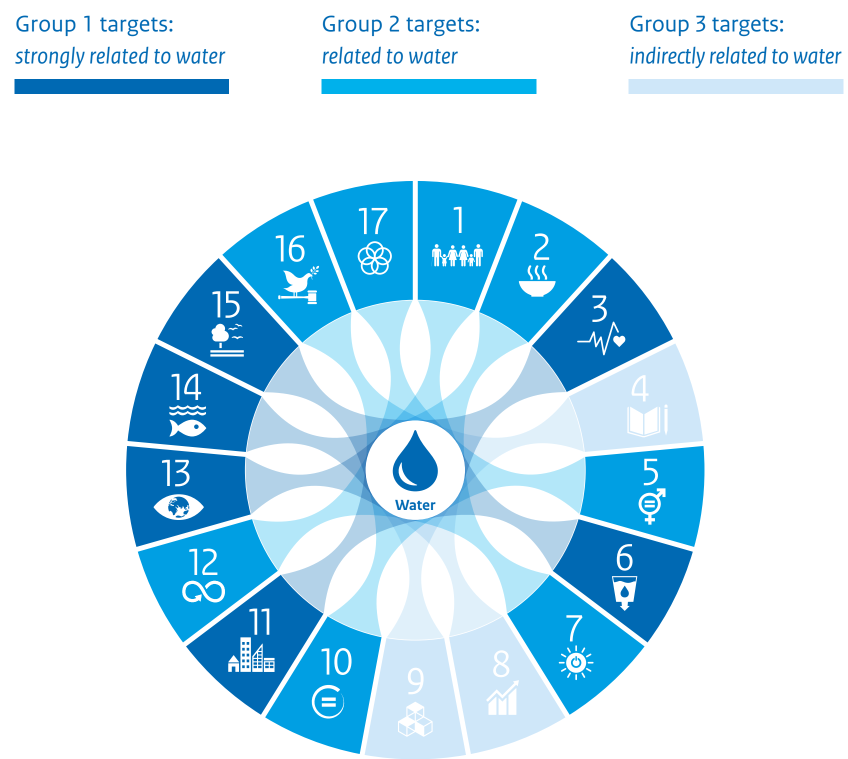
Using the Business-as-usual scenario as a baseline, we explore potential future pathways to reduce the water- and climate-related risks across the four hotspot landscapes. The pathways range from low to high levels of ambition. The latter are characterised by an integrated and SDG-inspired approach.

Rebalancing development and water systems and ecosystems
In the industrial revolution, the characteristics of water systems (i.e. rivers, lakes and coastal seas) determined land use and economic development. Cities, industries and agriculture developed where water systems provided good conditions for prosperity and wealth. Over time, the pressures of human water and land use have become increasingly dominant and have set limits on the quality of water systems. The IPCC (2022) concludes that Business-as-usual developments will increase rather than decrease the exposure of people and ecosystems to water and climate hazards, and that transformative approaches will be needed to turn the tide. The challenge is finding a new balance between ecosystem functioning and human land use: rebalancing ecosystem services. This calls for a transformation in which water systems will sustain socio-economic development and where ecosystem values of rivers, lakes and coastal seas are preserved.

Finding a new balance between ecosystem functioning and human use and interventions



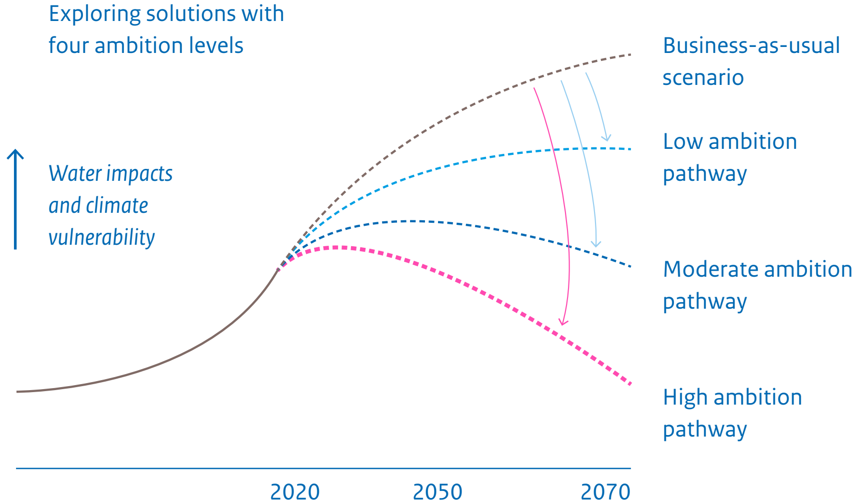
Source: PBL



Water is critical for Sustainable Development Goals
Water is directly and indirectly linked to many of the Sustainable Development Goals (SDGs), with connections to human health and well-being, clean water and sanitation, food production, sustainable cities and communities, and the quality of ecosystems.

In our exploration, we evaluate the potential contribution of future pathways to the SDGs to inspire the development of High ambition pathways. These pathways integrate water- and ecosystem-based approaches across sectors and domains, and rebalance socio-economic and ecological values.

Bending the trend
Exploring solutions with four ambition levels



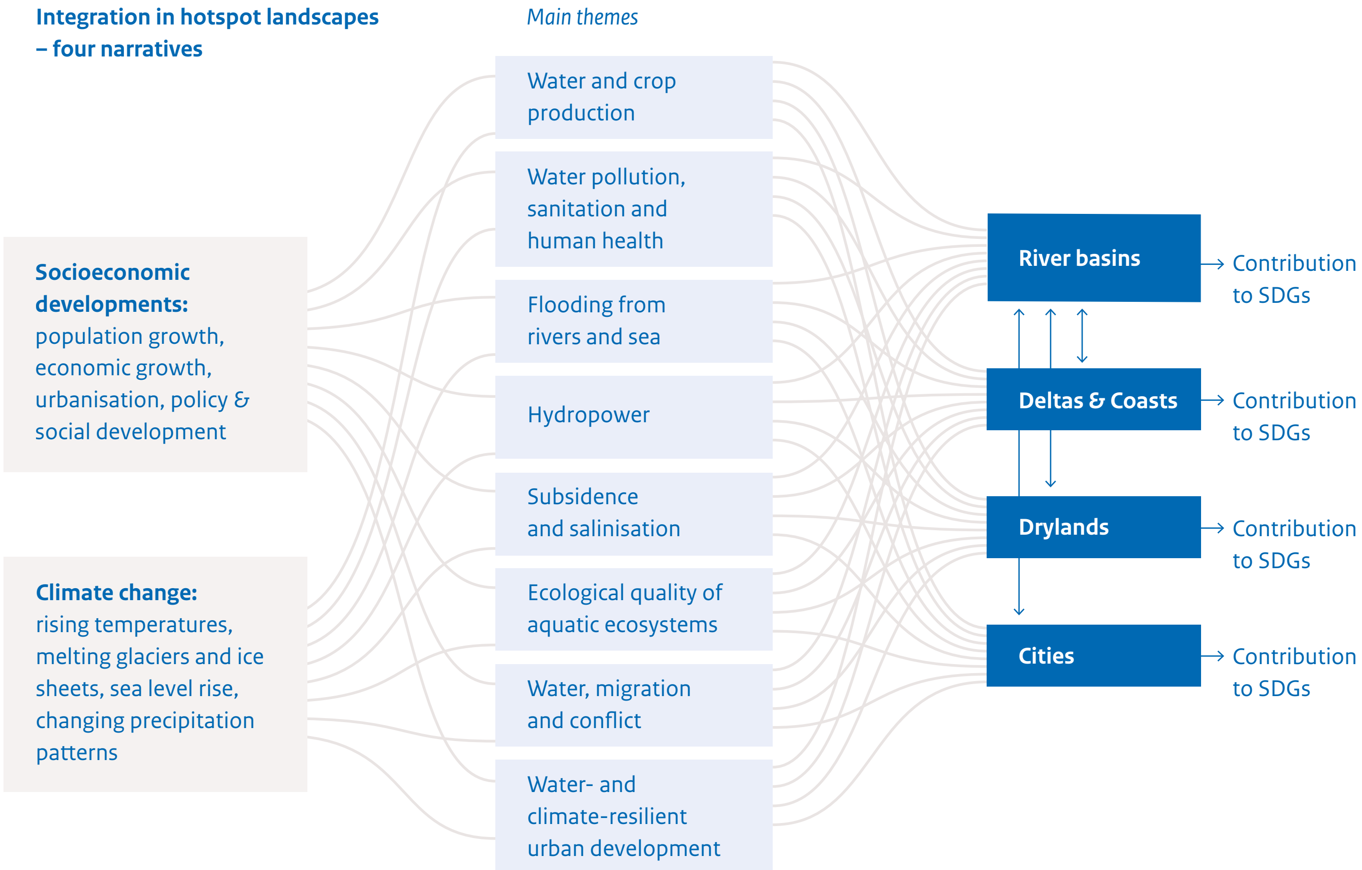
Exploring solutions: High, Moderate and Low ambition pathways
We explore pathways at low, moderate and high ambition levels, in comparison to the Business-as-usual scenario characterized by the socio-economic SSP2 pathway in combination with the RCP6.0 climate change scenario.

HIGH AMBITION PATHWAY: NAVIGATING TOWARDS A SUSTAINABLE FUTURE

By focusing in particular on High ambition pathways, in which applying ecosystem services and nature-based solutions plays a more dominant role, we present a perspective for navigating towards a climate-resilient and sustainable future.

Exploring pathways and solutions: what can be achieved?
Acknowledging the complex interactions between water, climate change and development, this study explores pathways with potential solutions towards reducing the water- and climate-related risks in the four hotspot landscapes. It focuses on the physical measures and addresses eight water- and climate-related topics. To explore 'what can be achieved', we elaborate future pathways with approaches and measures for Low, Moderate and High ambition pathways (cf. Appendix p. 207). The elaboration of these pathways, the topics addressed and the dominant types of water- and climate-related challenges, varies between the four hotspot landscapes.

Integration in hotspot landscapes – four narratives



Source: PBL

Ambition pathways
While the Low and Moderate ambition pathways are dominated by sectoral approaches in management and technical measures, the High ambition pathway is based on an integrated systems approach and inspired by the SDGs as guiding values for sustainable development. Under the High ambition pathway, we assume strong institutional capacities (SDG16), partnerships for the goals (SDG17) and due attention for reducing inequalities (SDG10).

The High ambition pathway builds on the Sharing the Planet pathway, which was developed to explore future biodiversity pathways (Immovilli and Kok, 2020). This pathway is based on the same socio-economic context and climate change scenario (SSP2/RCP6.0) as the other pathways, but with a larger global area of protected nature reserve (30% versus 17% for the 'normal' SSP2 pathway). It also focuses on applying ecosystem services and nature-based solutions, such as green and blue infrastructure in cities, restoring wetlands and tidal forests for flood protection, and using buffer zones along agricultural fields to reduce nutrient run-off.

Conceptual characteristics of ambition levels of the various pathways

		Management / Technology / Spatial planning
Low ambition level	• Sectoral approach • Simple measures and technology • Low costs	**Increasing level of transformation, inspired by water, climate-resilient development and SDGs, and under innovative governance**
Moderate ambition level	• Sectoral approach • Upscaling efforts and measures	
High ambition level	• Integrated system approach • High level of efforts	

Source: PBL

2
EXPLORING FUTURE PATHWAYS

RIVER BASINS

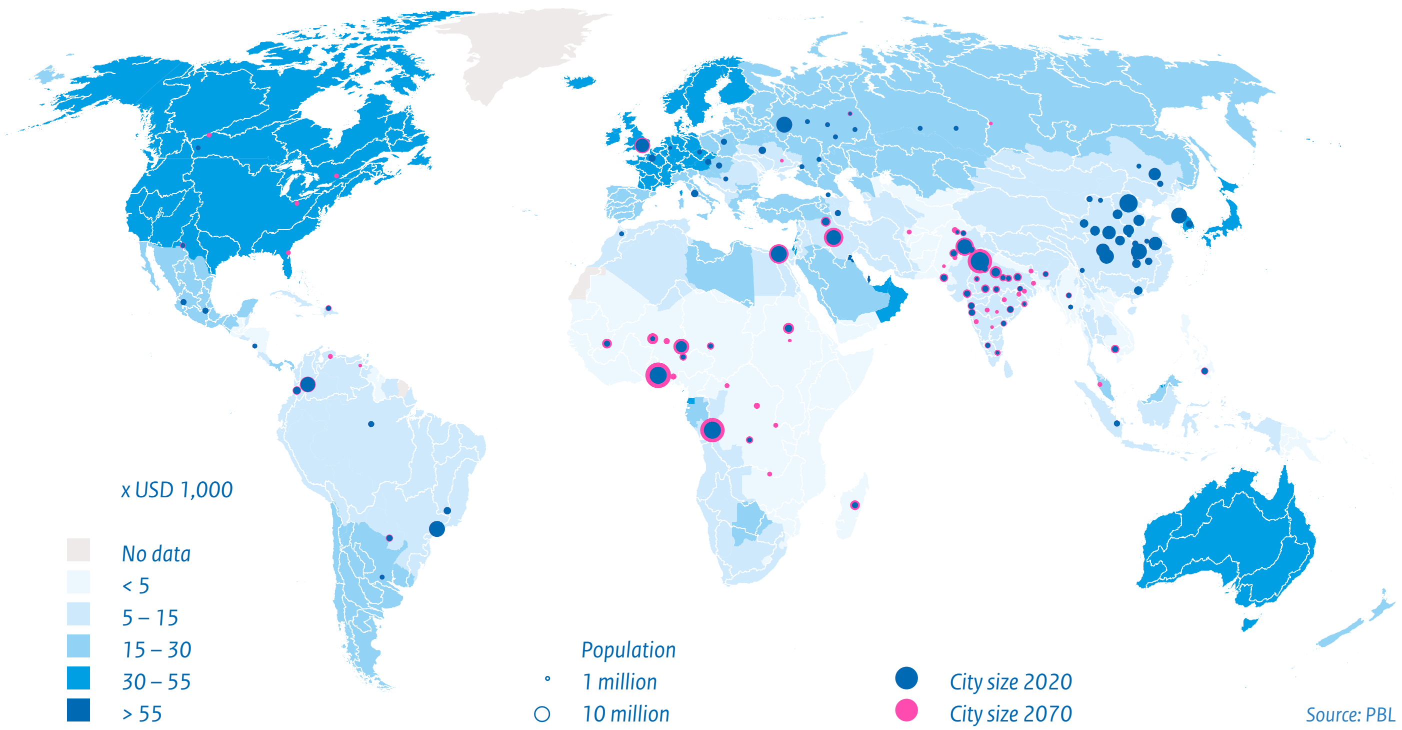
MANY PRESSURES TO TACKLE

Many river basins are greatly under pressure due to land-use changes, dam construction, over-exploitation of water resources, pollution, canalisation and climate change. Bending the trend and breaking away from the Business-as-usual scenario will require rebalancing the impact of human use and the functioning of river basin systems while integrating climate adaptation.

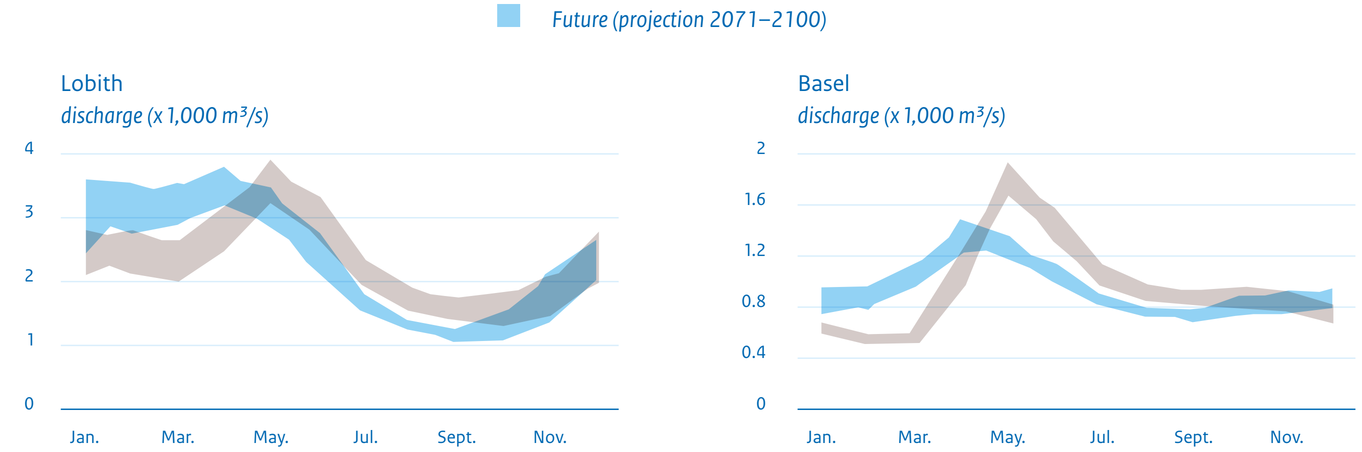
The wealth of nations and their governance capacities determine their ability to tackle the pressures in river basins. GDP per capita is one way to express this ability. This indicator is relatively high in western countries and low in Asia, parts of South America and especially in Africa.

However, the size of a river basin relative to its population also determines the capacity of the population to act. It may be more difficult for small, rich populations in large river basins to address existing pressures than for less wealthy populations in smaller river basins.

GDP per capita in river basins and large river cities, 2020



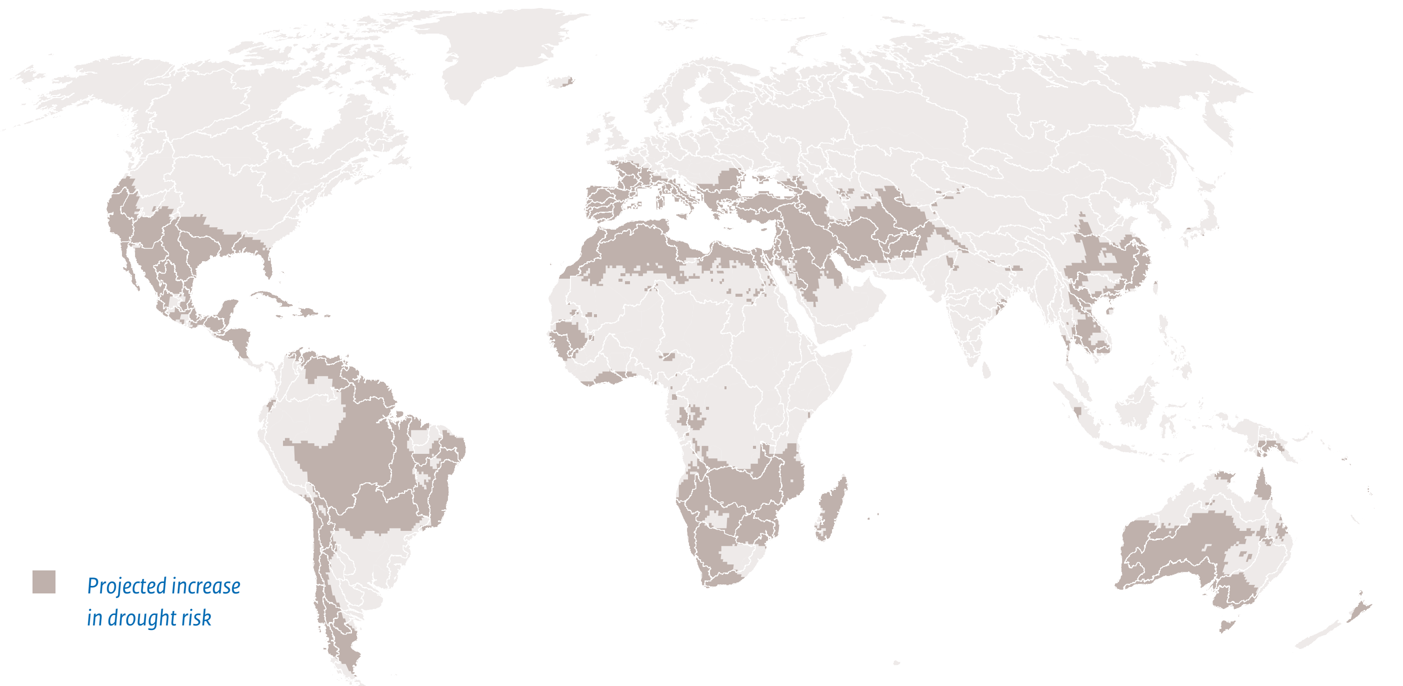
Changes in discharge regime Rhine



Source: Sperna Weiland et al., 2022

Changes in precipitation patterns and snow- and glacier melt will cause significant additional stresses to the existing human interventions and to the pressures on river basins. The changes are projected to affect river flow patterns and may increase drought risk, especially in regions and river basins where drought risk is already relatively high. The more irregular rainfall patterns can result in unpredictable and irregular low and high river discharges, increasing both drought and flood risk. Worrying examples can already be found, globally, such as the unprecedented scale of droughts and wildfires in both the United States and Europe, extreme droughts and flooding events in Australia and Pakistan, extreme multi-year droughts in Eastern Africa, and extreme flooding events in Nigeria and Sudan.

Projected increasing drought risk in large parts of the world, 2070



Source: UU, PBL

MANY POTENTIAL SOLUTIONS

Using Low, Moderate and High ambition pathways for the future, we explore what could be achieved in bending the trend at various ambition levels. We focus on improving water use efficiency, reducing water pollution and the impact of dams, improving ecological quality and reducing the risk of transboundary conflict.

Restoring natural water and sediment dynamics and the ecological quality of river systems is vitally important if we are to bend the trend and rebalance human use and river basin functioning. The disruptive effects of climate change on precipitation patterns and on the frequency, timing and intensity of low, mean and high water flows bring new and more uncertain challenges to river basin management. This requires due consideration when building robust future development plans from a local to a river basin scale.

Climate change

- increasing temperature and heat
- changing precipitation patterns
- increasing drought and flood risks
- increasing water temperature

River system approach: overview of potential measures
Cf. Appendix Overview of measures (p. 207)

Reducing the risk of transboundary conflict

- improving institutional resilience and transboundary collaboration
- reducing water use/transboundary dependence

Restoring ecological quality

- ecological dam construction
- reducing water pollution
- reducing water use/over-exploitation
- nature-based solutions in flood protection
- restoring wetlands

Reducing flood risks

- improve protection (dykes/levees)
- waterproofing buildings
- spatial zoning
- integrating climate adaptation
- nature-based solutions

Reducing water pollution/nutrient emissions

- from agriculture: sustainable intensification
- nutrient buffer zones
- from cities: improving sanitation and wastewater treatment

Reducing the impacts of dams

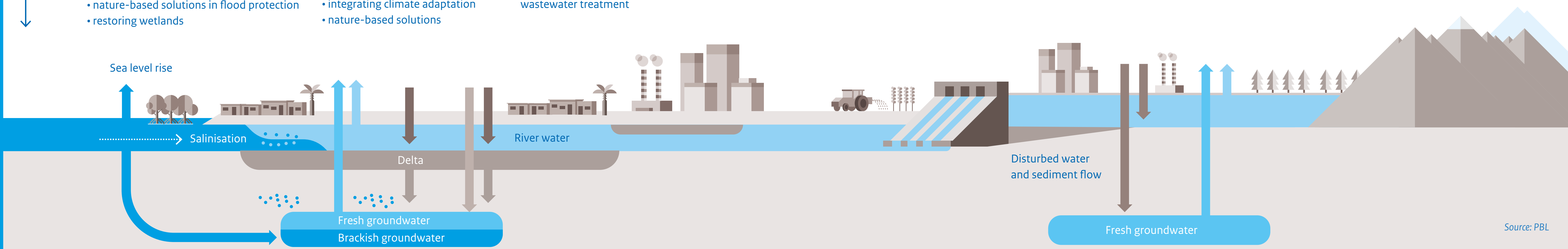
- ecological hydropower construction

Reducing water use

- improving water use efficiency in agriculture, households and industries
- integrating climate adaptation

Forestation/deforestation

- sharing the planet: improved protection of nature areas



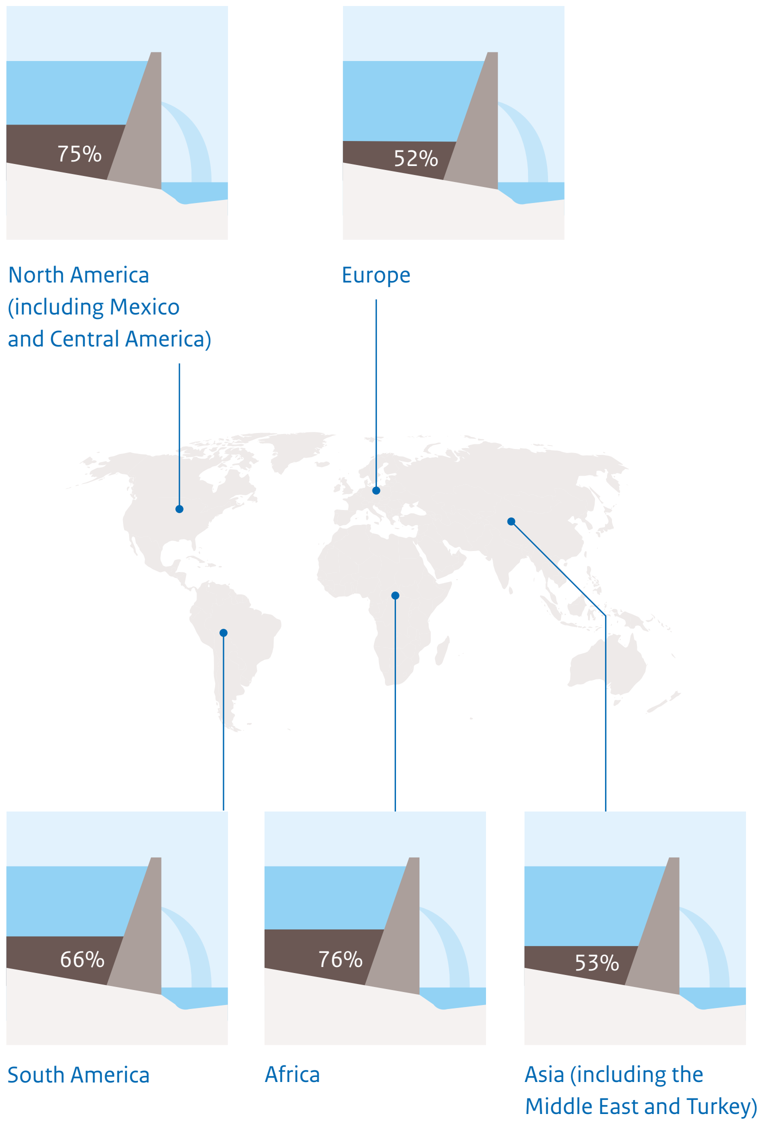
Source: PBL

MANY NEW HYDROPOWER DAMS ARE LIKELY TO BE BUILT

Over the past century, many dams were built for hydropower, irrigation and water regulation, particularly in the Northern Hemisphere. Construction of another 3700 dams is being planned, for the coming decades, many of them in the Southern Hemisphere.

The reservoirs behind the dams trap a large part of the sediment in the upstream reaches of rivers. This sediment, thus, no longer supplies the deltas and coastal zones, with coastal erosion and loss of land as a result. Sediment input and accretion is however needed in deltas and coastal zones to counter sea level rise and subsidence. See Deltas and coasts (p. 82).

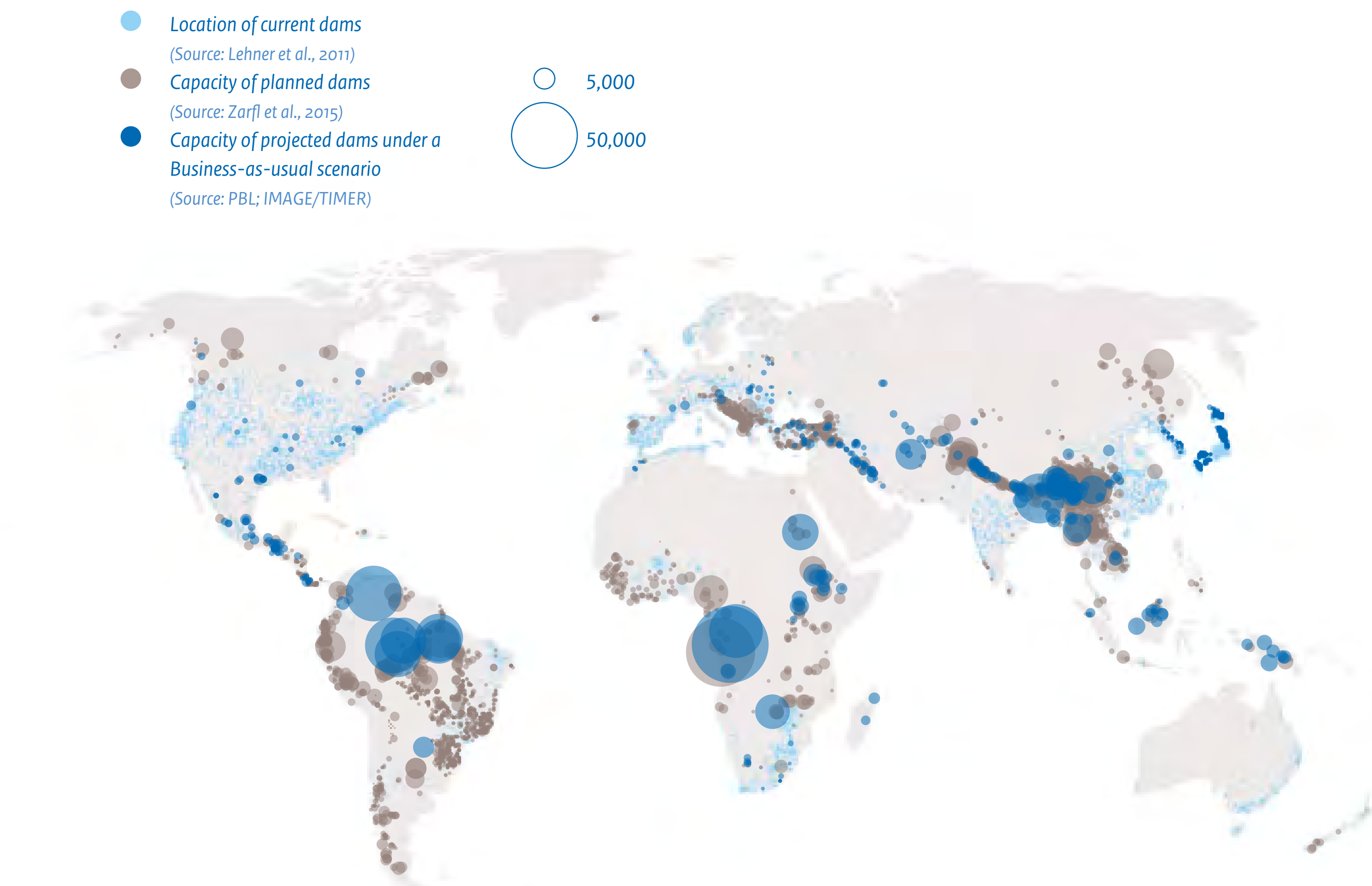
Upstream sediment trapped by dams in 2010
in %



Source: Ericson et al., 2006

The location of dams, both existing and planned
There are already many thousands of dams around the world, changing water flows and river habitats and blocking sediment flows from the mountains to the deltas and coastal zones. The demand for renewable energy will result in the construction of more hydropower dams. Under our Business-as-usual energy pathway, 950 new hydropower dams are projected to be built in the years up to 2070, increasing production capacity from the current 16 billion to around 22.5 billion GJ/yr by 2070. However, this may be an underestimation as an inventory in 2015 revealed existing plans for 3700 new dams. Under a higher ambition pathway for climate change mitigation, the demand for renewable energy and also for hydropower may significantly increase, compared to the Business-as-usual scenario.

Location and capacity of future dams
in MW

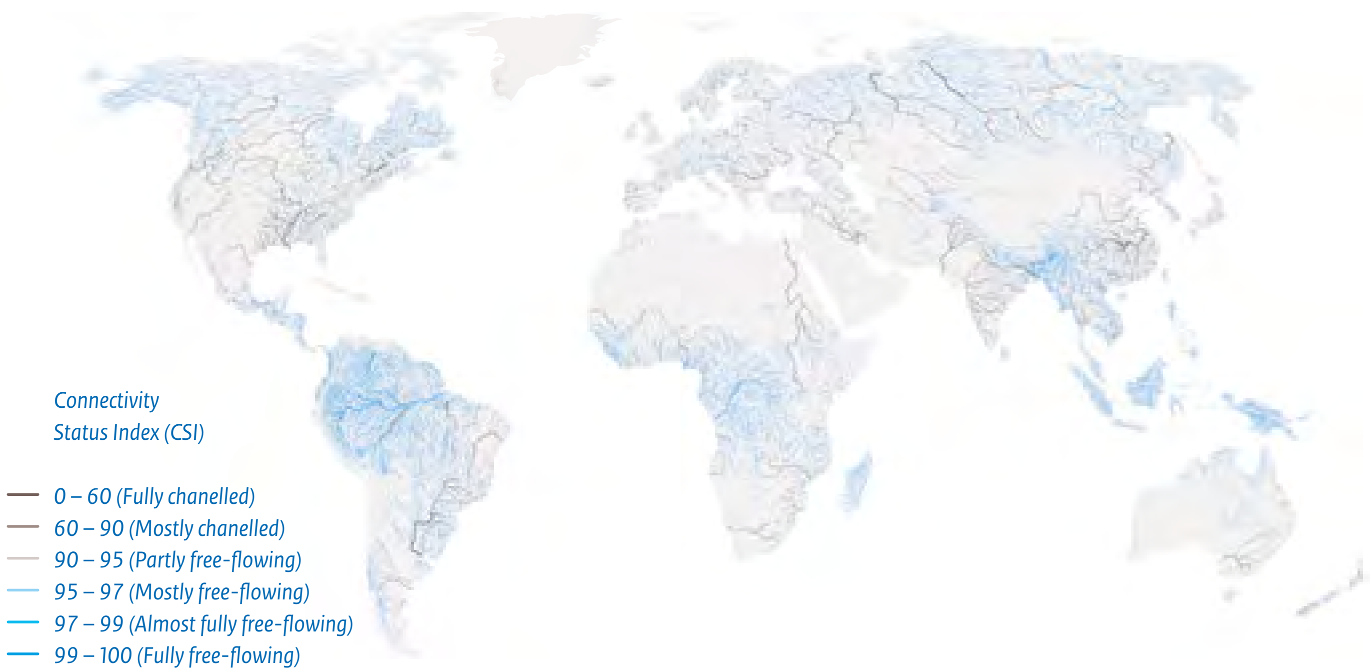


REDUCING THE IMPACTS OF NEW DAMS ON RIVER ECOLOGY

Ecological criteria can be included in the design of new dams to minimise further river fragmentation and the impacts on water flow and obstacles for fish migration, while keeping the hydropower production capacity at the same level, by 2070.

Only 37% of rivers are free-flowing
Today, only 37% of rivers longer than 1,000 km still flow freely over their entire length (Grill et al., 2019). Dams pose a threat to survival for, especially migrating, fish species, because they prevent fish from reaching their breeding grounds. Upstream, dams turn a flowing river stretch into a stagnant reservoir, thereby structurally changing the environmental conditions for the local aquatic ecosystem. Downstream, they change a river's discharge regime and substantially reduce natural water dynamics, negatively affecting the ecological functioning and values for a wide variety of animal and plant species.

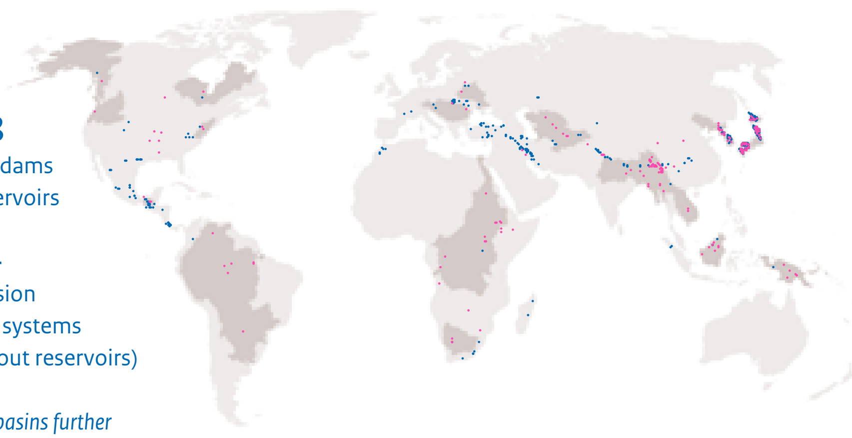
Mapping the world's free-flowing rivers: state of interventions



Source: Grill et al., 2019

The location of hydropower facilities, 2070
Business-as-usual scenario

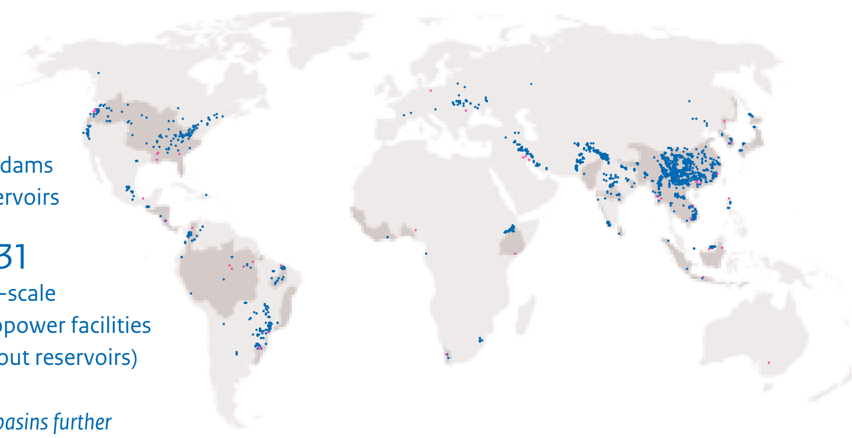
- 208 large dams + reservoirs
- 744 diversion canal systems (without reservoirs)
- *River basins further fragmented by new large dams*



Reducing the ecological impact of dams
Improving fish passages around barriers or removing dams are key solutions for reconnecting freshwater habitats but hardly feasible for the existing large dams. Under the Business-as-usual scenario, 744 diversion canal systems are projected to be built, in addition to 208 large dams.

Moderate ambition pathway

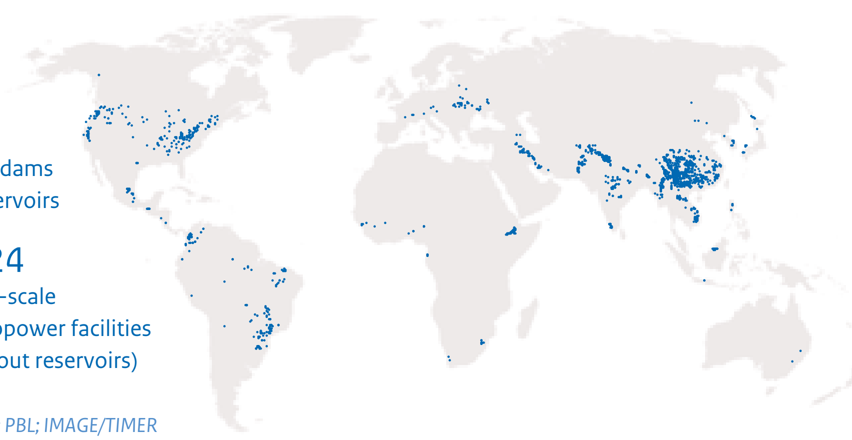
- 42 large dams + reservoirs
- 2,031 small-scale hydropower facilities (without reservoirs)
- *River basins further fragmented by new large dams*



The solutions that are implemented under the Moderate ambition pathway include piped hydropower plants, where dams and reservoirs are no longer needed, 20 m high dams with passages for fish migration, fish-friendly turbines, and management strategies that ensure some continuity of water and sediment flow (Van der Meer et al., 2019). Rivers that are currently free-flowing are excluded from new dam construction.

High ambition pathway

- 0 large dams + reservoirs
- 2,124 small-scale hydropower facilities (without reservoirs)



Source: PBL; IMAGE/TIMER

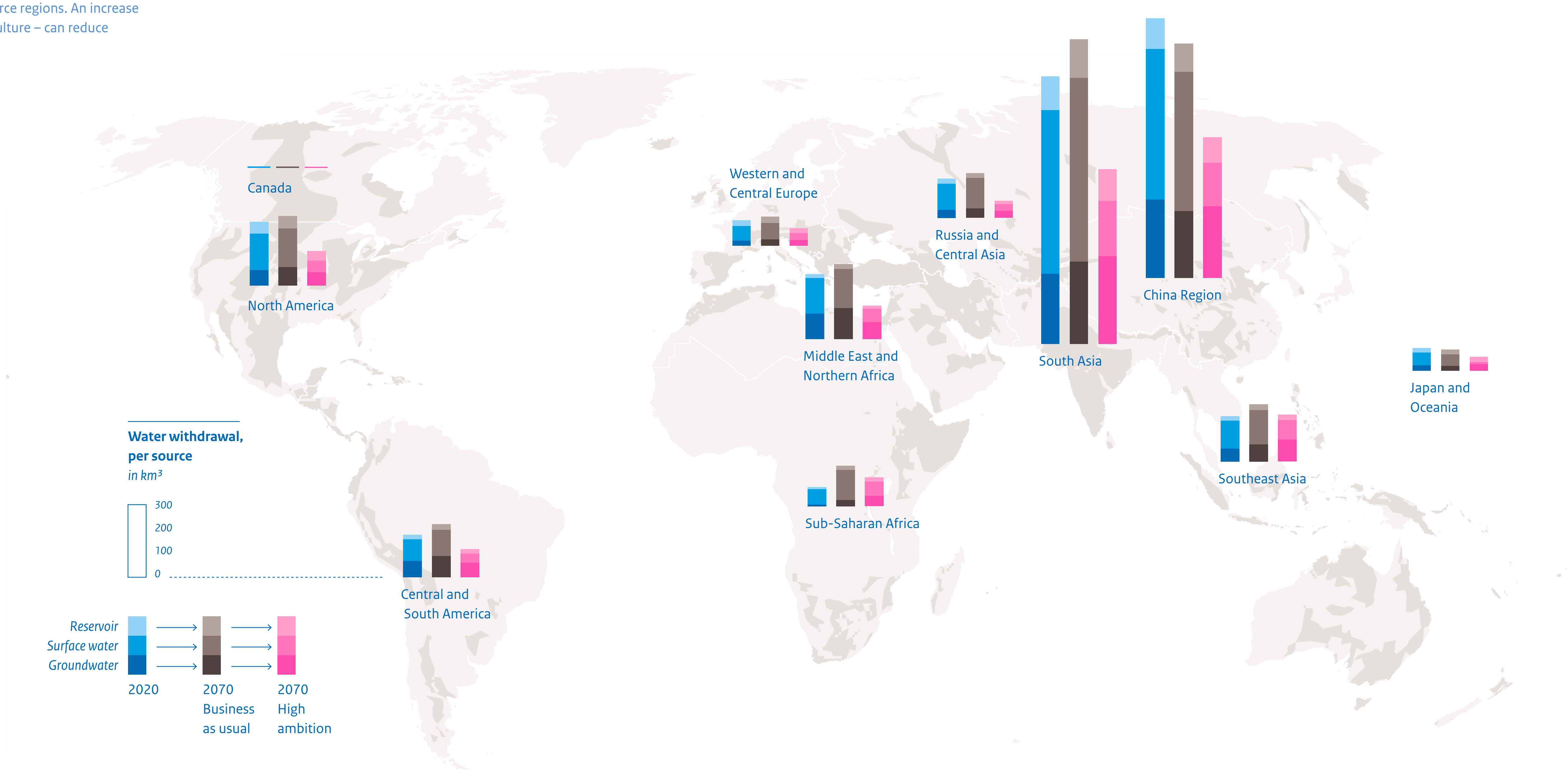
The High ambition pathway contains only diversion canal systems and no large dams. While the electricity production capacity is the same for all pathways, the number of small-scale hydropower facilities in this pathway increases substantially. The latter results in no further fragmentation compared to the current situation and retains the percentage of free-flowing rivers at 37%.

WATER USE CAN BE REDUCED SUBSTANTIALLY

Increasing water demand and water use can lead to increased water stress, especially in densely populated or relatively water-scarce regions. An increase in water use efficiency across sectors – primarily agriculture – can reduce water stress in river basins.

With a share in total water use of more than 80%, globally, agriculture uses by far the most water. The water abstracted from lakes and rivers for agriculture may deplete rivers to such a degree that, in dry seasons, rivers will hardly reach the coast and salt water will intrude further upstream.

Depletion of non-renewable groundwater reserves threatens the water supply for irrigation and, thus, food production. In the United States (Ogallala Aquifer in the Great Plains), India (Indo-Gangetic Plain), Iran, China (Manchurian Plain) and the Middle East, water is mostly abstracted from non-renewable aquifers.



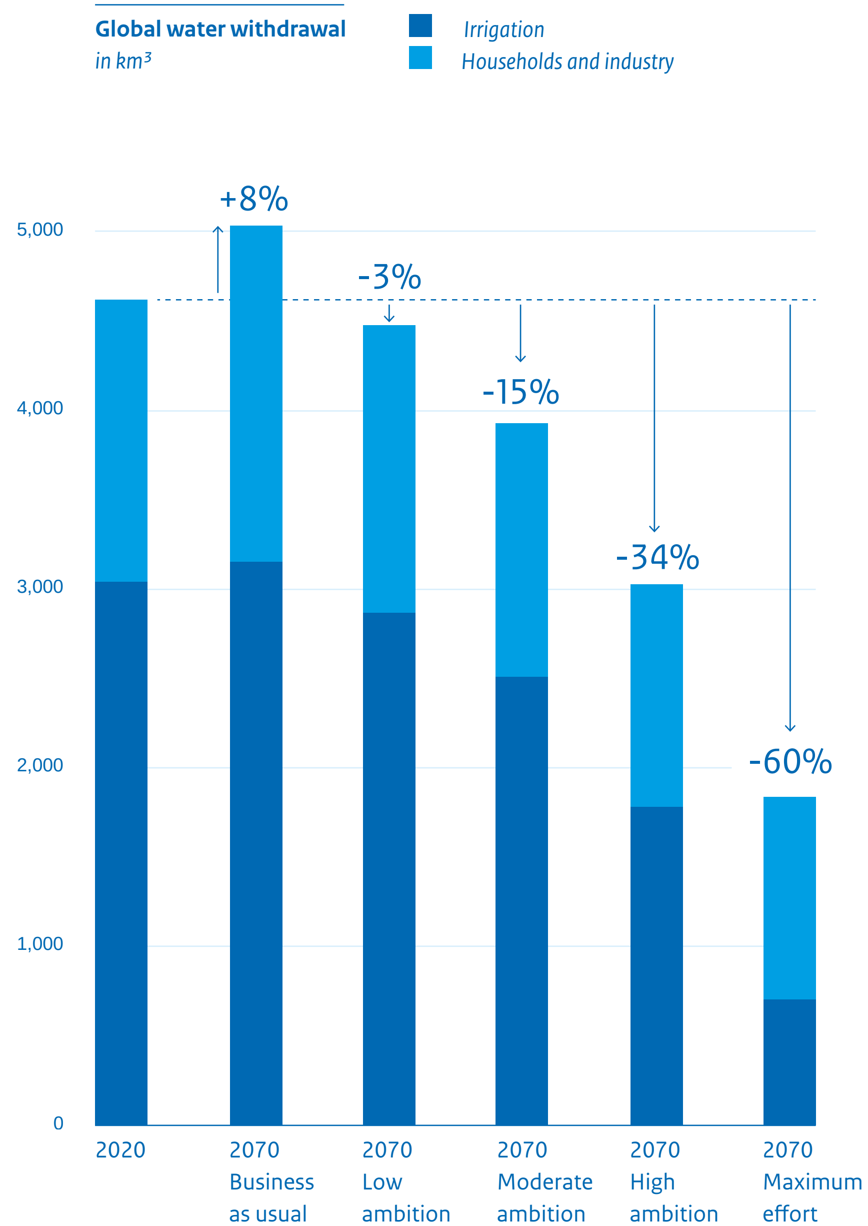
Source: WEnR; OECD

MORE CROP PER DROP: REDUCING CLIMATE VULNERABILITY

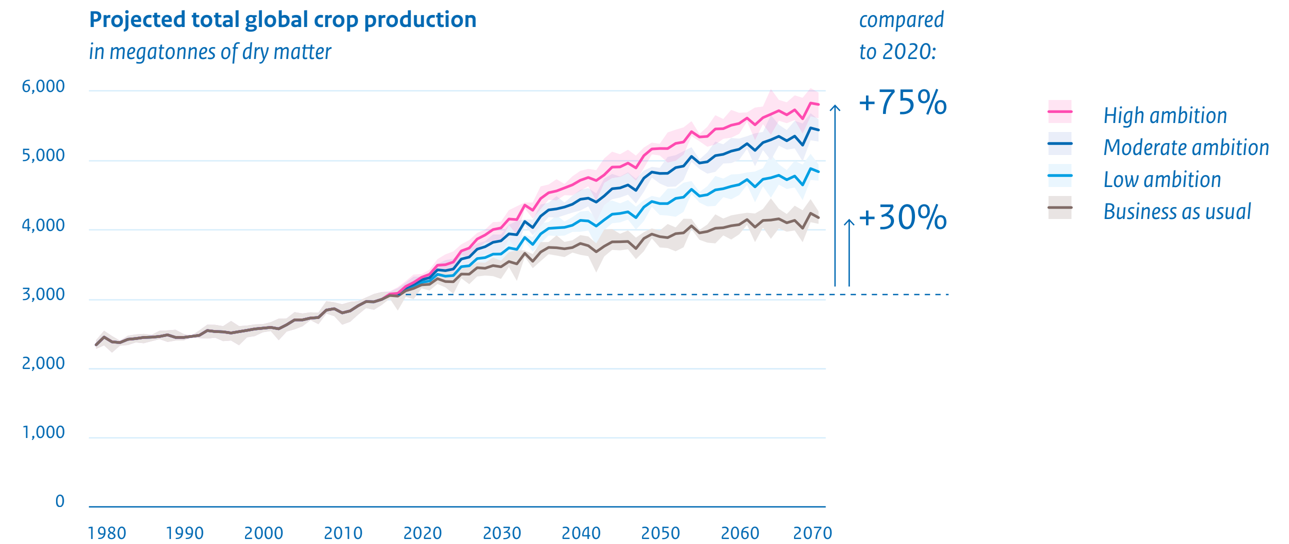
Reducing water use by increasing water use efficiency, on the one hand, reduces the impact on river flow and groundwater systems, while, on the other, reducing the vulnerability of sectors to the climate-change-induced increased variability in water availability.

More efficient irrigation strongly reduces abstraction of ground-water and surface water
Under our future pathways, a strong reduction in total water withdrawal can be reached for household and industrial uses and, especially, by implementing more efficient irrigation in agriculture. Under the High ambition pathway, water use in households, industries and agriculture may be reduced by 34% between now and 2070. Also, rainwater management can improve rainfed agricultural pro-duction, being the major part of global crop production

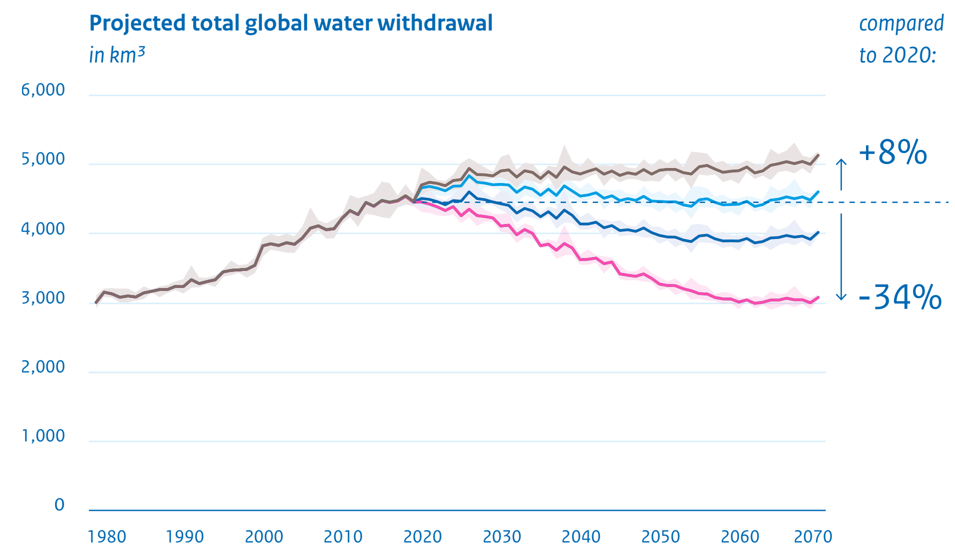
Global water withdrawal
in km³



Projected total global crop production
in megatonnes of dry matter



Projected total global water withdrawal
in km³



Source: WEnR

More crop per drop: reducing water use and climate vulner-ability by increasing water use efficiency
Of all sectors, agriculture uses by far the most water. Increasing the efficiency of agricultural water use, therefore, is of high import-ance. A reduction in water use can be realised without reducing crop production. In fact, combining efforts to reduce water use and improve water conservation and crop management is projected to result in higher crop yields and lower water use in rainfed and irri-gated agriculture. This also applies to crop production and water use in drylands.

WATER STRESS CAN BE RELIEVED BUT CRITICAL AREAS REMAIN

Even under the High ambition pathway, a large number of people are projected to live in water-stressed river basins by 2070. The densely populated central Asia and South and East Asia, in particular, remain potential future hotspots of water stress.

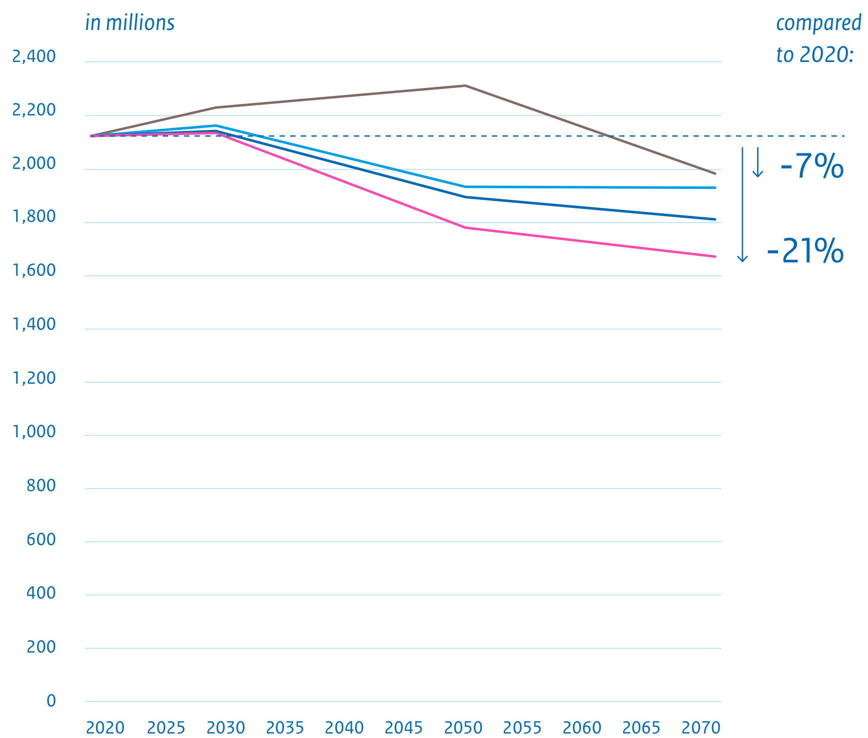
The increasing water use efficiency results in fewer people living in river basins with a high or very high water stress by 2050. After 2050, the difference between the Business-as-usual scenario and our future pathways becomes smaller due to the declining population in the China region.

Our High ambition pathway includes an annual 0.75% increase in water use efficiency in households and industries, and over half of the agricultural area using sprinkler systems or area- and crop-dependent drip irrigation.

Even under this pathway, a large number of people are projected to live in water-stressed river basins by 2070. For the definition of low, moderate, high and extremely high water stress, see: https://www.wri.org/data/water-stress-country

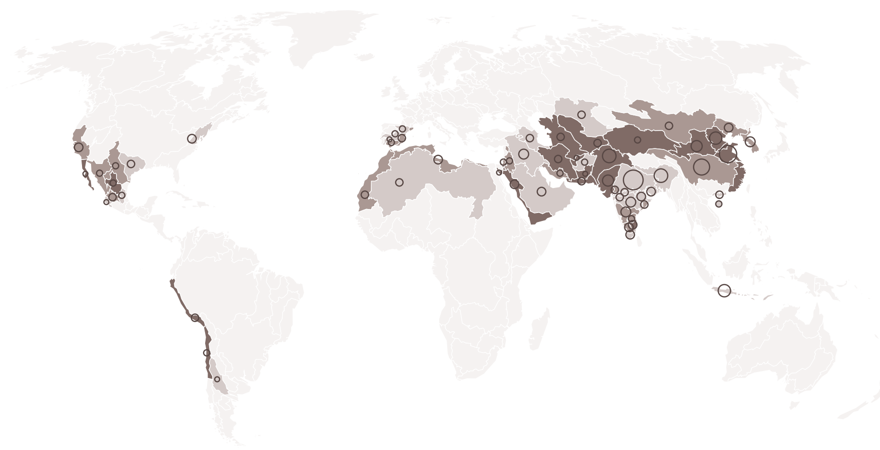
Number of people living in water stressed river basins

Business as usual
Low ambition
Moderate ambition
High ambition



Source: WEnR, PBL

Number of people living in water-stressed river basins
2020



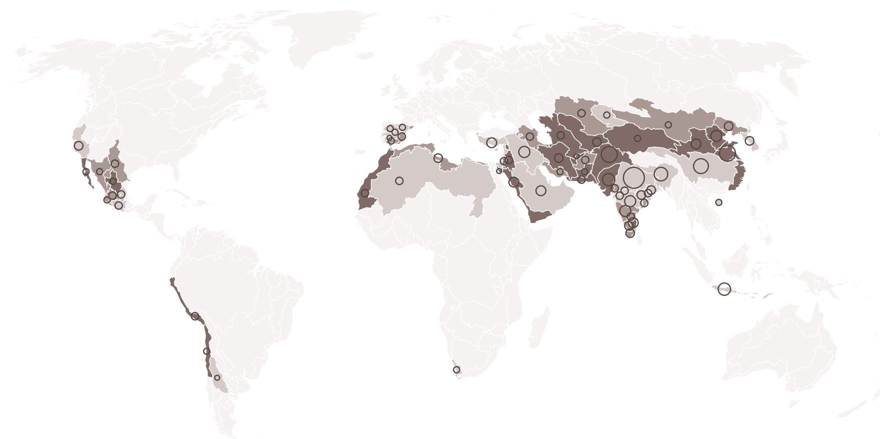
Water stress in river basins is high in Northern Africa and the Middle East, in large parts of Asia, and in the western part of the United States.

Population

50 million
500 million

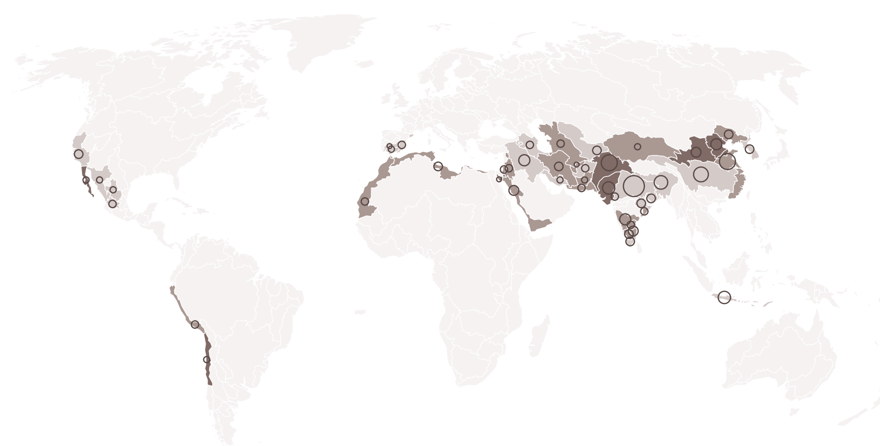
No to low water stress
Moderate water stress
High water stress
Extremely high water stress

Business-as-usual scenario, 2070



Under the Business-as-usual scenario, water stress in river basins will remain high in regions where water stress is already high today. In fact, water stress will increase, locally, because of changes in water availability due to climate change.

High ambition pathway, 2070



Under the High ambition pathway, water stress decreases. The densely populated regions of Central Asia and South and East Asia remain potential future hotspots of water stress. Improved water conservation and water use efficiency can structurally relieve water stress in dryland regions.

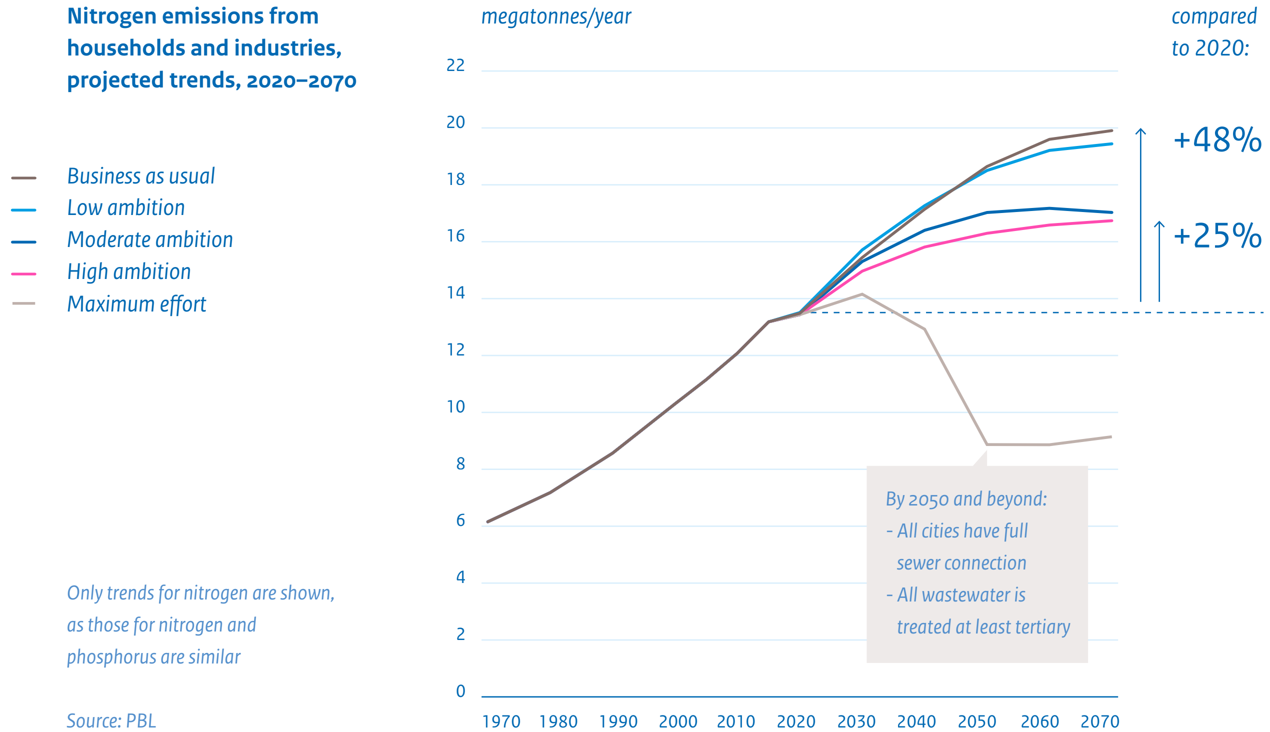
Source: WEnR, PBL

URBANISATION: HUGE EFFORTS IN REDUCING NUTRIENT EMISSIONS

Even under the High ambition pathway, nutrient emissions from cities are projected to increase by 25% between 2020 and 2070. Adequate investments in wastewater treatment will be required, especially in East and South Asia and Africa, to benefit from improved sewage connections and to compensate for population growth.

Households and cities are major sources of nutrients in river basins. Global nutrient emissions from households and cities are projected to increase under all pathways, from almost +50% under the Business-as-usual scenario to +25% under the High ambition pathway. This illustrates that, while the number of sewage connections increases, wastewater treatment continues to fall short, even under the High ambition pathway. A structural reduction in nutrient emissions, compared to 2020, can only be reached under a strategy of maximum investment in both sewage and wastewater treatment systems.

Nitrogen emissions from households and industries, projected trends, 2020–2070



Only trends for nitrogen are shown, as those for nitrogen and phosphorus are similar

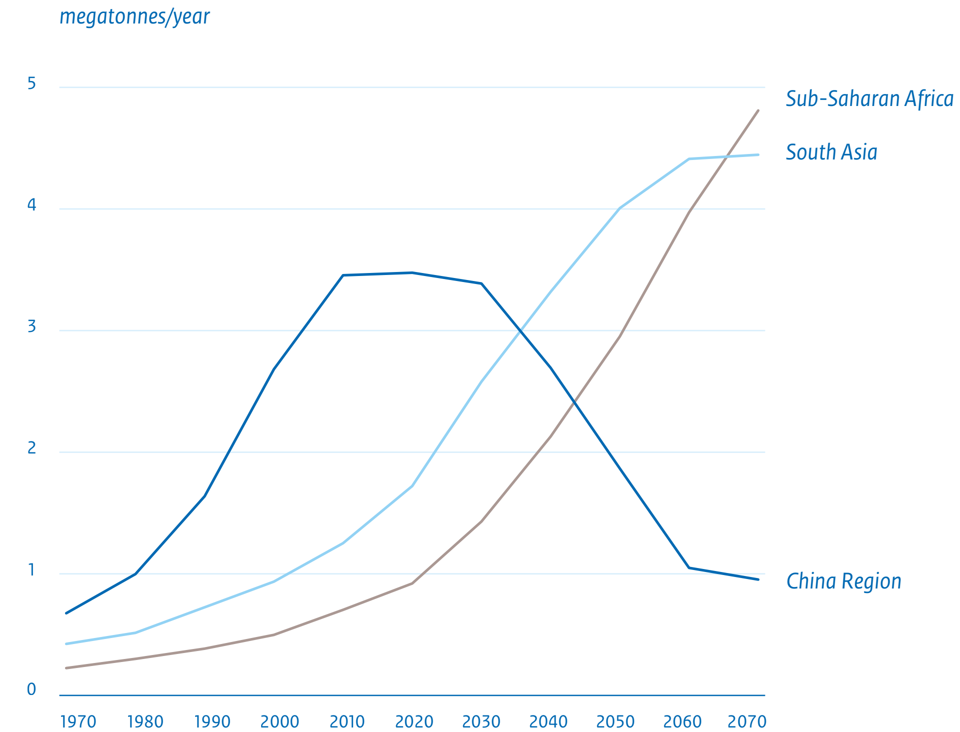
Source: PBL

If sewerage systems are not combined with adequate wastewater treatment systems, the loading of nutrients and polluting substances to surface waters will increase. Three regions dominating global trends show different patterns:

- the China region with a strong decreasing trend due to a declining population and improved sewage and wastewater treatment;
- South Asia and
- Sub-Saharan Africa

In these regions, emissions are projected to increase strongly under the High ambition pathway due to large increases in population and the projected related increase in the number of households with a sewage connection but without the required investment in treatment systems.

Nitrogen emissions, 1970–2070: regions with dominant trends



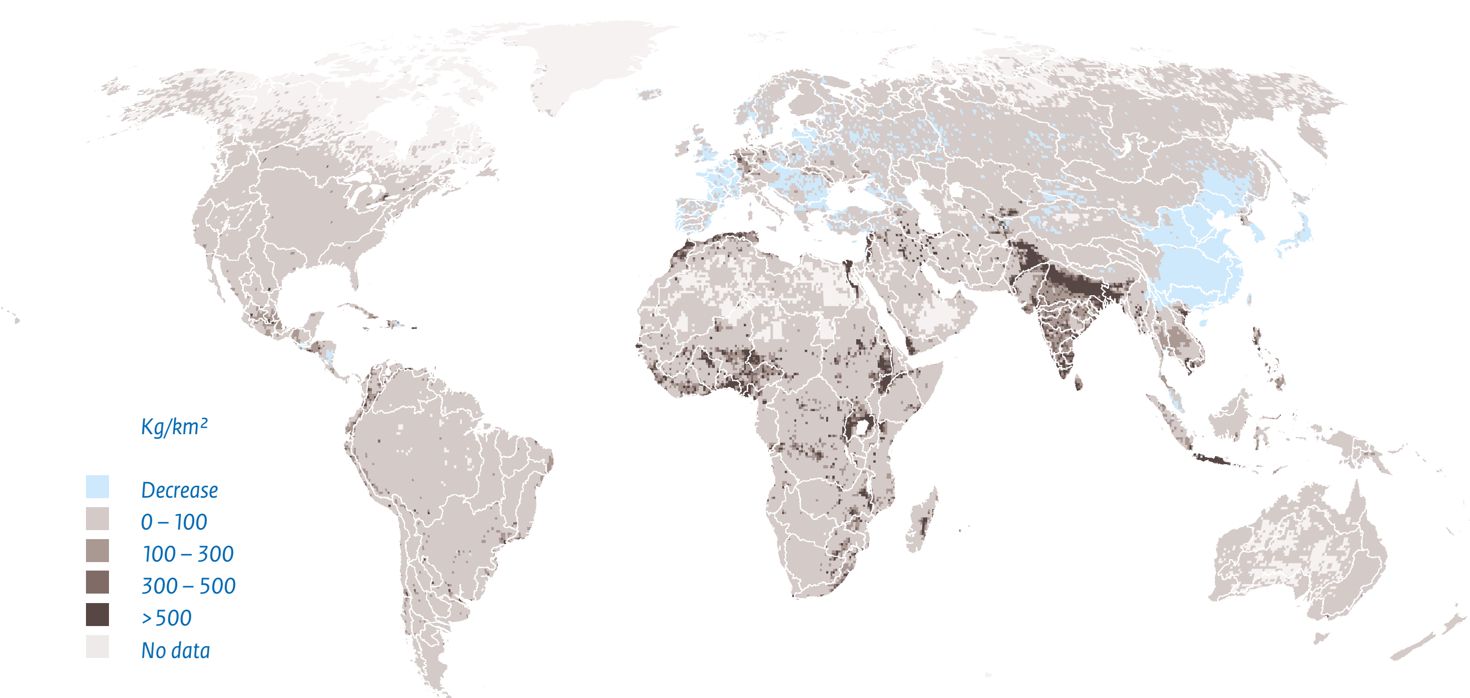
Source: PBL

NUTRIENT EMISSIONS FROM CITIES INCREASE IN MOST REGIONS

Only slighly lower nutrients emissions are projected under the High ambition pathway. In East Asia, Sub-Saharan Africa and parts of India the increase in sewage connections is not accompanied by adequate investments in wastewater treatment.

The comparison between 2020 and 2070 shows regional differences in nutrient emission trends. Under the Business-as-usual scenario, emissions decrease in countries with declining populations (especially China) or in countries where wastewater treatment improves significantly.

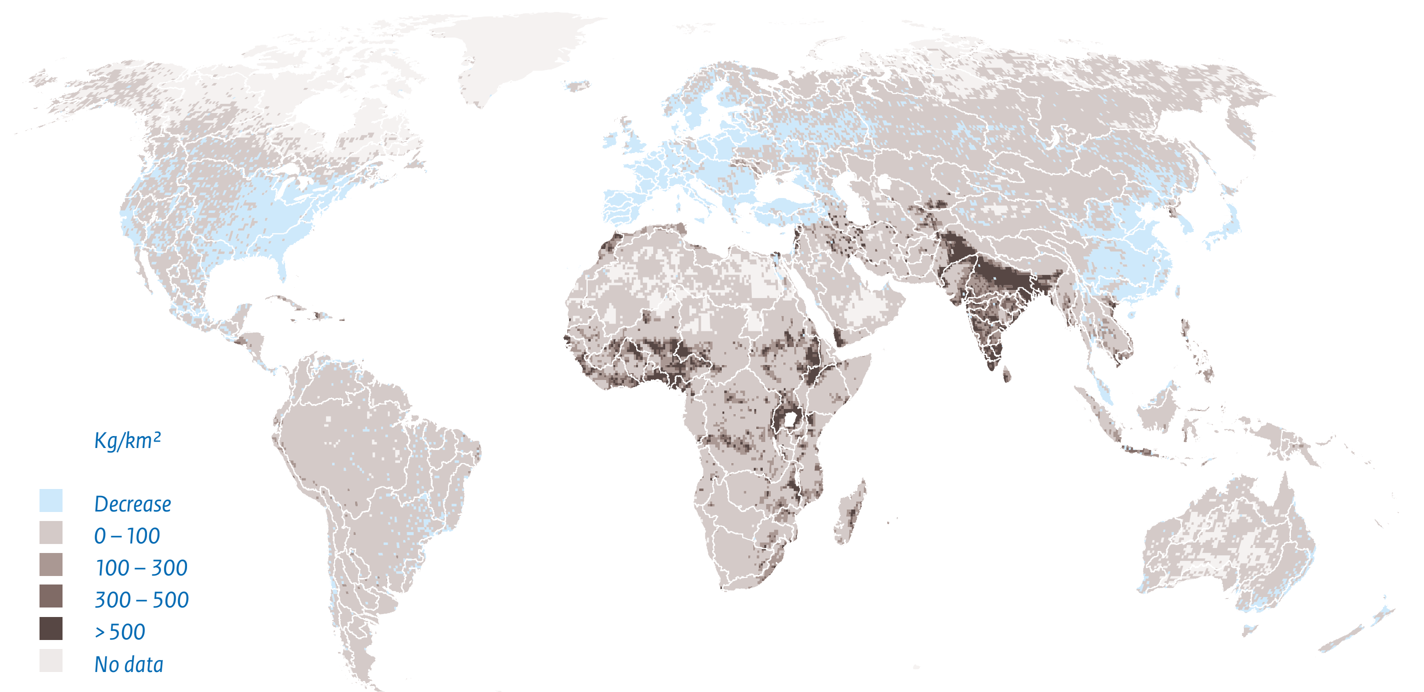
Projected change in nitrogen emissions from households and urban environment, 2020–2070
Business-as-usual scenario



Source: PBL

Under the High ambition pathway, slightly lower emissions are projected for many regions, compared to 2020 levels. A strong increase is projected for regions such as East Asia, Sub-Saharan Africa and parts of India, where – compared to the Business-as-usual scenario – the increase in sewage connections is not accompanied by adequate investments in wastewater treatment.

Projected change in nitrogen emissions from households and urban environment, 2020–2070
High ambition pathway



Source: PBL

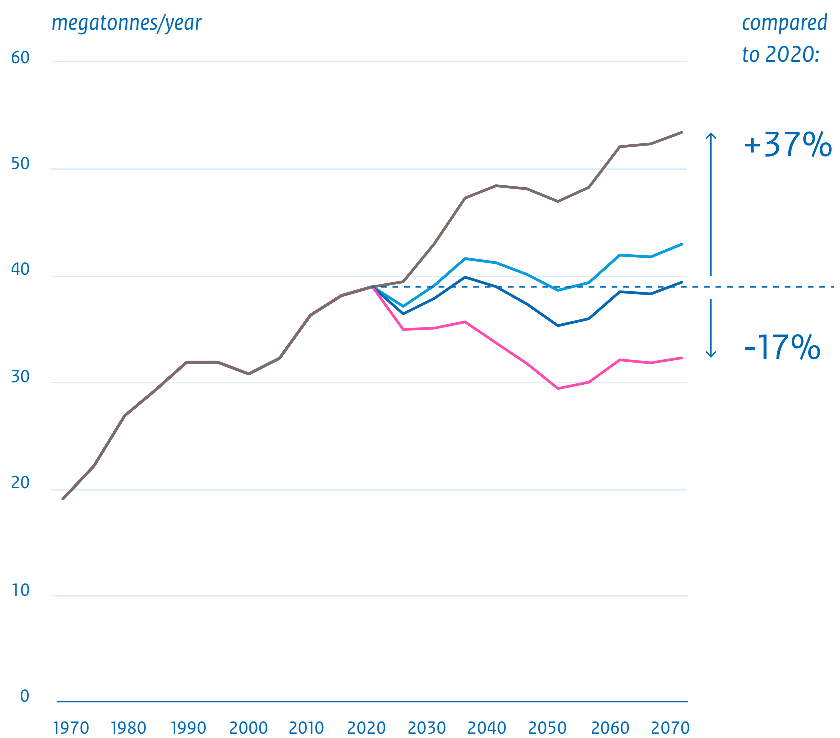
SUSTAINABLE AGRICULTURE MAY REDUCE NUTRIENT EMISSIONS BY 20%

Nutrient emissions to water from agriculture are projected to stabilise under a Moderate ambition pathway and reduce under a High ambition pathway, with a transition to sustainable intensification in the use of fertilizer and buffer zones along agricultural fields.

Under the Business-as-usual scenario, nutrient emissions from agriculture are projected to increase strongly, by almost 40% between 2015 and 2070, continuing the historical trend of nitrogen fertilizer use. Relative to this pathway, the Low and Moderate pathways result in a substantial decrease in nutrient emissions, but emissions will only fall below the level of 2015 under the High ambition pathway with a sustainable use of nitrogen fertilizer and use of buffer zones along agricultural fields.

Nitrogen emissions from agriculture to rivers: projected trends, 1970–2070

Business as usual
Low ambition
Moderate ambition
High ambition



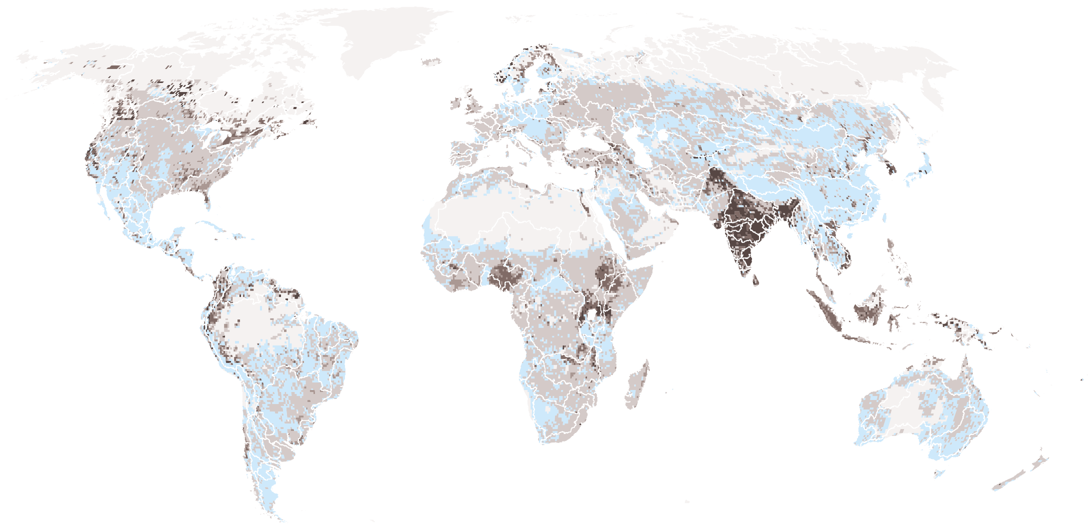
Source: PBL

Also for agriculture, the comparison between 2020 and 2070 shows large regional differences in nutrient emission trends. Under the Business-as-usual scenario, both regions with increasing and decreasing emission trends are found. South Asia stands out with the highest emission levels, caused by the high intensity of nitrogen fertilizer use. Under the High ambition pathway, with a transition towards a sustainable use of fertilizer (balancing input and output) and the implementation of buffer zones, a structural decrease in nitrogen emissions is projected across all regions.

Projected change in nitrogen emissions from agriculture to rivers 2020–2070
Business-as-usual scenario

Kg/km²

Decrease
0 – 500
500 – 1,000
1,000 – 2,500
> 2,500
No data

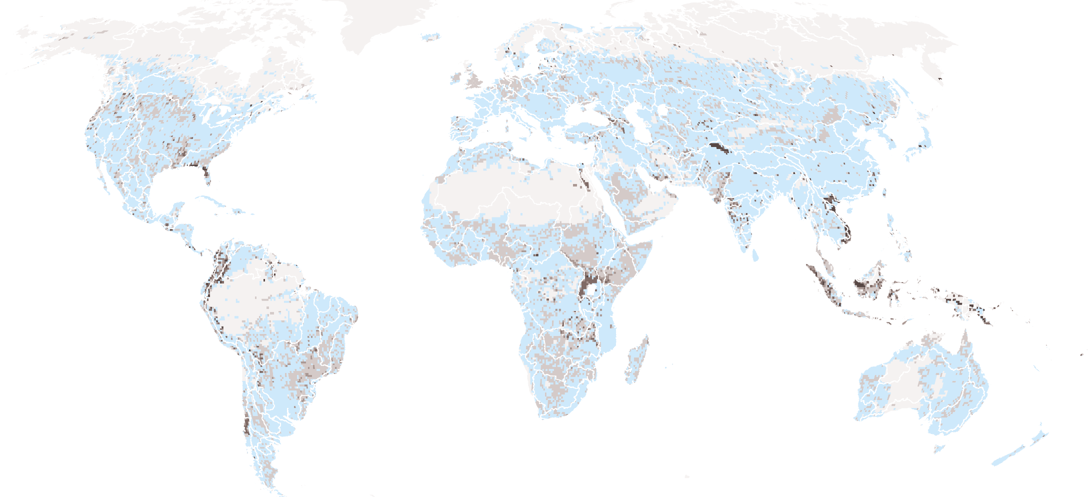


Source: PBL

High ambition pathway

Kg/km²

Decrease
0 – 500
500 – 1,000
1,000 – 2,500
> 2,500
No data



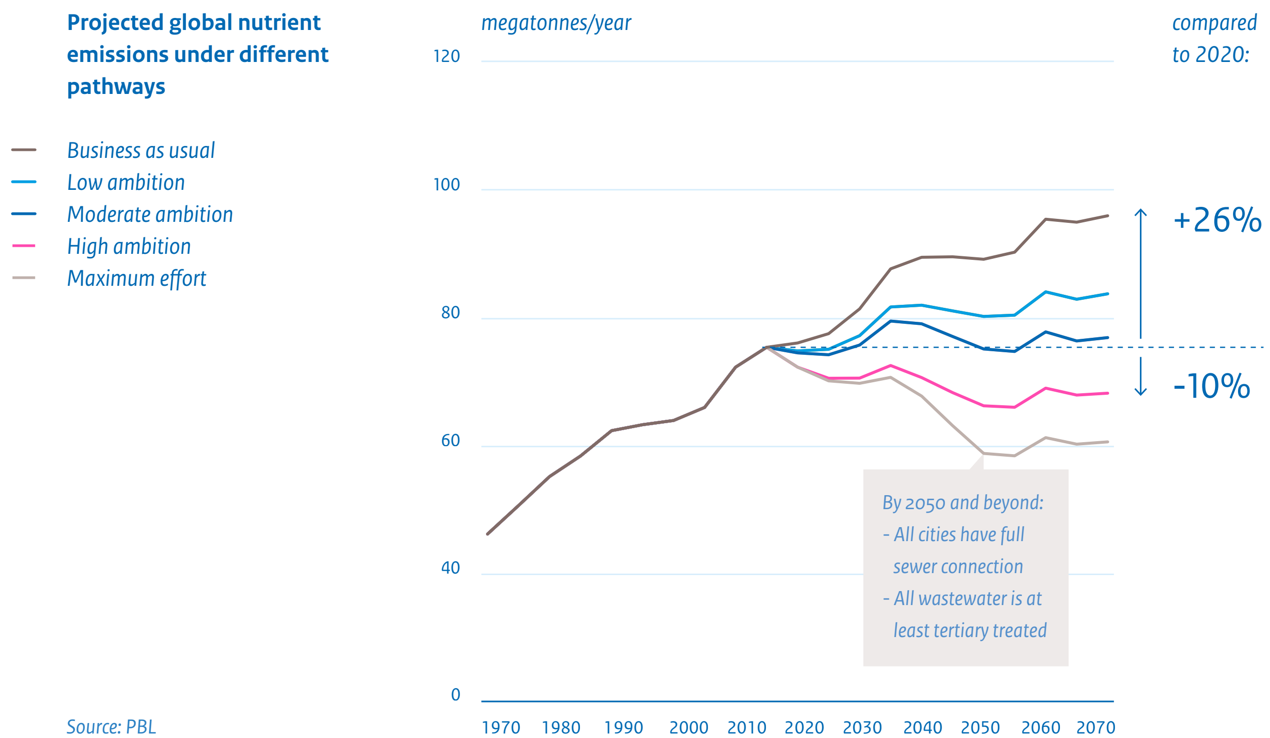
Source: PBL

NUTRIENT EMISSIONS REDUCED UNDER HIGH AMBITION PATHWAY

Reducing nutrient emissions from cities and agriculture is critical for restoring the ecological quality of freshwater ecosystems. Only under a High ambition pathway, the combined reduction in nutrients from cities and agriculture brings emissions just below current levels.

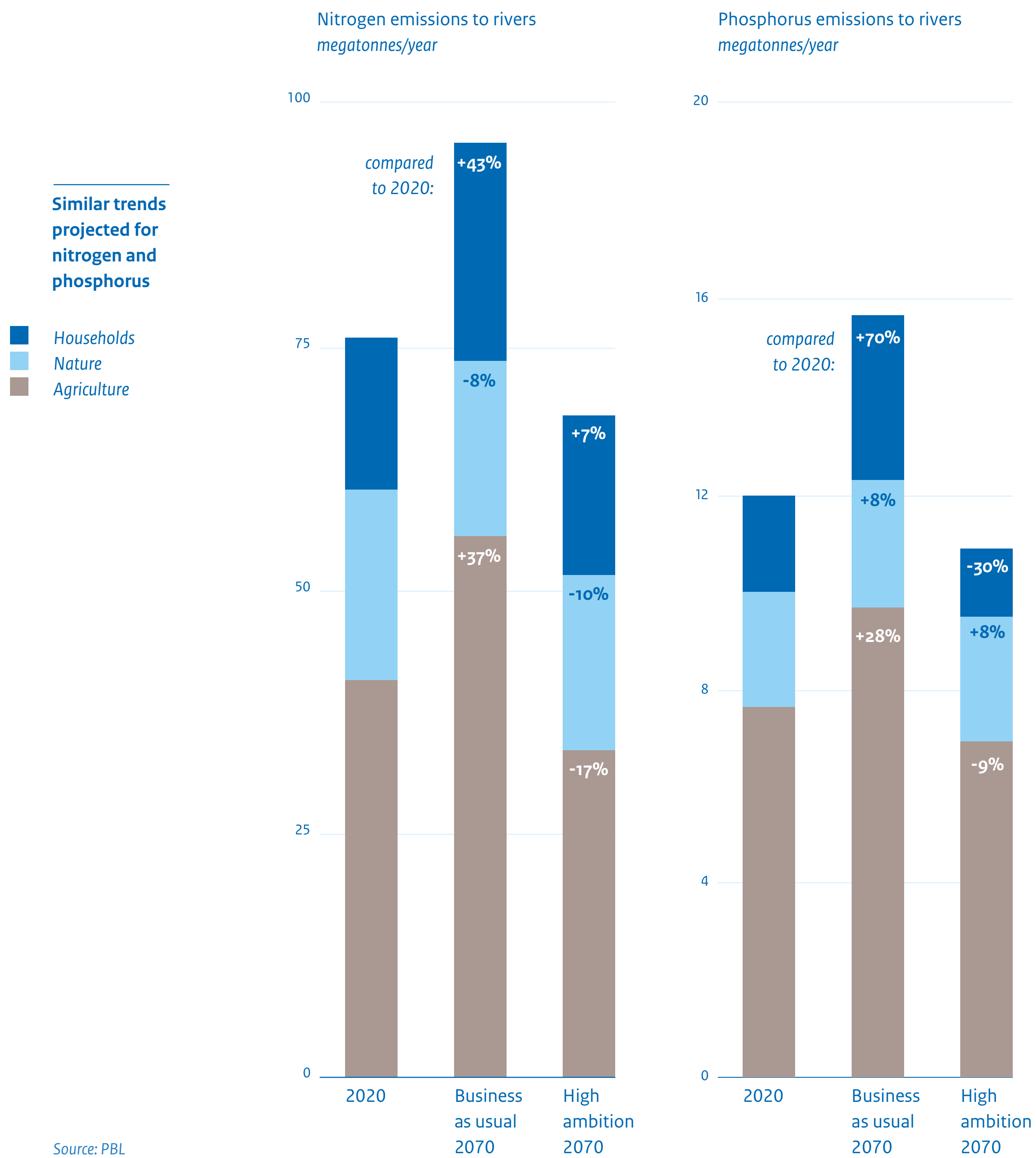
High ambition pathway compensates projected increase in nutrient emission levels
Under the Business-as-usual scenario, nutrient emissions are projected to increase in most world regions, resulting in a global increase of 26% over the 2020–2070 period. Even under the High ambition pathway, the realised global reduction in nutrient emissions hardly compensates for the projected increase under the Business-as-usual scenario. This in spite of a strong improvement in sanitation and wastewater treatment in cities and a transition to a sustainable intensification of agriculture worldwide, including nutrient buffers along agricultural land as nature-based solutions. The risks of algal blooms and oxygen depletion are unlikely to decrease. In fact, they may even increase as a result of higher water temperatures (p. 68).

Projected global nutrient emissions under different pathways



Source: PBL

Similar trends projected for nitrogen and phosphorus



Source: PBL

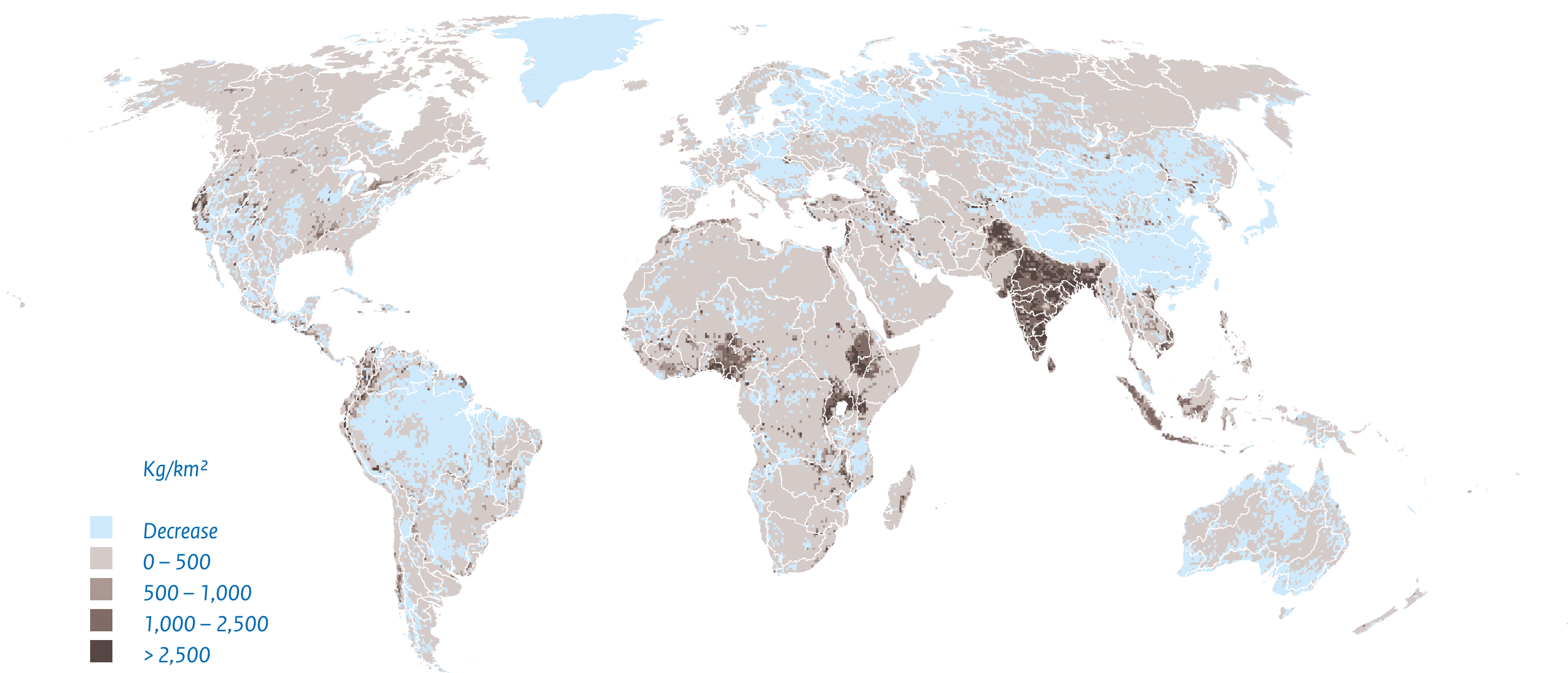
HIGH AMBITION: DECREASING NUTRIENT EMISSIONS IN MANY REGIONS

Under the High ambition pathway, a decrease in nitrogen emissions is projected for the larger part of the world, excluding Africa, India and the Middle East.

Projected change in nitrogen emissions from cities and agriculture combined
The combination of projected changes in nutrient emissions from cities and agriculture between 2020 and 2070 emphasises the relatively high levels of nutrient emissions in India and Africa.

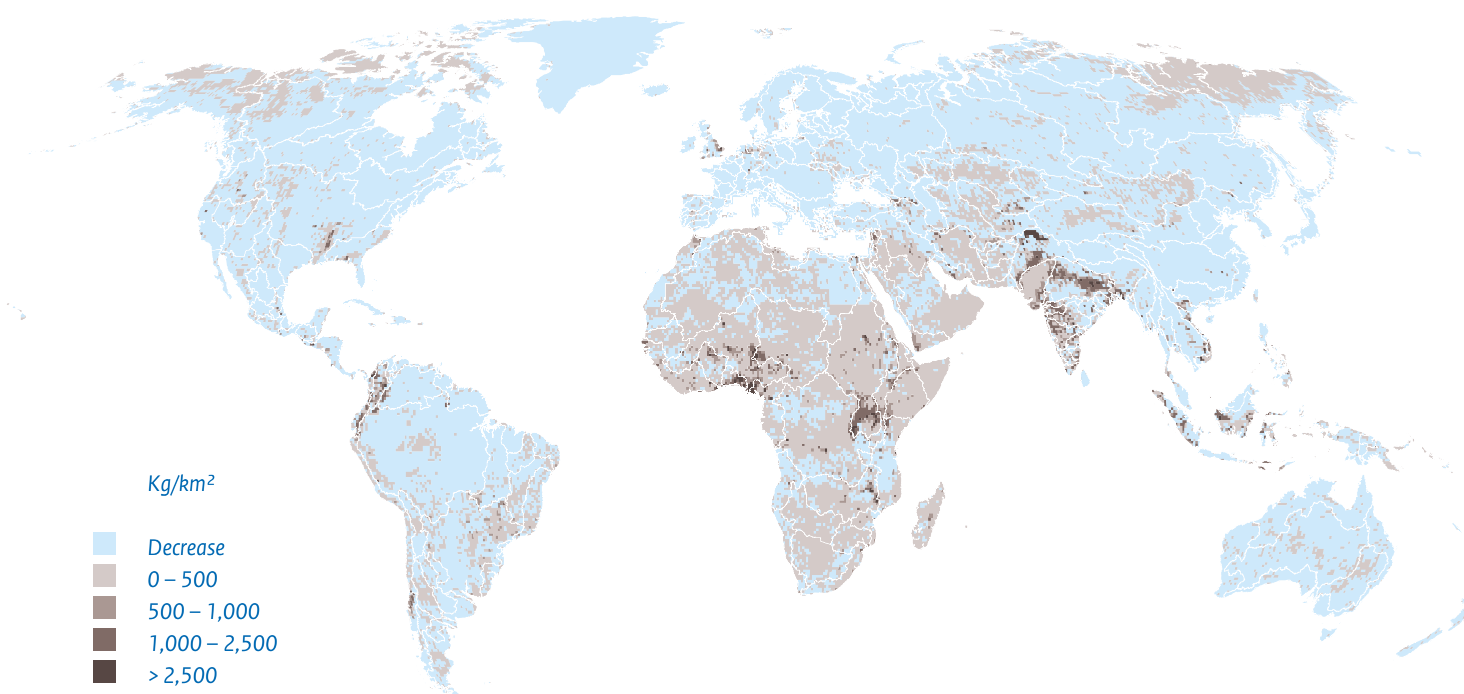
High ambition pathway
Under the High ambition pathway, a decrease in nitrogen emissions is projected for the larger part of the world, excluding Africa, India and the Middle East.

Increase in nitrogen emissions to rivers 2020–2070
Business-as-usual scenario



Source: PBL

Increase in nitrogen emissions to rivers 2020–2070
High ambition pathway

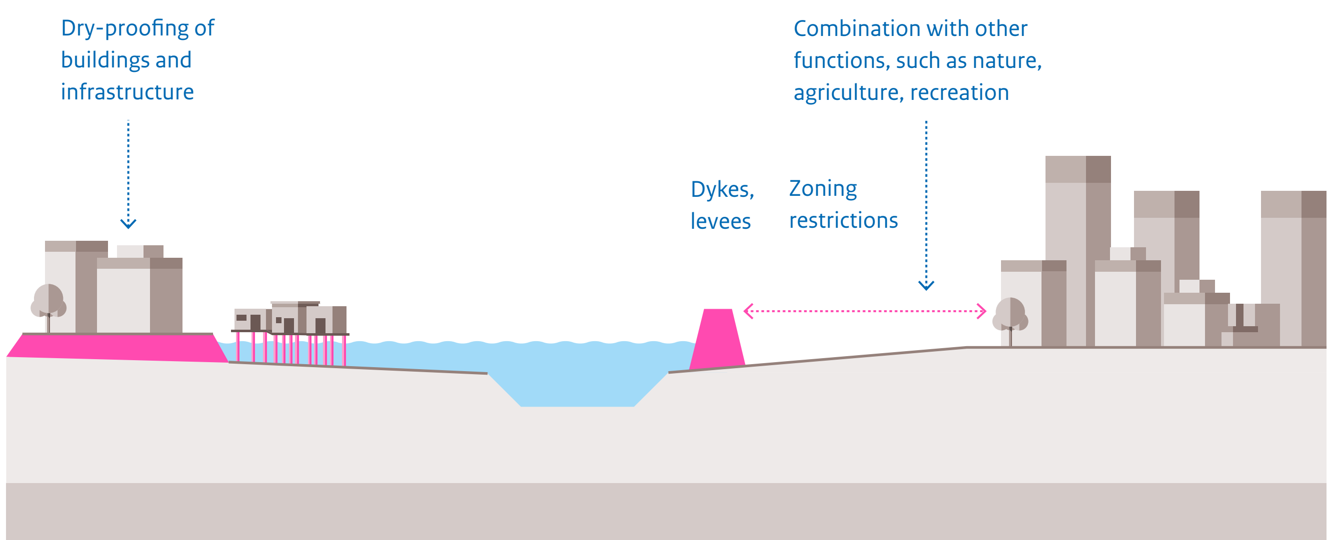


Source: PBL

ADAPTATION MEASURES FOR RIVERINE FLOOD RISK REDUCTION WILL PAY OFF

Benefit–cost ratios for measures to reduce flood risk are very positive. There is much room for manoeuvre when managing flood risk. The choices to be made depend on the overall national and transnational strategies, the local situation, the financial capacity and local community preferences.

Investments in reducing riverine flood risks: 3 main options
There are many ways to protect people and their assets against flooding and the related consequences, ranging from emergency and recovery plans to warning systems in combination with shelters, flood protection such as dykes and levees, dry-proofing of buildings and infrastructure and zoning restrictions in spatial planning. Stronger and higher dykes and levees reduce the probability of flooding (the hazard). Using zoning restrictions in the spatial planning of flood-prone areas reduces exposure, and dry-proofing buildings and infrastructure reduces vulnerability to flooding. The combination of hazard, exposure and vulnerability defines the level of flood risk. Zoning restrictions, in particular, offer opportunities to combine flood protection with other functions in floodprone areas, such as nature, agriculture and recreation.



Source: PBL

Ambition pathways to reduce riverine flood risk
Dykes and levees are highly effective measures to reduce flood risk. Under the High ambition pathway, these measures are used to
1. keep economic flood risk – as a percentage of GDP – constant in time, or in addition
2. increase the protection of urban areas.

In the Moderate ambition pathway, primarily zoning restrictions and dry-proofing are used, complemented with dykes and levees, to keep economic flood risk constant in time.
In the Low ambition pathway, only the relatively cheap strategies of zoning restrictions and dry-proofing are implemented without additional measures being taken to keep economic flood risk constant in time.

Effectiveness and Benefit–Cost Ratio of three types of flood-risk reduction measures

Effectiveness

Low
Moderate
High

On a global scale, all of these measures have a benefit–cost ratio of >1, indicating that all of them pay off. On a local scale, there is much flexibility in managing flood risk by turning the dials of hazard, exposure and vulnerability.

Risk = hazard x exposure x vulnerability	✓ Type of measure	Measure effectiveness in terms of flood protection*	Measure effectiveness in terms of benefit-cost ratio (BCR)*	Types of measures in the Low ambition pathway	*'Turning the dial'* in the Low ambition pathway	Types of measures in the Moderate ambition pathway	Types of measures in the High ambition pathway	*'Turning the dial'* in the High ambition pathway
Reducing hazard	Dykes and levees	High	Low			✓	✓	Increased protection of cities
Reducing exposure	Zoning restrictions	High	High	✓	Lower level of zoning restrictions	✓		
Reducing vulnerability	Dry-proofing of buildings, infrastructure	Low	Low	✓		✓		

**Effectiveness is determined for the local situation and then visualised at the global scale*

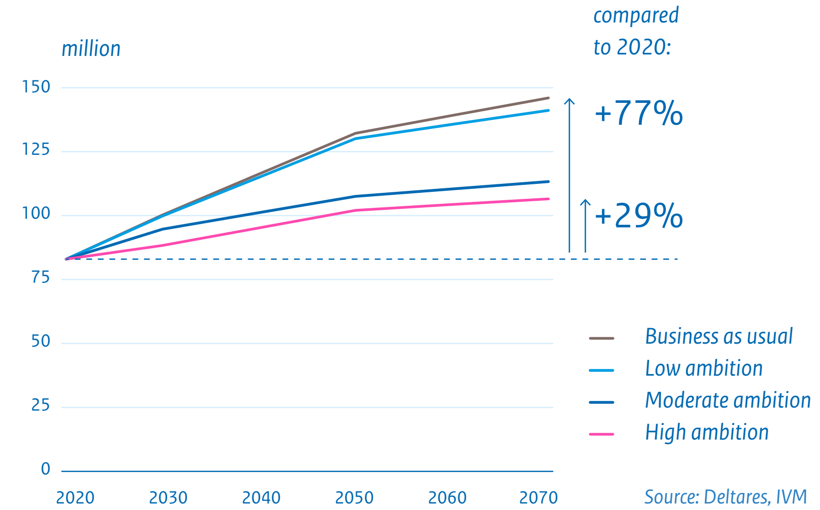
Source: PBL

OPTIMISING PROTECTION AGAINST RIVER FLOODING

Without effective improvements in flood protection, future annual flood risk in terms of the expected exposed population and expected urban damage is projected to increase strongly. Optimised combinations of dykes and levees, spatial zoning restrictions and the dry-proofing of buildings are cost-effective in greatly reducing flood risk.

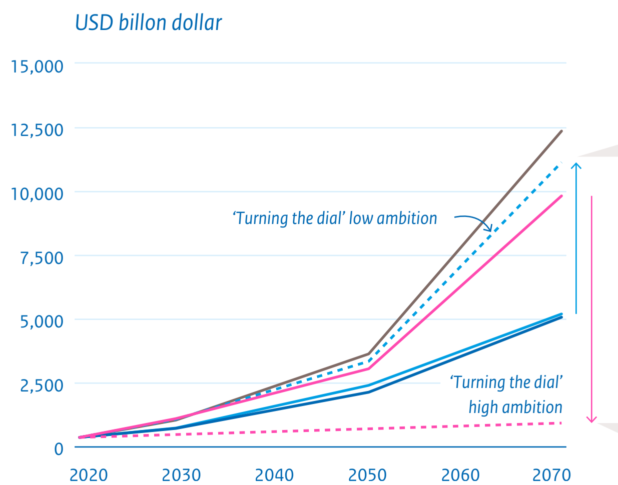
Large increases in riverine flood risk are projected for the coming decades.Under the Business-as-usual scenario, the expected population annually exposed to flood risk is projected to reach 150 million by 2070 — an almost twofold increase in comparison with 2020. Investments in dykes and levees (High ambition level) are vitally important to control flood risk and protect people.

Annually exposed population



The results under the High ambition pathway vary widely, with the strategy of extra protection for urban areas resulting in the lowest monetary value of the expected annual urban damage. Spatial zoning may also result in a wide range of effects, depending on the area kept clear of urbanisation (e.g. zoning based on a 1/10, 1/100 or 1/1000 year flooding event). The Low and Moderate pathways, thus, may halve the risk of flooding that would result under the Business-as-usual scenario. The '*turning the dial*' visualisation illustrates the flexibility in flood risk management.

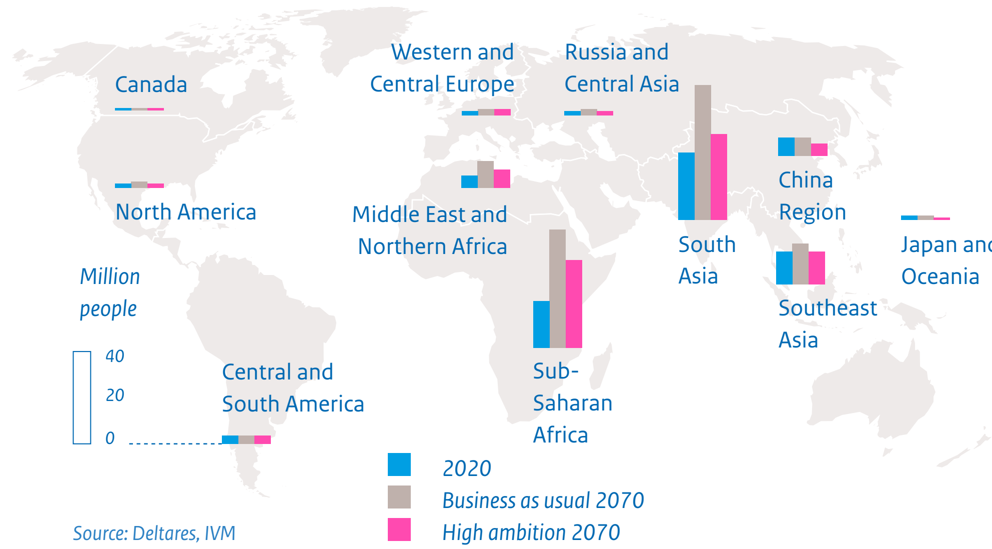
Annual urban damage



A wide range of flood risk reduction can be realised, depending on the choice of the level of zoning restrictions for developments in river basins.

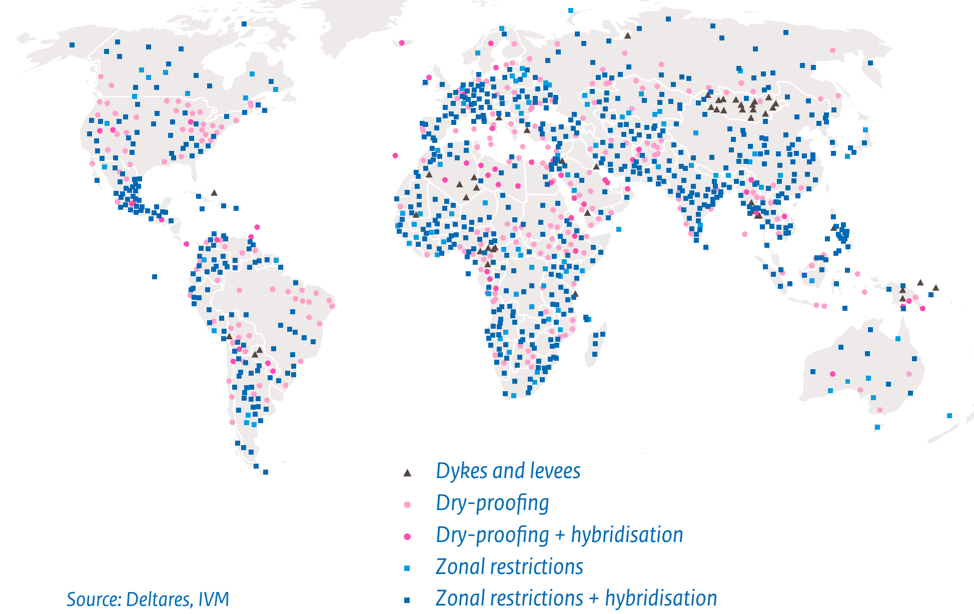
Increased protection of cities to a probability of 1:100 – 1:1000 would strongly reduce river flood risk (GFWC 1 p. 52), including exposed urban real estate.

Population annually exposed to river flooding



The projected share of the global population exposed to riverine flood risk in 2070 is predominately located in South Asia, Sub-Saharan Africa and Southeast Asia. In absolute terms, substantial reductions in flood risk can be achieved in these regions if a High ambition pathway is followed, but risks remain relatively high.

The locally most cost-effective strategies in achieving flood risk reduction towards 2070



Combinations of various measures are often the best option

Restricting and regulating future urban and industrial development in flood-prone areas in river basins in combination with building or strengthening dykes and levees lead to effective flood-risk reduction across many river basins. The zoning restriction measure specifically offers opportunities to combine flood protection with nature development and other functions. This measure also offers much flexibility in adjusting flood protection to future changes in river peak discharges and, therefore, contributes to a more climate-robust society.

ECOLOGICALLY HEALTHY RIVERS

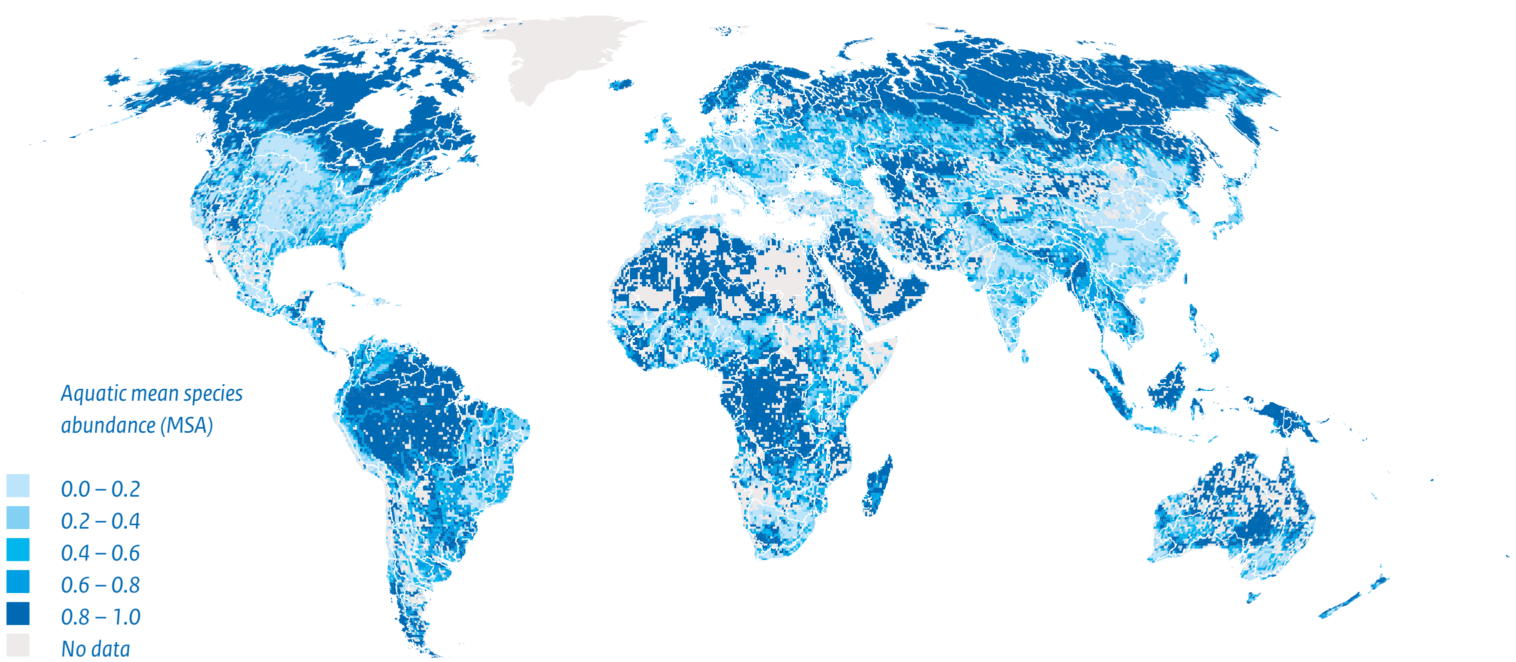
Healthy rivers are of high importance for humankind and biodiversity. These freshwater systems are under high pressure, however, especially in temperate and tropical zones. Restoring river quality requires a wide variety of measures.

Freshwater biodiversity under high pressure, especially in temperate and tropical zones
Although they only occupy 0.8% of the Earth's surface, freshwater systems such as lakes and rivers are immensely important ecosystems. Floodplain and non-floodplain wetlands occupy another 2% of the Earth's surface. Apart from the fresh water they provide, these water systems also host around 40% of all described fish species in the world and are important for many amphibians, reptiles, birds, mammals and invertebrates. Especially the tropical river systems, such as the Amazon and Mekong rivers, are very biodiverse.

The biodiversity of freshwater systems is already under high pressure in large parts of the world, especially in the temperate and tropical zones. Relatively high biodiversity levels are found in the northern regions, and within the Amazon and Congo river systems.

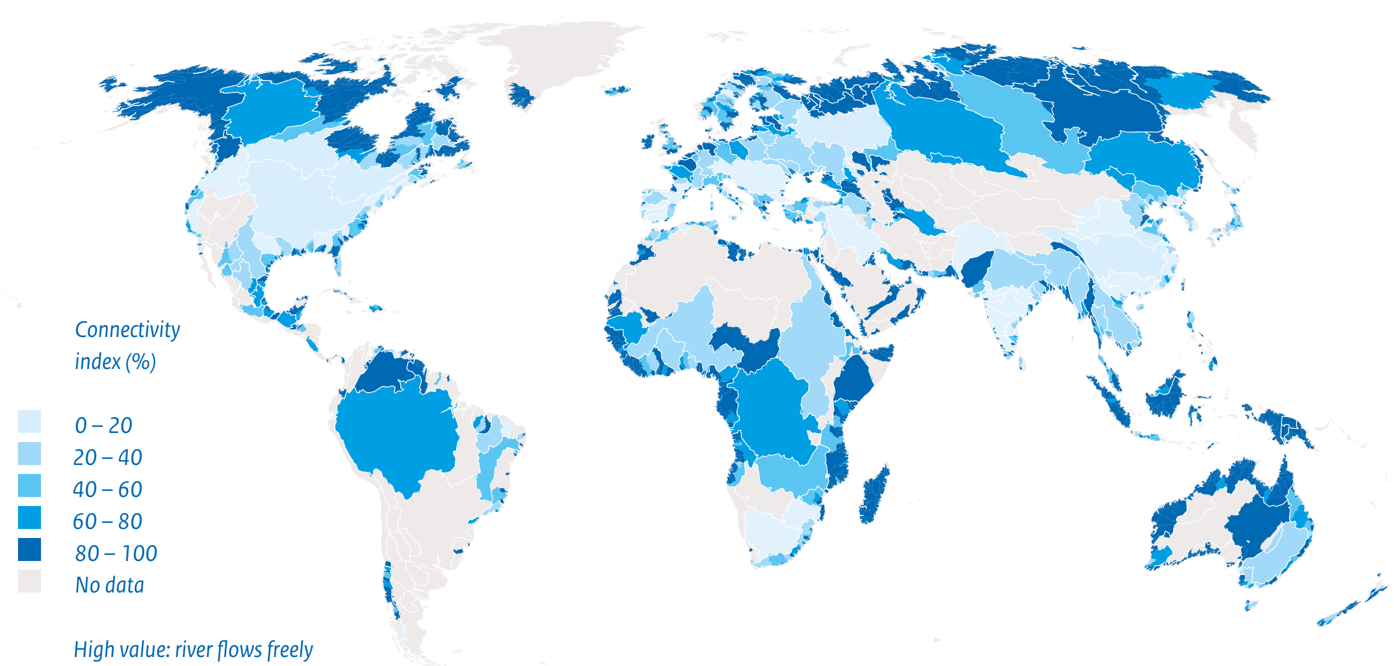
Fish migration is severely hampered by dams
Fish are severely restricted in their movement, especially in the temperate and tropical zones where many dams have been built. This is also reflected in the Living Planet Index for migratory fish, showing a 76% decline in migratory fish species, globally (Deinet et al., 2020).

Level of aquatic biodiversity intactness, 2015



Source: PBL/GLOBIO

The extent to which freshwater fish species can migrate freely



Source: Barbarossa et al., 2020

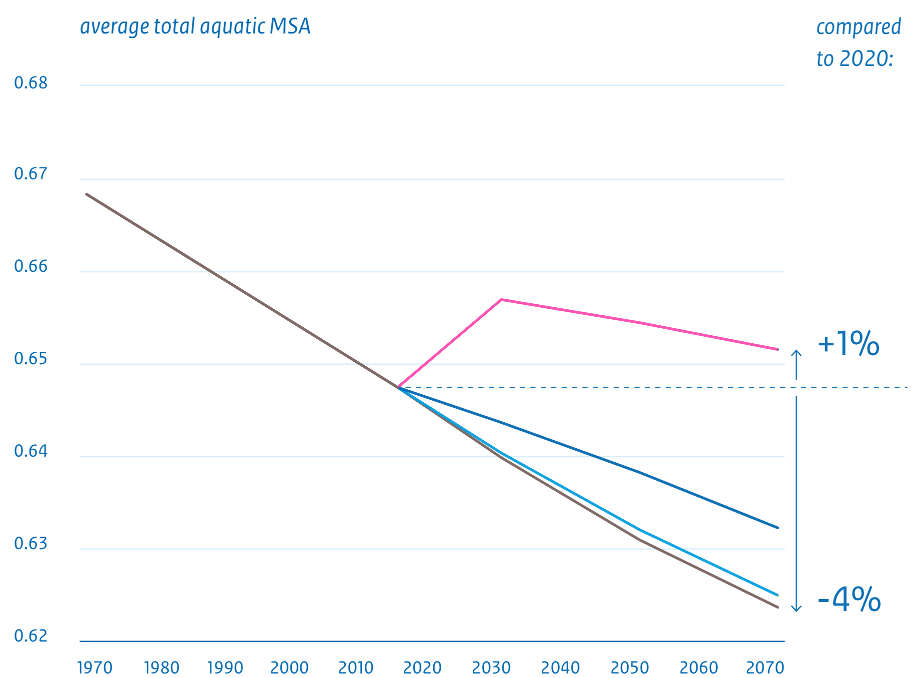
HIGH PRESSURES ON ECOLOGICAL QUALITY

In spite of the efforts under the High ambition pathway, the projected nutrient emissions and impact of dams by 2070 remain on the current high levels. The restoration of wetland areas will improve local ecological quality, but on average the ecological improvement is limited.

The Mean Species Abundance is an indicator of local biodiversity intactness and, therefore, of the ecological quality of freshwater ecosystems. The indicator ranges from 1, meaning that the species assemblage is fully intact, to 0, meaning that all original species are locally extinct. Globally averaged, the ecological quality of freshwater ecosystems is not projected to increase, not even under a High ambition pathway. This may be expected as projected pressures from dams and nutrient emissions do not differ much compared to today: under the High ambition pathway these pressures just have been neutralised.

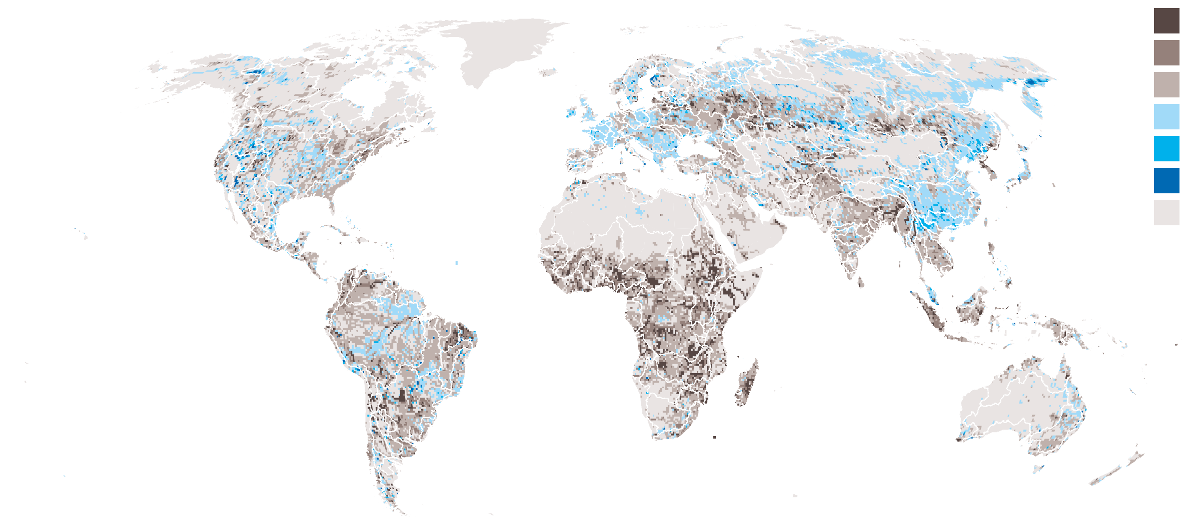
Even under a High ambition pathway, there will be only limited improvement in the ecological quality of river systems, around the world

Business as usual
Low ambition
Moderate ambition
High ambition



Source: PBL/GLOBIO

Projected change in aquatic biodiversity intactness, 2015–2070
Business-as-usual scenario

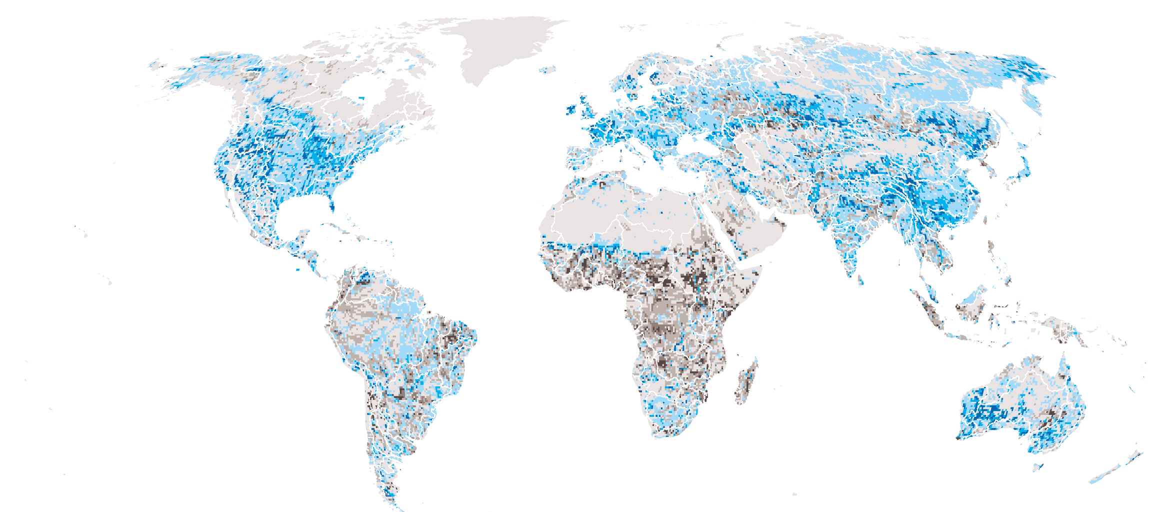


Change in aquatic biodiversity (MSA)

-1.0 – -0.2
-0.2 – -0.1
-0.1 - 0.0
0.0 – 0.1
0.1 – 0.2
0.2 – 1.0
No change / no data

Source: PBL/GLOBIO

High ambition pathway



Source: PBL/GLOBIO

Differences in projected changes in ecological quality are large
Mirroring the patterns of today, the human pressures on river basins in the northern zone, between 2015 and 2070, will remain low, while, in the temperate and tropical zones, river basins are projected to face much higher pressures.
In most river basins in Africa and South America further deterioration is expected in the future in the Business-as-usual scenario due to decreasing water quality, while in China, Europe and North America some improvement is projected, albeit far from recovery, especially in Asia. In the High ambition scenario some improvement is projected in many more regions, but not in India, Africa and parts of South America.

WATER TEMPERATURE INCREASE WILL FURTHER IMPAIR ECOLOGICAL QUALITY

Global warming will increase water temperature, which in turn will increase the risk of eutrophication and toxic algal blooms in lakes and affect the distribution of aquatic species. Temperature increases will thus interfere with ecological restoration efforts.

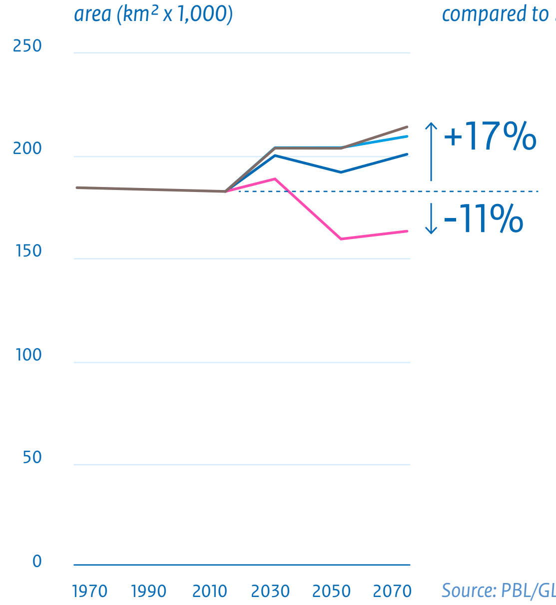
High ambition pathway for nutrient reduction slightly reduces the risk of harmful algal blooms
Higher water temperatures due to global warming in combination with high nutrient emission levels adversely affect the ecological quality of freshwater ecosystems and increase the risk of algal blooms in lakes that are harmful to human health.

Global area of freshwater systems with moderate to high risk of harmful algal blooms

Business as usual
Low ambition
Moderate ambition
High ambition

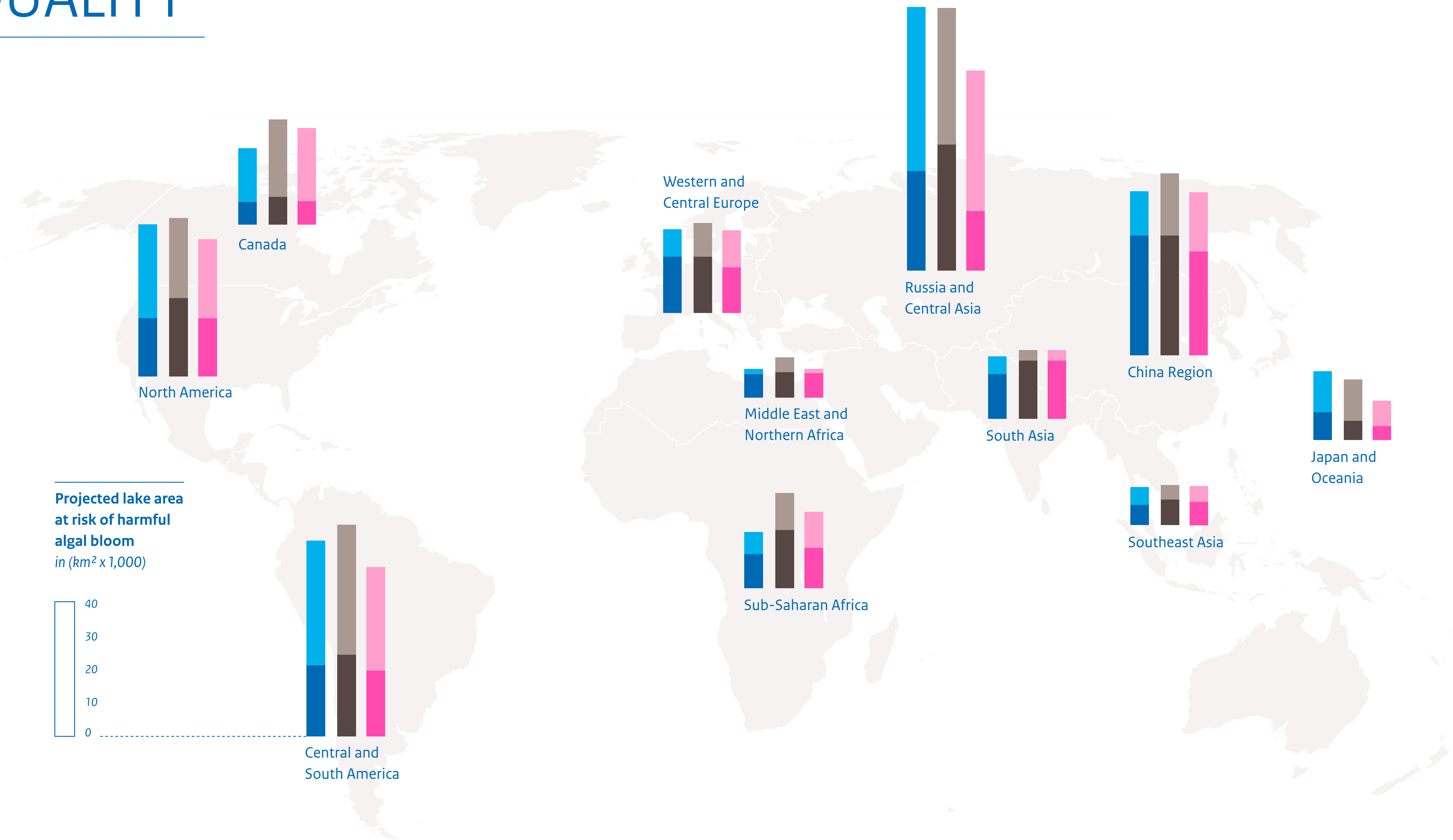
area (km² x 1,000)

compared to 2015:



Source: PBL/GLOBIO

Projected lake area at risk of harmful algal bloom
in (km² x 1,000)



Low risk
Moderate to high risk

2020
2070 Business as usual
2070 High ambition

Source: PBL/GLOBIO

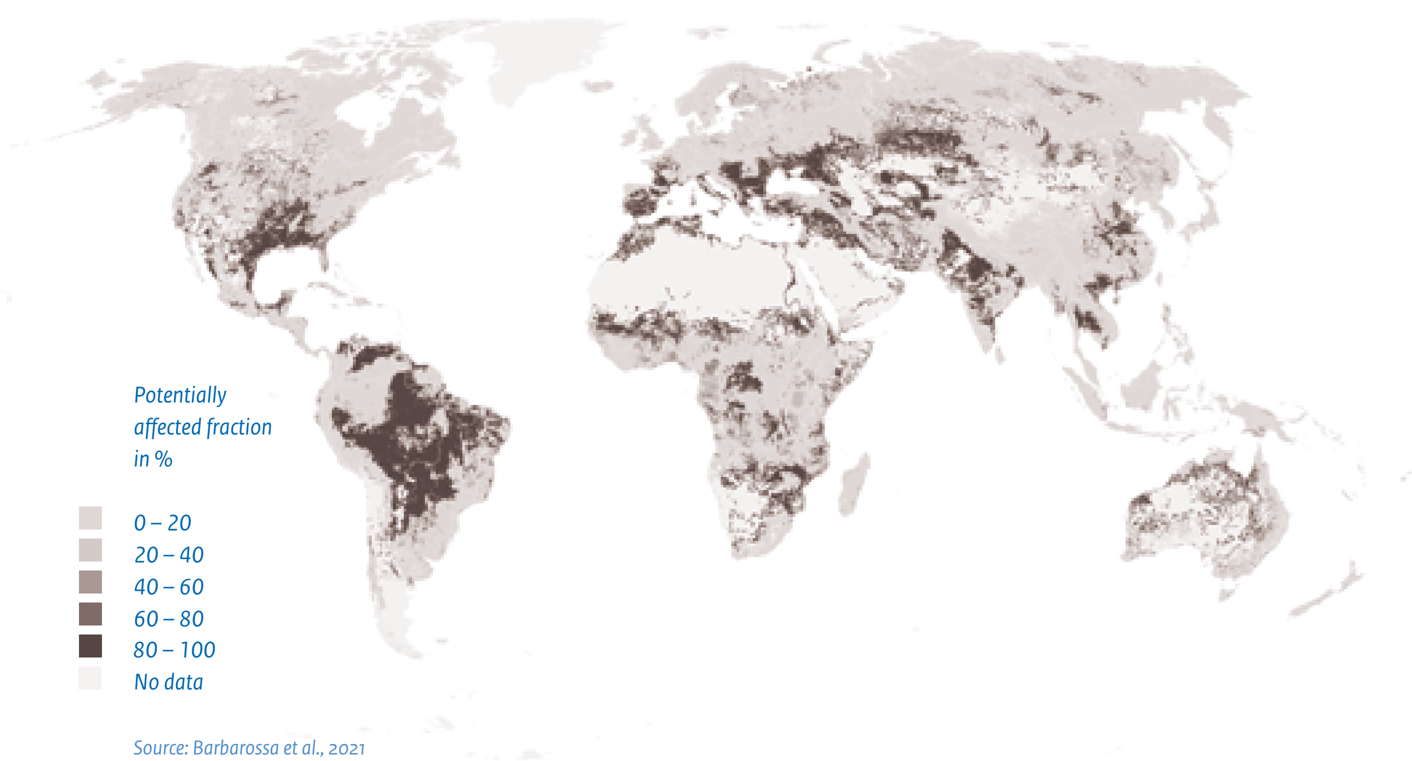
The global lake area with algal concentrations above WHO standards for health risk (WHO, 2021) is projected to further increase by 15% under the Business-as-usual scenario and Low ambition pathway, and by about 10% under the Moderate ambition pathway. This area will probably decrease under the High ambition pathway, especially in China, Europe and North America, as a result of nutrient reduction measures (p. 58).

EFFECT OF TEMPERATURE INCREASE ON FISH POPULATIONS EXACERBATED BY DAMS

Increasing water temperature can negatively affect fish species in their lifecycle patterns and by changing ecosystem conditions. Fragmentation of river habitats by dams disrupt natural movements and adaptation opportunities.

Higher temperatures affect the distribution of fish species
Temperature also affects the habitat suitability and geographical distribution of species, both terrestrial and aquatic. Projections show that, in the case of a 3.2 °C temperature increase and little dispersal potential for fish, the most vulnerable regions for freshwater fish species are East Asia, Central Asia, Sub-Saharan Africa and large parts of South America.

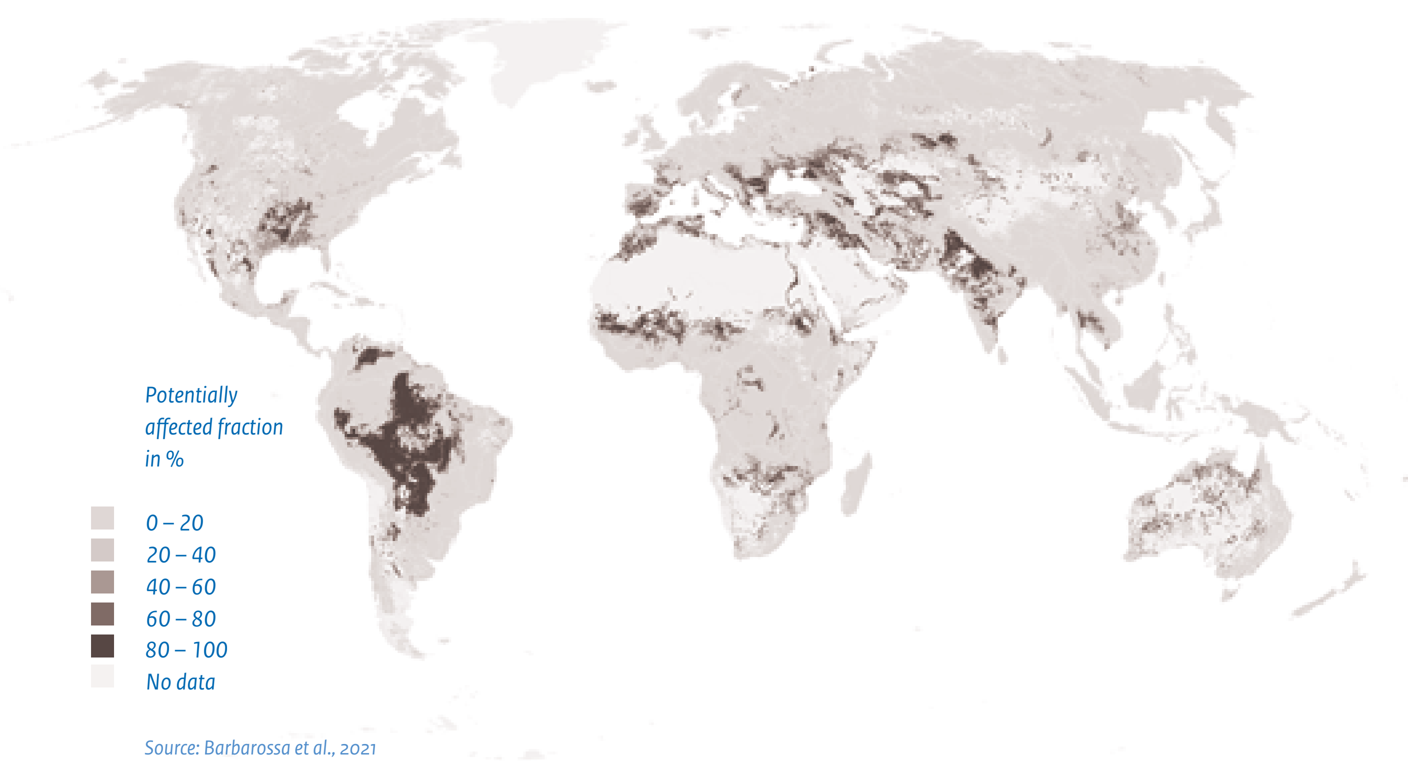
Fraction of freshwater fish species potentially affected by 3.2 °C global warming
Assumption: fish will not be able to migrate to cooler water



Source: Barbarossa et al., 2021

Structurally reducing the fragmentation impact of dams could achieve the maximum feasible level of dispersal, which would substantially reduce the affected proportion of fish species in many regions. Conserving and restoring fish dispersal opportunities, thus, may reduce the potential impact of temperature increase. In this way, reducing the number of dams in river systems may be a strategy for mitigating the effects of climate change on fish populations.

Fraction of freshwater fish species potentially affected by 3.2 °C global warming
Assumption: fish will be able to migrate to cooler water



Source: Barbarossa et al., 2021

MANAGING CONFLICT RISK IN SHARED RIVER BASINS

Historically, cooperation in transboundary river basins has prevailed over violent conflict. However, the pressure on transboundary institutions and collaboration will increase, because of the growing demand for water, changes in the availability of water and the construction of new dams.

By 2070, 4.4 billion people are projected to be living in transboundary river basins. Shared river basins may face increasing tensions and risks of conflict, given the increasing pressures on water resources.

Important contextual factors include:
1. institutional resilience in the form of water treaties and river basin organisations,
2. the level of upstream dependence on water and the construction of large hydropower dams potentially controlling water flows, and
3. exacerbating risk factors, governance and socio-economic pressures within countries.

In addition to water- and climate-related factors, the level of education and governance, and the economic bottlenecks to dealing with water-related challenges on a national level can exacerbate the risk of conflict. These exacerbating risk factors may be especially important in river basins in parts of the Sahel, the Horn of Africa and parts of southern Africa as well as in Afghanistan and Pakistan.

Factors that influence the risk of transboundary conflict

Comply with the United Nations Watercourses Convention
Including prior notice and consultation, dispute resolutions and data sharing

Institutional resilience
Facilitate and empower inclusive and transparant river basin organisations, consult a variety of stakeholders

Water infrastructure
No new big dams that adversely affect downstream countries

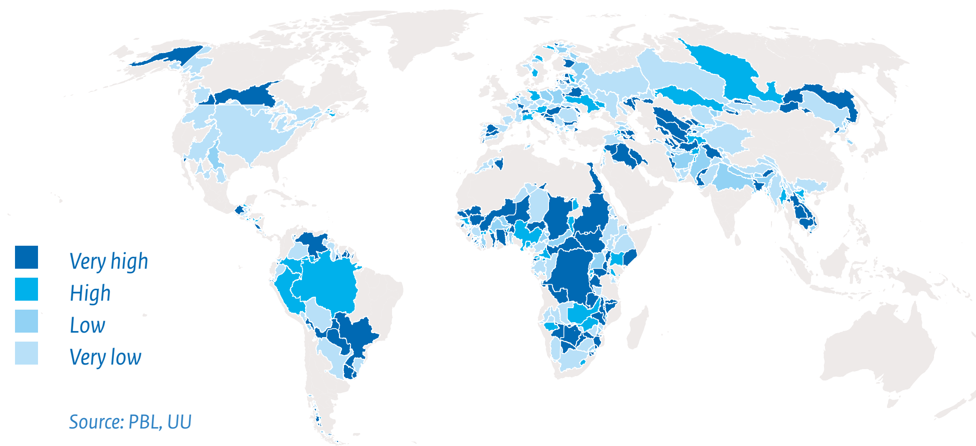
Water treaties
Make or adapt treaties that are fit for future climate challenges

Science networks
Create basin-wide networks of scientists from various disciplines

Upstream/downstream dependence
Upstream and downstream countries can reduce their water demand through reuse and efficiency

Respect the autonomy of riparian areas
Consultation and collaboration between riparian authorities

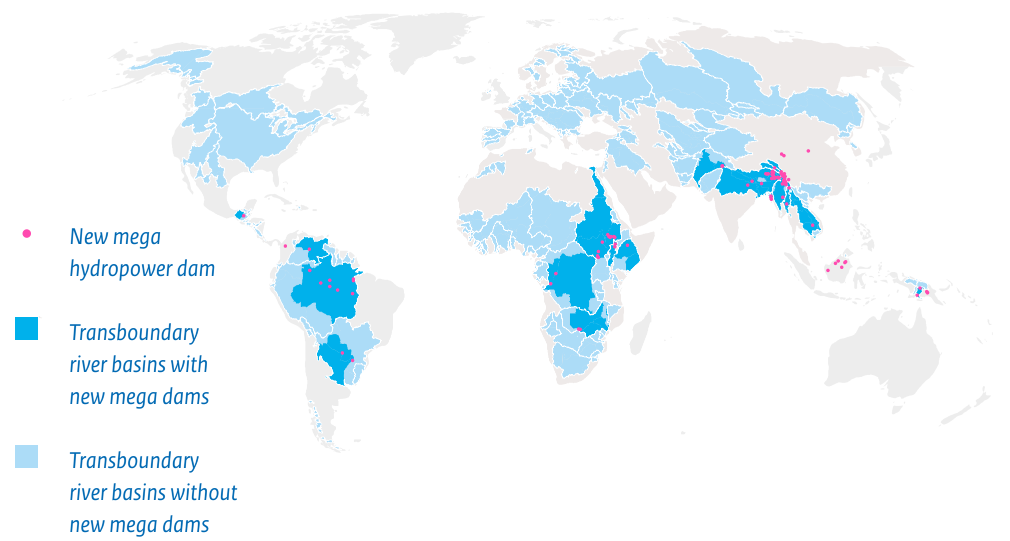
Upstream basin dependence of basin country units
High ambition pathway, 2070



Source: PBL, UU

Water context: upstream dependence and large hydropower dams
Also under the High ambition pathway, many countries in transboundary river basins are projected to remain highly dependent on water from upstream, especially in Africa, South America, and Central Asia. This dependence on upstream sources may increase in the future, due to reduced availability and increased demand for water.

Projected locations of new mega hydropower dams
2020–2070



Source: PBL, UU

Mega dams and conflict risk
The 86 large new dams for hydropower (>400MW) that are projected to be constructed in transboundary river basins under the Business-as-usual scenario may cause additional tensions. Many of these dams will be located in Southeast Asia, South America and the Horn of Africa.

IMPROVING FUTURE INSTITUTIONAL RESILIENCE

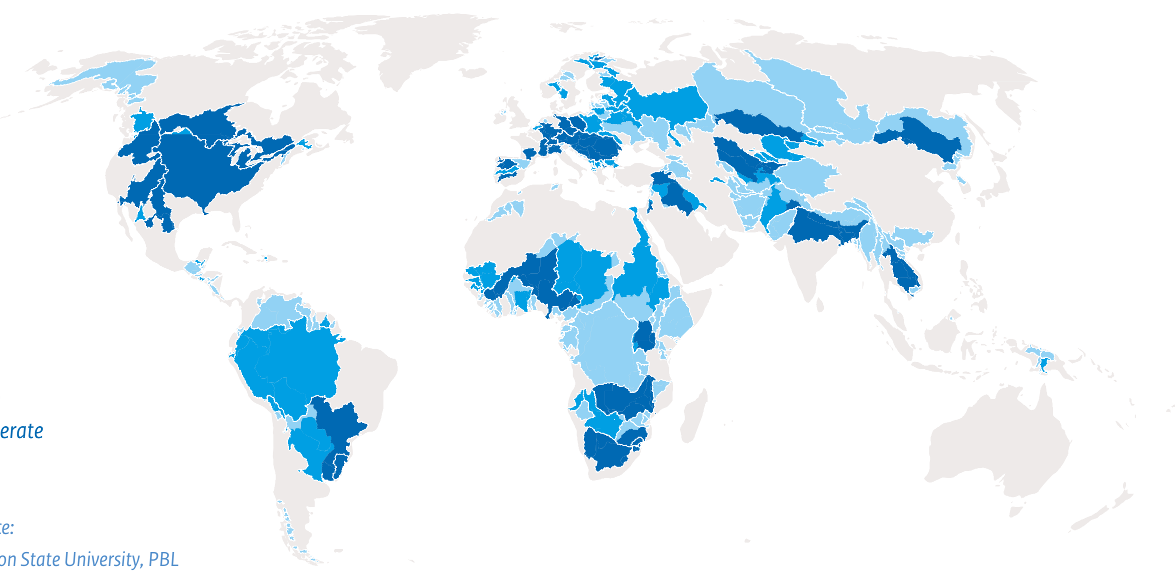
The institutional capacities and resilience to manage the projected increase in the pressure on transboundary collaboration will be critical. The assessment of the actual situation — being the basis for the Business-as-usual scenario — shows much potential for improvement.

Institutional resilience towards 2065
Institutional resilience is based on five factors:

- Ratification of at least 1 water treaty
- Inclusion of a conflict resolution mechanism in the treaty
- Inclusion of an adaptation mechanism in the treaty
- Principle of no significant harm to people downstream (fair water use)
- Establishment of a river basin organisation

In an assessment of the current situation, the score of institutional resilience may range from zero (none of the factors apply) to five (all factors apply) (De Bruin et al., 2023). Assuming no improvement in the current situation, the level of institutional resilience under the Business-as-usual scenario is low in many river basins, and the population is vulnerable to water- and climate-related pressures. Most river basins with low institutional resilience are found in Africa and Asia.

Institutional resilience of basin country units
Business-as-usual scenario

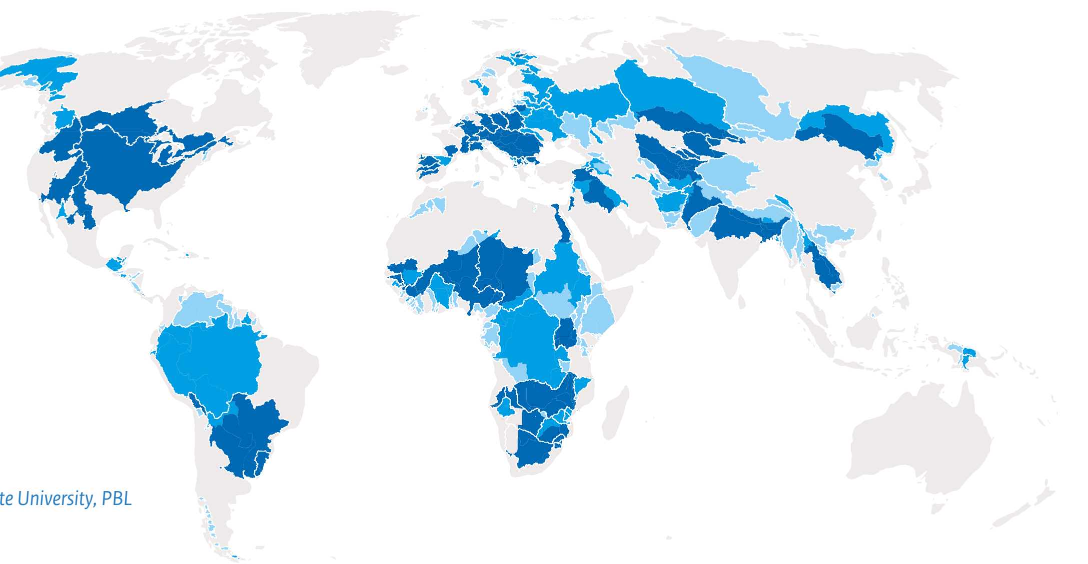


High
Moderate
Low

Source:
Oregon State University, PBL

Under the Low ambition pathway, institutional resilience increases in all river basins, with a score of +1, already showing a substantial improvement, compared to the Business-as-usual scenario. Furthermore, under the High ambition pathway, institutional resilience improves in all river basins, with a score of +2. This improvement means that this pathway shows no river basins with low resilience, reducing the risk of transboundary conflict.

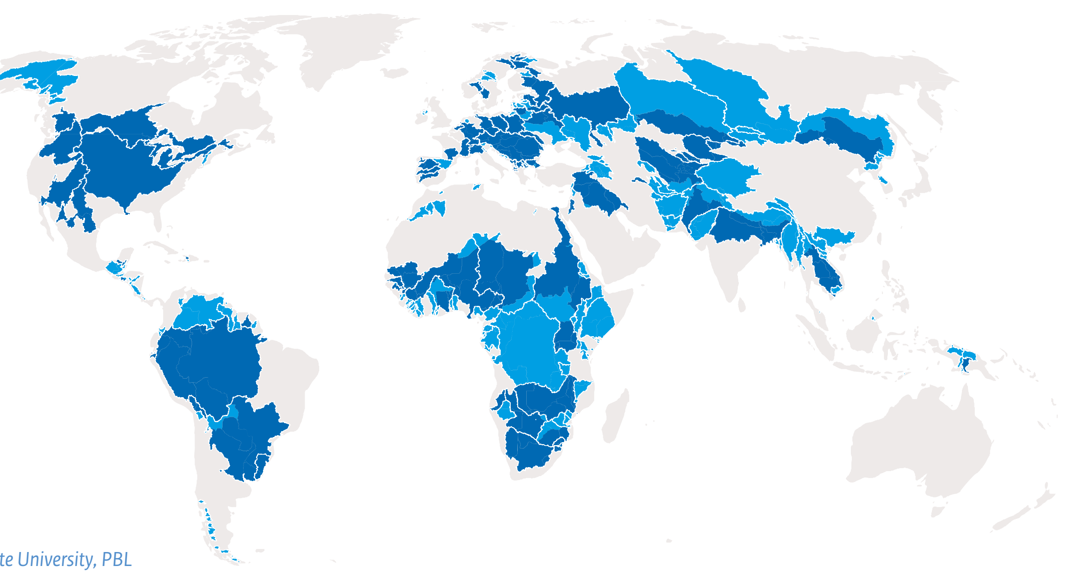
Low ambition pathway



High
Moderate
Low

Source:
Oregon State University, PBL

High ambition pathway



High
Moderate
Low

Source:
Oregon State University, PBL

TRANSBOUNDARY RISKS CAN BE REDUCED, SUBSTANTIALLY

Building on the pathways to institutional resilience, transboundary risks in river basins can be reduced, substantially. Under the High ambition pathway, the number of people living in high-risk river basins may decrease by 90%.

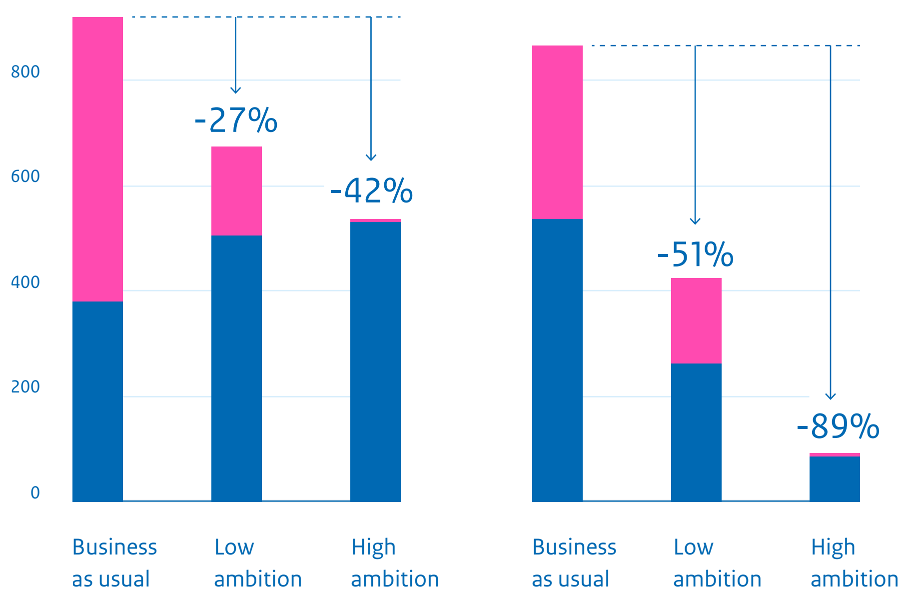
Strong decrease in the risk of transboundary conflict can be achieved
Of the 4.4 billion people living in transboundary river basins, 920 million people are projected to live in areas with a high to very high risk of conflict, by 2070, under the Business-as-usual scenario.

Improving institutional resilience will significantly reduce the number of people living in river basins with a high to very high risk of conflict, by 2070. Under the Low ambition pathway, this number of people may decrease by 51% to about 400 million people, and under the High ambition pathway by 89% to fewer than a 100 million people.

Number of people living in transboundary river basins with a high to very high risk of conflict

2050
in millions of people

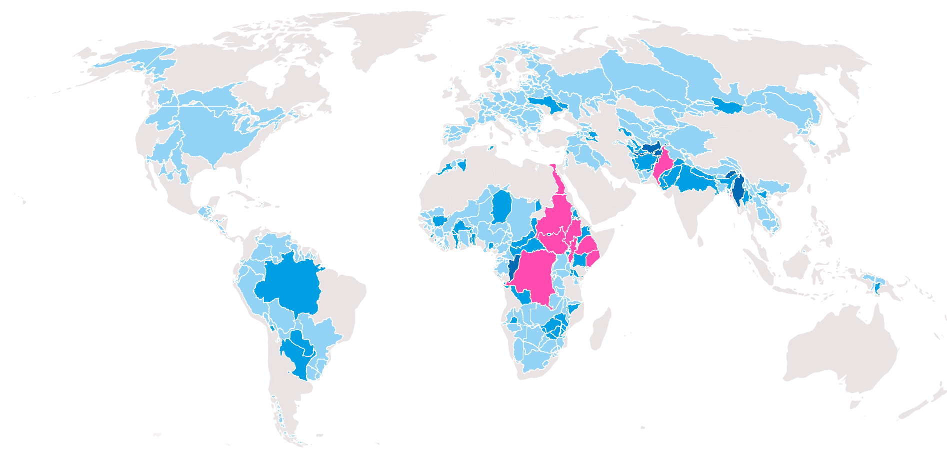
2070
in millions of people



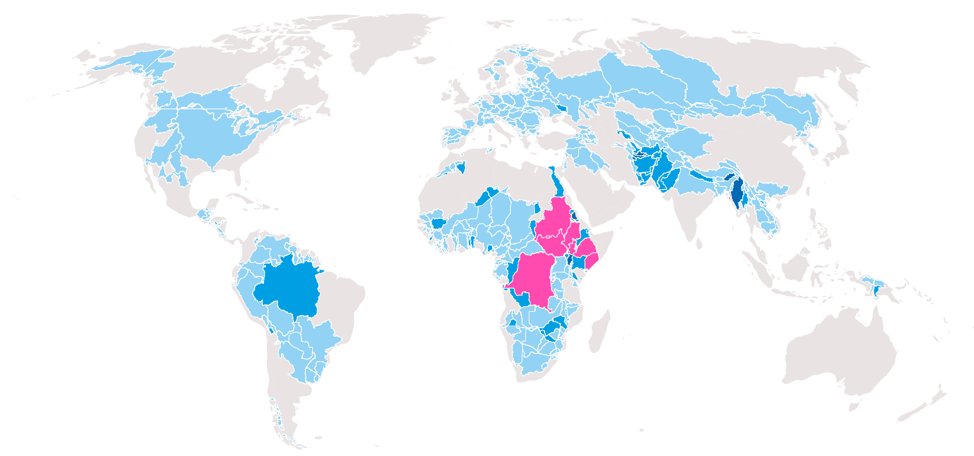
High risk
Very high risk

Source: PBL, WEnR, UU

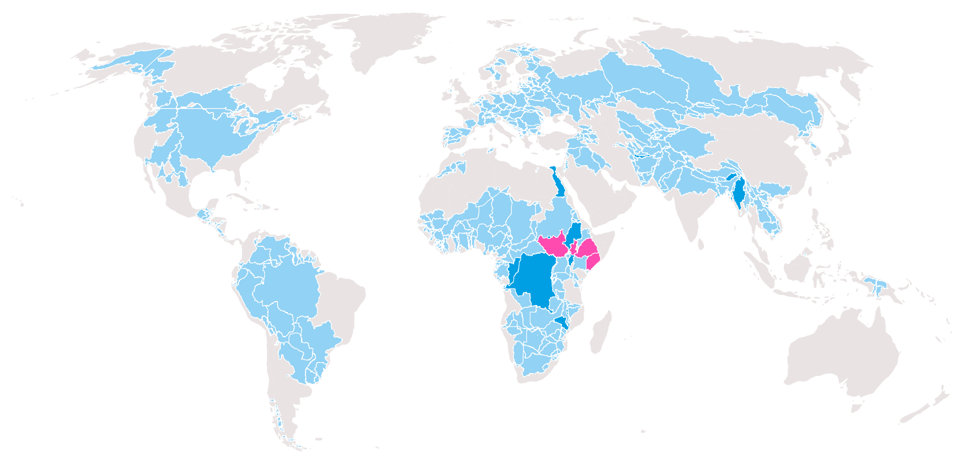
Overall risk of transboundary conflict by 2070
Business-as-usual scenario



Low ambition pathway



High ambition pathway



Low risk
Moderate risk
High risk
Very high risk

Source: PBL, WEnR, UU

River basins with relatively high compounding risks are those of the Nile, the Juba-Shibeli, Lake Turkana, the Congo, the Zambezi (all Africa), the Orinoco (South America), large parts of the Ganges-Brahmaputra, the Indus and the Aral Sea (all Asia).

THE VALUE OF WATER – SUPPORTING THE SDGs

Reducing water- and climate-related risks is projected to contribute in many ways to achieving the SDGs in all hotspot landscapes. A major challenge will be addressing inequality in future strategies.

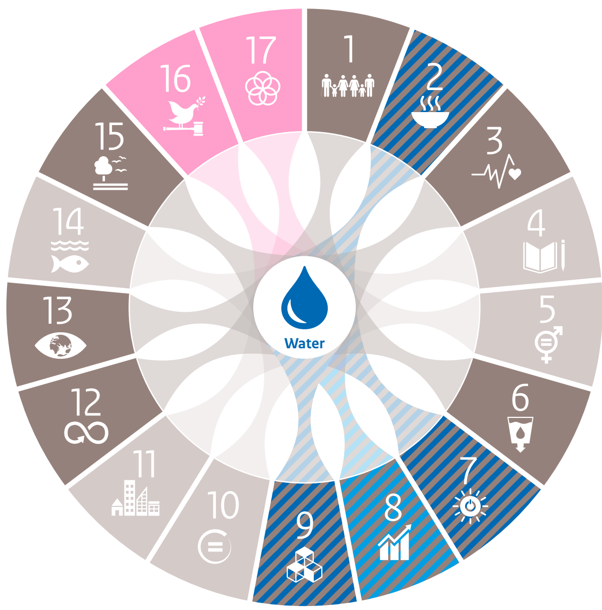
Projected improvement 2070, compared to 2020
- *based on quantified indicators*
- *qualitative appreciation*

Projected deterioration 2070, compared to 2020
- *based on quantified indicators*
- *qualitative appreciation*

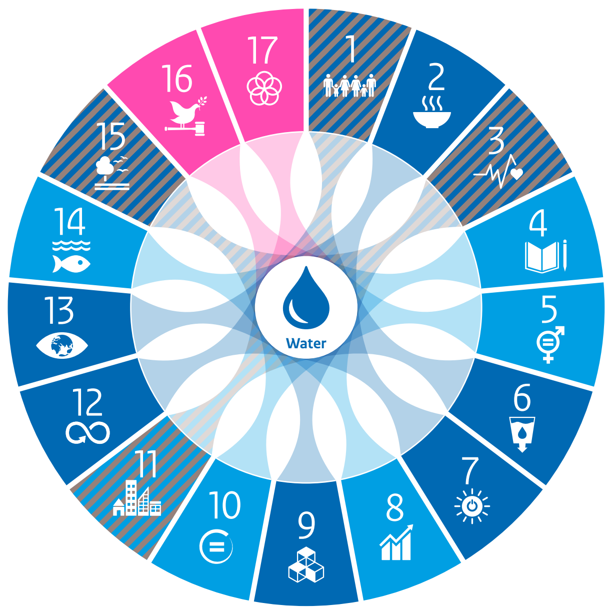
Important condition for transition
- *assumed to be fulfilled*
- *assumed not to be fulfilled*

partial improvement, partial deterioration or standstill 2070 compared to 2020

SDGs, Business-as-usual scenario 2070



SDGs, High ambition pathway 2070



The main differences in impact of the High ambition pathway on river basins, compared to the Business-as-usual scenario

SDG	
1	The increase in GDP per capita is associated with only a small increase in the number of people affected by water- and climate-related disasters.
2	Greater increase in crop production (100% vs 20%) in combination with less water pollution and a higher level of agricultural water use efficiency.
3	Reduction in the number of people annually affected by flooding and those vulnerable to changes in climate in terms of water availability and food production, contributing to human health and well-being.
4	Reduction in the number of children exposed to water-borne diseases and the number of schools exposed to flood risk.
5	Safer living conditions for women and girls because of increased sanitation and wastewater treatment, water availability and food production and more effective flood risk management.
6	Strong improvement in sanitation and wastewater treatment and, as a result, in the health and living conditions of the poor, in particular. However, nutrient emissions to surface water remain high.
7	Lower risk of flooding disturbing the energy supply under a 70% increase in hydropower production.
8	Higher GDP per capita in combination with lower climate vulnerability in terms of water volumes available for agriculture, households and industries, and more effective flood risk management.
9	Higher GDP per capita associated with innovations geared to flood protection, water use and reuse, water- and climate-robust building and restoring ecological quality.
10	Efforts to reduce inequality are integrated in development strategies, from global to local levels, especially contributing to SDG1.
11	Contribution to the development of sustainable cities and communities by improving flood protection, sanitation, water and food security and water use efficiency.
12	Greater water use efficiency and fewer polluting emissions contributing to achieving the goal on responsible consumption and production. Progress is lacking under the Business-as-usual scenario.
13	Implementation of adaptation strategies and measures, reducing the risks of flooding, drought and ecological deterioration, anticipating the RCP6.0 scenario.
14	Ecological quality of coastal seas improves by maintaining the continuity of freshwater and sediment flow, reducing nutrient emissions and applying nature-based solutions in flood risk protection.
15	Halting a further loss of freshwater biodiversity and reversing an additional 6% loss of wetlands by restoring wetland areas.
16	Strong improvement in the institutional capacity across scales enables effective river-basin and ecosystem-based approaches and reduces the risks of transboundary conflict.
17	Effective collaboration between public, private and societal actors and local communities results in new partnerships and coalitions supporting innovation and transformation.

DELTAS AND COASTS

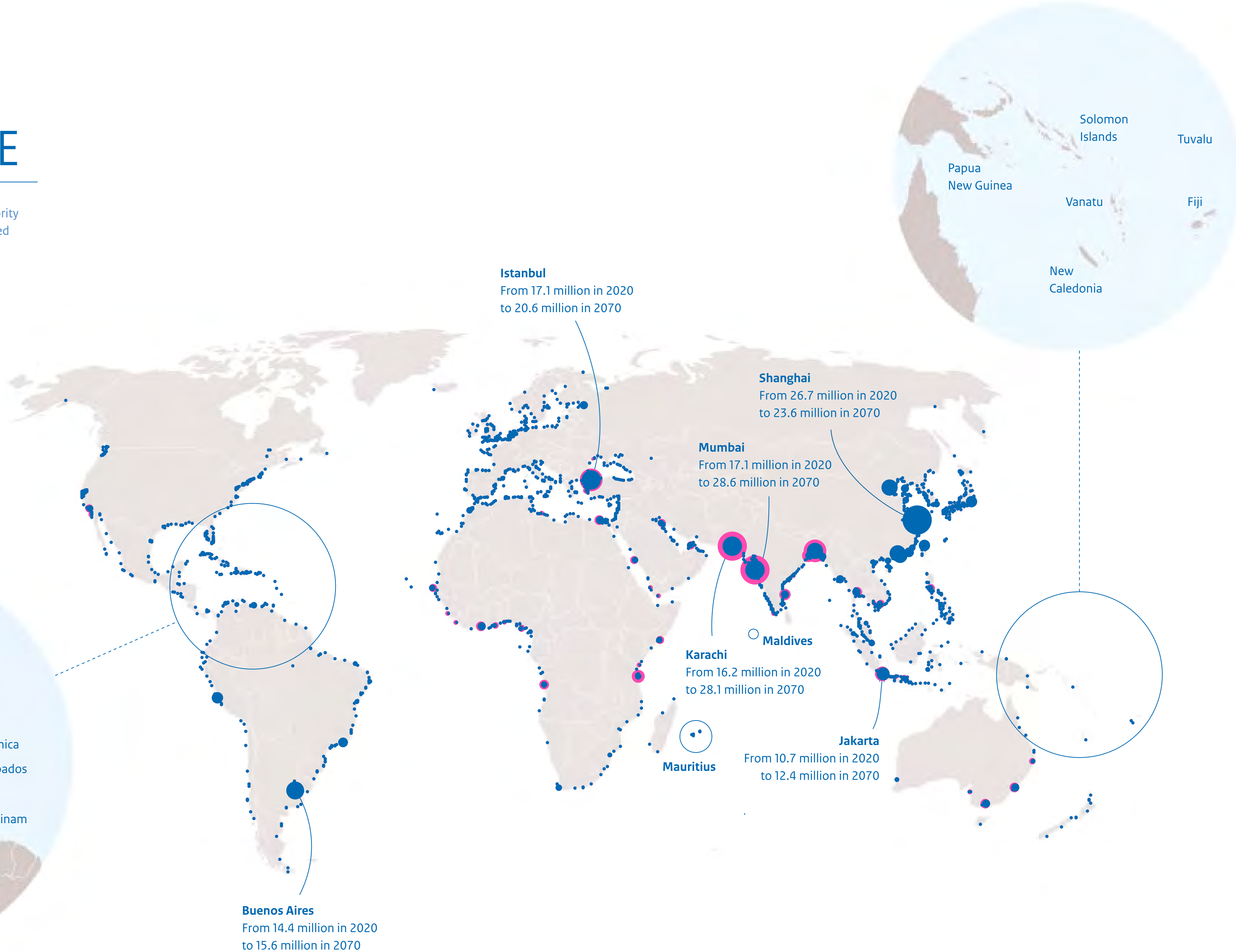
LIVING AT THE EDGE

Today an estimated 2 billion people live in deltas and coastal zones, a majority of them in cities. Deltas and coasts are projected to become more populated while sea level rise, increasing weather extremes, subsidence and water pollution undermine the future.

Deltas and coastal zones are attractive areas to live in and host many large cities
Deltas and coastal zones are home to hundreds of millions of people, many of whom are living in cities. These people are facing the consequences of climate change, including sea level rise, changes in weather patterns and tropical storms, and increased variability in their freshwater supply.

Population in delta and coastal cities in 2020
Population increase in delta and coastal cities in 2070

1 million
10 million

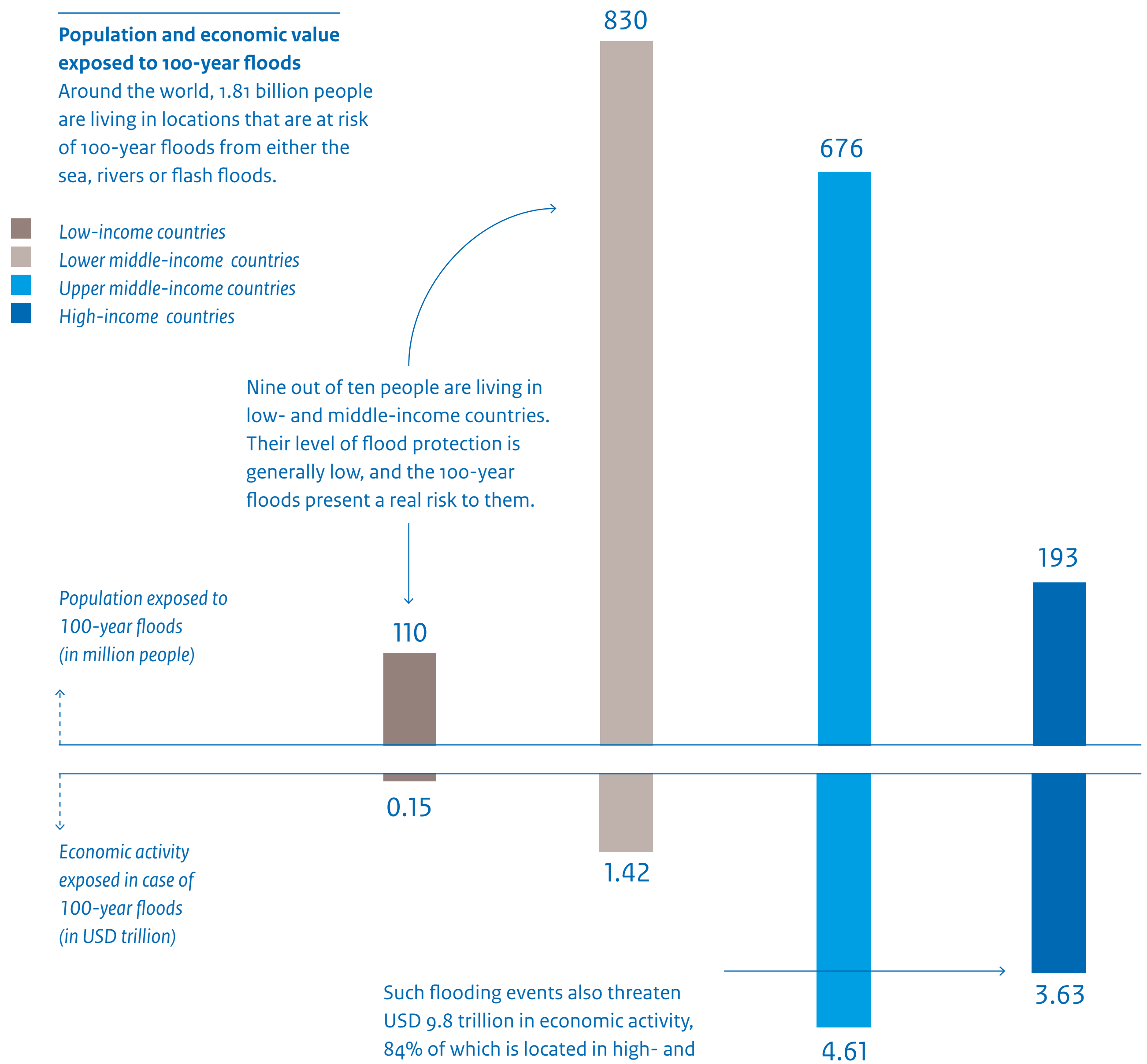


Source: PBL

1.8 BILLION PEOPLE EXPOSED TO 100-YEAR FLOODS

The largest share of the global population that is exposed to 100-year floods are people living in low- and middle-income countries. The largest share of economic activity exposed to these floods, however, is located in high- and upper middle-income countries.

Population and economic value exposed to 100-year floods
Around the world, 1.81 billion people are living in locations that are at risk of 100-year floods from either the sea, rivers or flash floods.

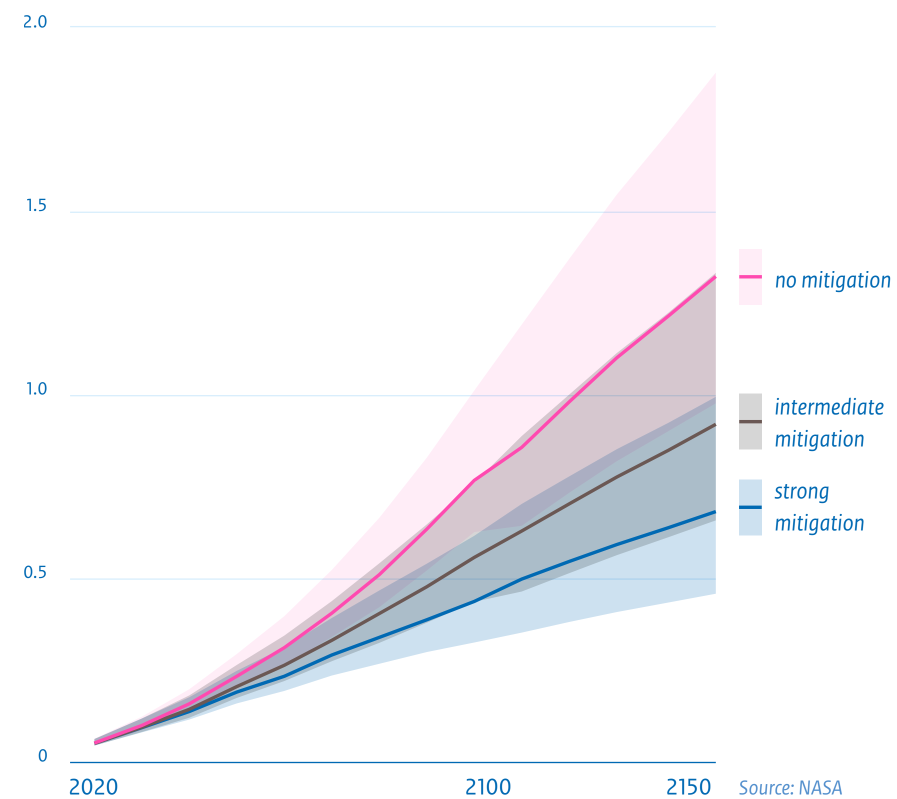


Source: Rentschler et al., 2022

Future sea level rise, changes in storm surges, high peak river discharges and local subsidence strongly increase the future vulnerability of low-lying coastal areas and deltas. The Small Island States are particularly vulnerable for sea level rise, although hardly visible in the economic value and number of people at risk. These states however are facing the most immediate threat of sea level rise already today – putting millions of people at risk of displacement. The world thus needs to adapt, but a large part of the global population lacks the financial means to do so. When prioritising investments in flood protection, investments may be concentrated in high-income countries and economic hubs. As a result, low-income countries would remain disproportionately exposed to flood risks and continue to be more vulnerable to disasters and long-term impacts (Edmonds et al., 2020).

Projected sea level rise is uncertain
The rate of future sea level rise is highly uncertain due to the uncertainty about the global achievements on greenhouse gas emission reductions (mitigation) and the complexity of the forces driving sea level rise and the still unknown probability of potential accelerating tipping points.

Projected global mean sea level rise
Sea level rise (m)



Source: NASA

SUBSIDENCE: A MAJOR THREAT

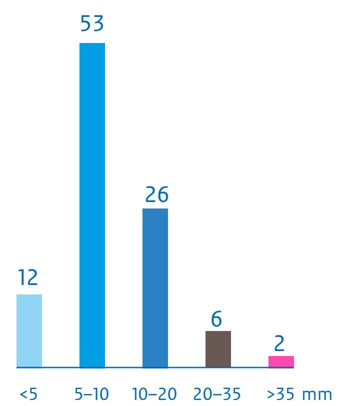
In addition to sea level rise, coastal communities are also facing the major threat of subsidence, which is primarily caused by groundwater abstraction for freshwater supply. Subsidence increases flood risk and the salinisation of groundwater systems. It is vital, therefore, to reduce groundwater abstraction in view of accelerating sea level rise.

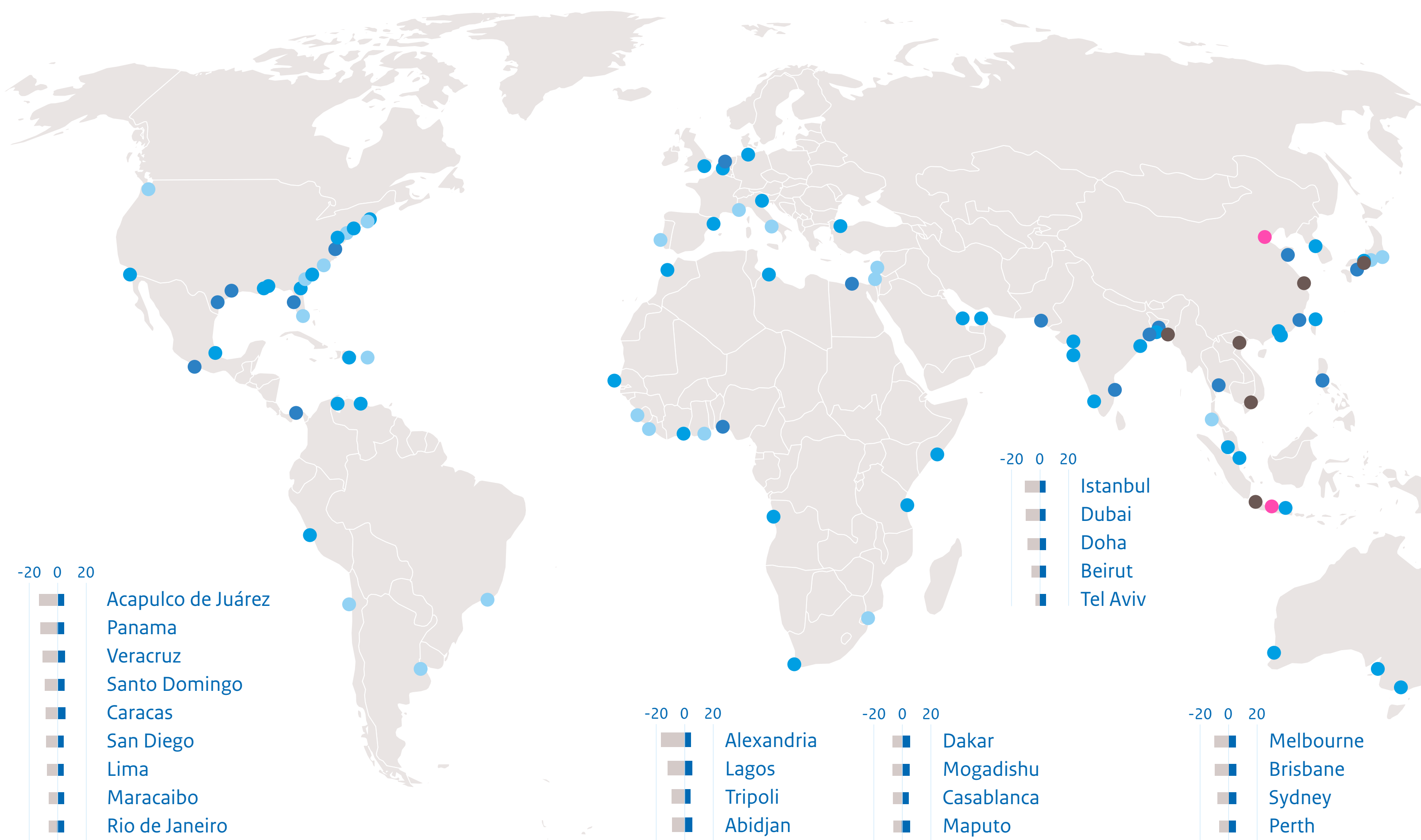
Subsidence: a common phenomenon in deltas and coastal zones
Subsidence is a common phenomenon in many deltas and coastal zones, mostly caused by human interventions. Groundwater abstraction and, to a lesser extent, oil and natural gas extractions are the main drivers of subsidence. In some areas, the construction of buildings and infrastructure, soil compaction and decomposition of organic matter after drainage may also lead to subsidence.

This map shows the maximum rate of subsidence between 2015 and 2020 in 99 cities around the world. The histogram shows that, for most of these cities, the rate of subsidence was between 5 and 20 mm/year.

Subsidence: a major contribution to relative sea level rise
Today, in many deltas and coastal cities, subsidence is exceeding the rate of sea level rise.

Subsidence in mm/yr for 99 cities
city count





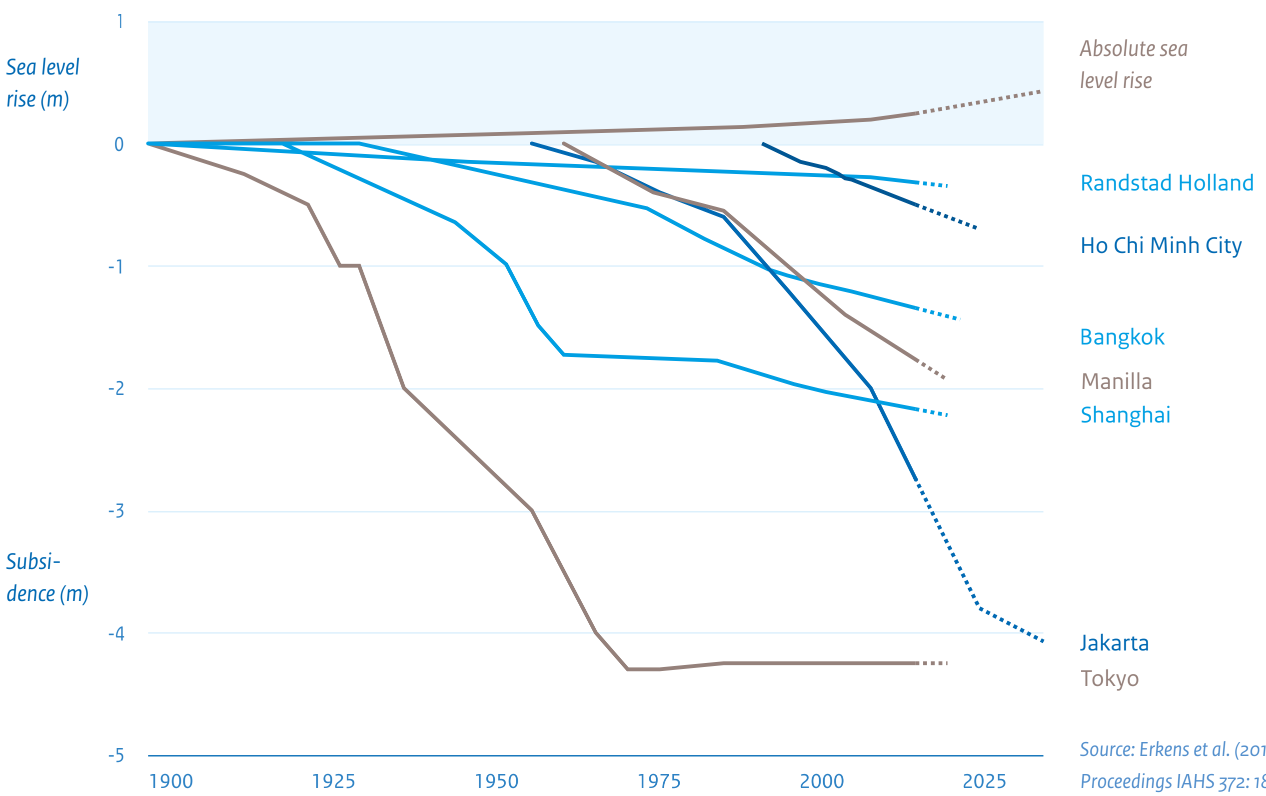
Source: Wu et al., 2022; NASA sea level change, 2022

GROUNDWATER ABSTRACTION IS MAIN CAUSE OF SUBSIDENCE

Rates of subsidence are high in deltas globally but especially in Asian deltas. Without measures, the currently high rates of subsidence are projected to persist and may affect an area the size of Spain by 2070 (480,000 km²).

Sinking coastal cities
In many large cities in Asia, especially, subsidence started more than 50 years ago and is still continuing today. Reducing groundwater abstraction and restructuring the freshwater supply system are vital measures to reduce subsidence. Tokyo stands out as an example where subsidence was halted around 1975, as a result of a strong reduction in groundwater use by households and industries.

Impact of global sea level rise and average subsidence, for several coastal cities

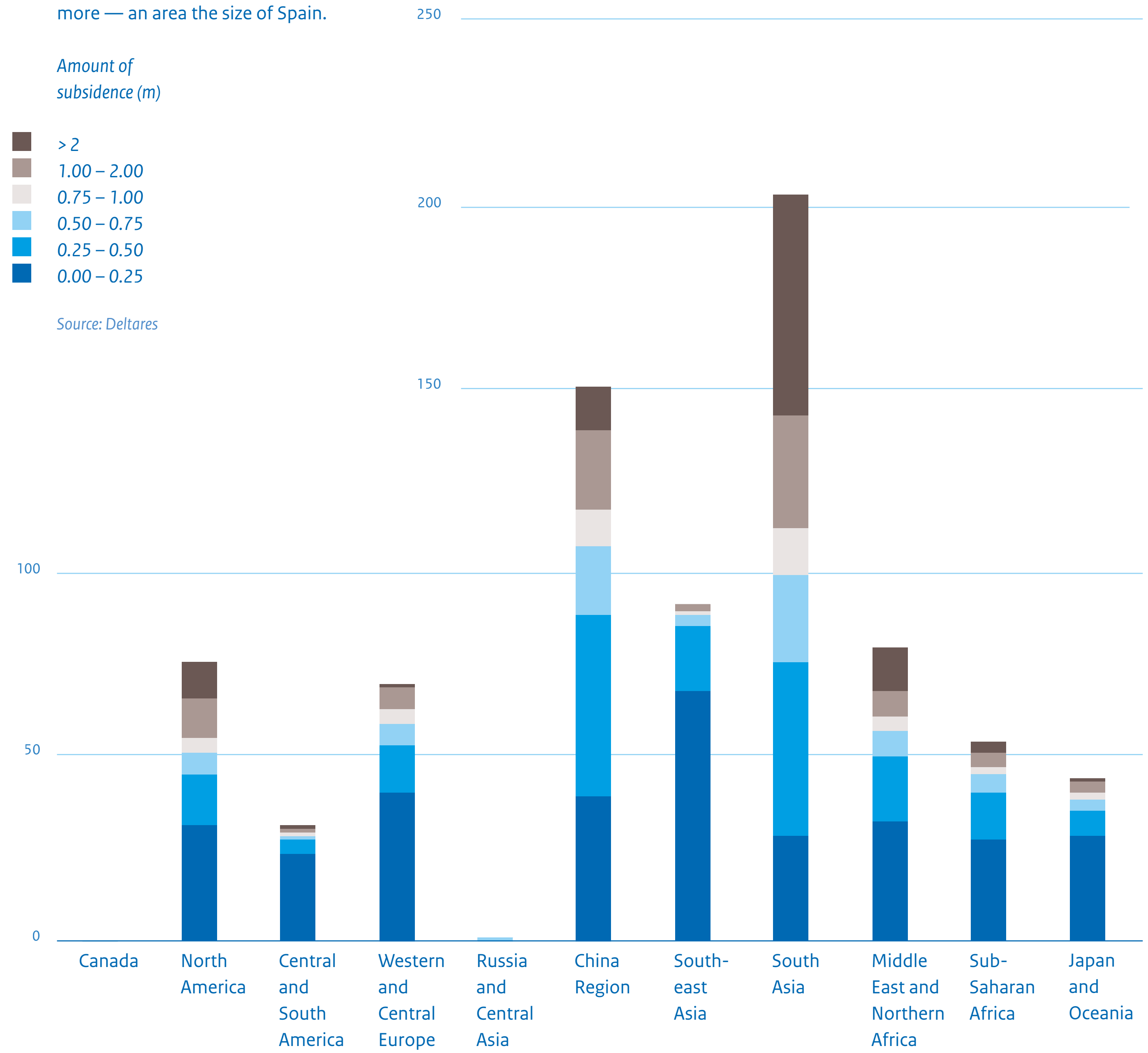


Source: Erkens et al. (2015). Proceedings IAHS 372: 189-198.

Without measures, the currently high rates of subsidence are projected to persist. By 2070, a total area of circa 480,000 km² is projected to subside by 0.25 m or more — an area the size of Spain.

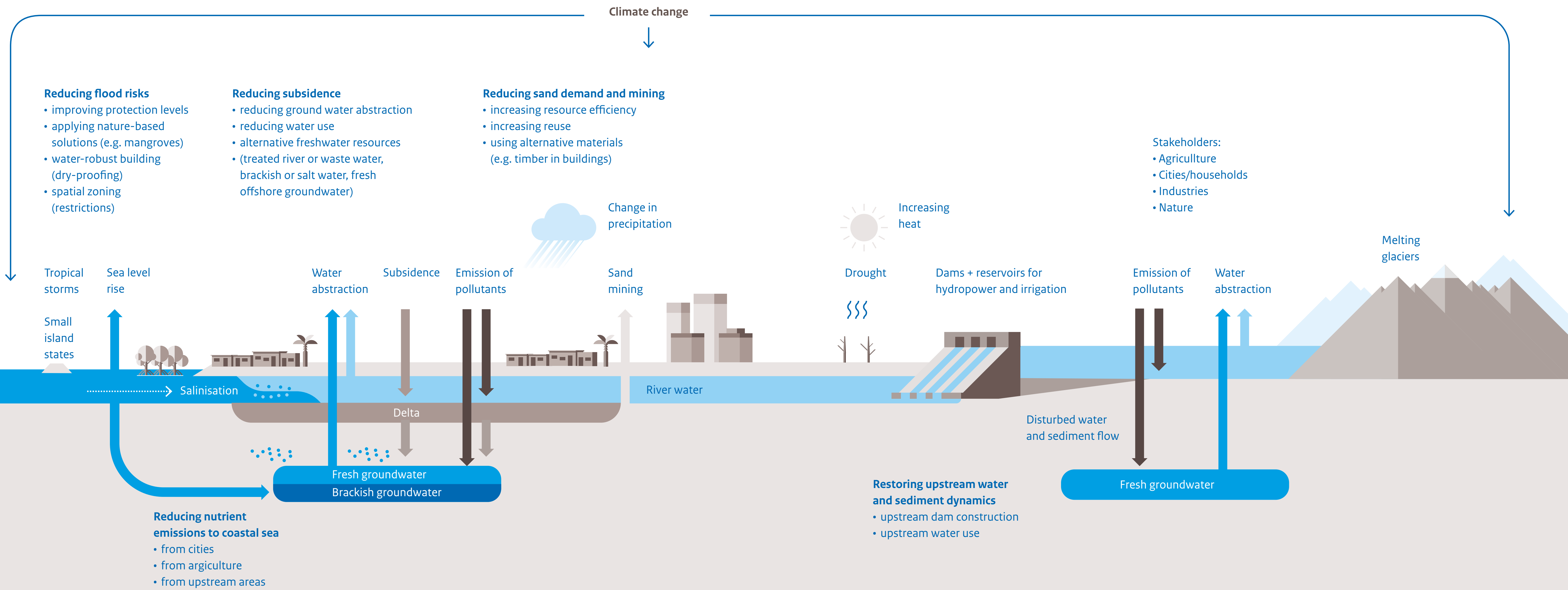
Total area with coastal zone subsidence due to groundwater abstraction per region, 2000–2080

area (1,000 km²)



BENDING THE TREND: PATHWAYS OF SOLUTIONS

The long-term security and sustainability of deltas and coasts will depend on a coherent and adaptive long-term strategy, involving a comprehensive set of measures both in upstream river basins and the deltas and coastal zones.



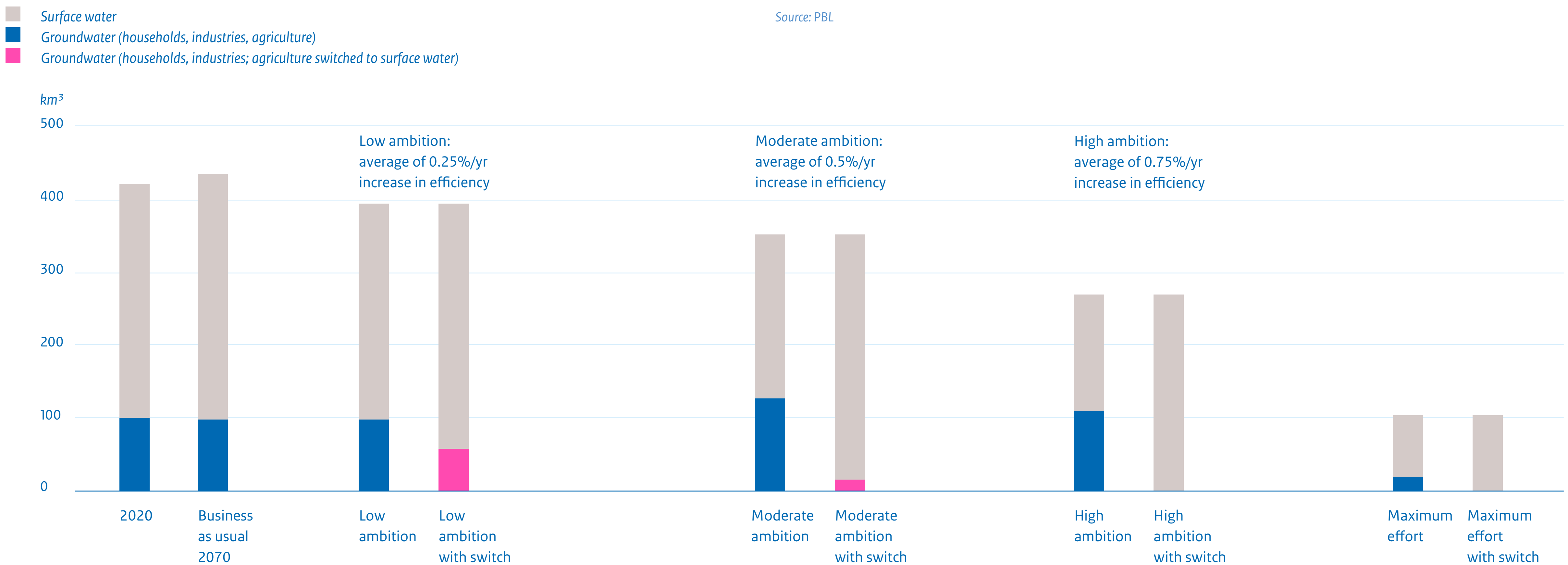
REDUCING SUBSIDENCE: ADAPTING FRESHWATER DEMAND AND SUPPLY

In many world regions and cities, groundwater abstraction is the main cause of subsidence. To structurally bend the trend, freshwater use and supply systems must be restructured, water demand must be reduced and freshwater supply from other sources must be increased.

Most sustainable option: reducing freshwater demand
It is of vital importance to reduce groundwater abstraction to reduce subsidence. At many locations in coastal zones and deltas, high quality groundwater is primarily used by households and industries. Increasing their water efficiency will contribute considerably to reducing groundwater demand and abstraction. Upgrading old and leaking water supply systems is also an effective measure to reduce water use.

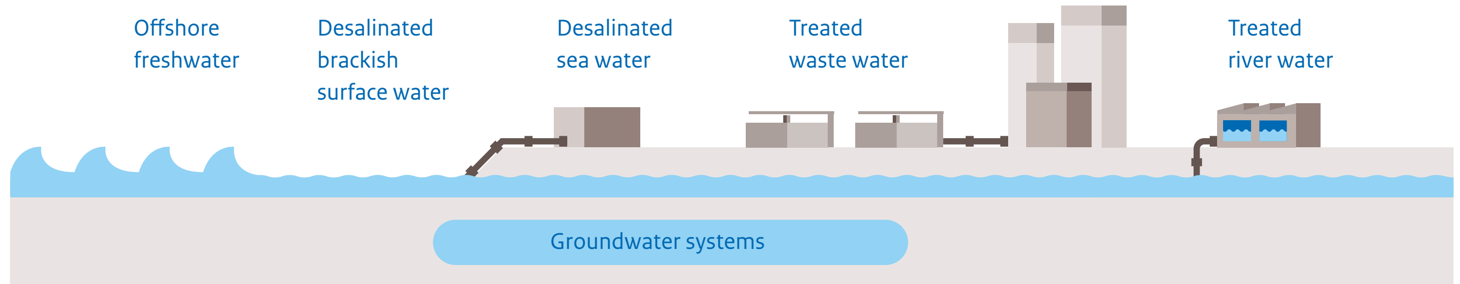
Scenarios with more efficient water use illustrate that less surface water is needed. In fact, under a High ambition pathway, an average annual 0.75% increase in efficiency would decrease surface water use by almost 50%, by 2070, compared to the current situation. Groundwater is abstracted for irrigation purposes, but as a result of the strong reduction in surface water use, groundwater will no longer need to be abstracted and a switch can be made in agriculture from groundwater to the use of surface water. Future pathways where surface water use is reduced allow for a switch from groundwater to surface water use, which in turn also effectively reduces subsidence.

Global water withdrawal from deltas



Source: WEnR; Deltares, PBL

Developing alternative freshwater resources
Reduced groundwater abstraction may be combined with the use of other freshwater resources, including:



Source: PBL

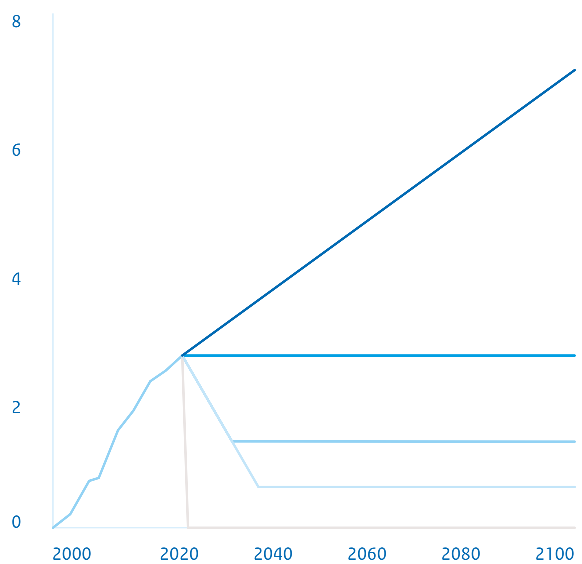
REDUCING SUBSIDENCE: CHANGING GROUNDWATER ABSTRACTION

A strong reduction of groundwater abstraction can structurally reduce and even halt subsidence. In many regions, offshore groundwater exploration may be a promising option to increase freshwater supply and halt overexploitation of groundwater resources in deltas.

Reducing groundwater abstraction works: an example
In the Mekong Delta, as in many others, groundwater abstraction is the main cause of subsidence. For this delta, the impact of various groundwater abstraction pathways on the rate of subsidence was modelled from 1991 to 2100. The results show that subsidence can be structurally reduced and even halted under a High ambition pathway with zero abstraction. How rapidly subsidence reacts to reduced groundwater abstraction in deltas depends on the specific geological situation.

Source: Minderhoud et al., 2020.

Daily abstraction
in million m³

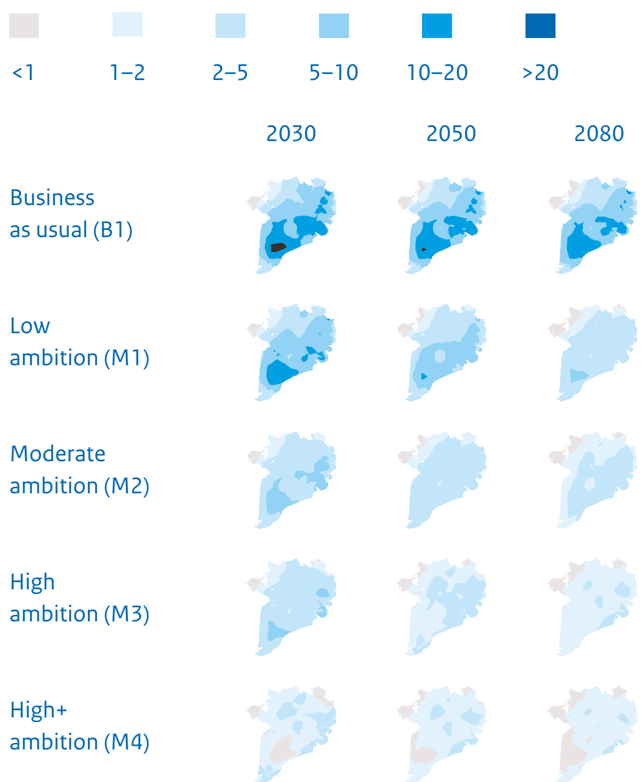


Non-mitigation scenarios:
B1: annual growth (4% of 2018 volume)

Mitigation scenarios:
M1: 0% growth after 2020
M2: gradual reduction of 50% after 2018
M3: gradual reduction of 75% after 2018
M4: zero abstraction after 2018

Subsidence rate in the Mekong Delta following different groundwater abstraction pathways

annual rate (mm/yr)



Estimated regional offshore groundwater volumes

Offshore fresh groundwater volumes in km³

- < 5,000
- 5,000 – 10,000
- 10,000 – 25,000
- 25,000 – 50,000
- 50,000 – 100,000
- > 100,000

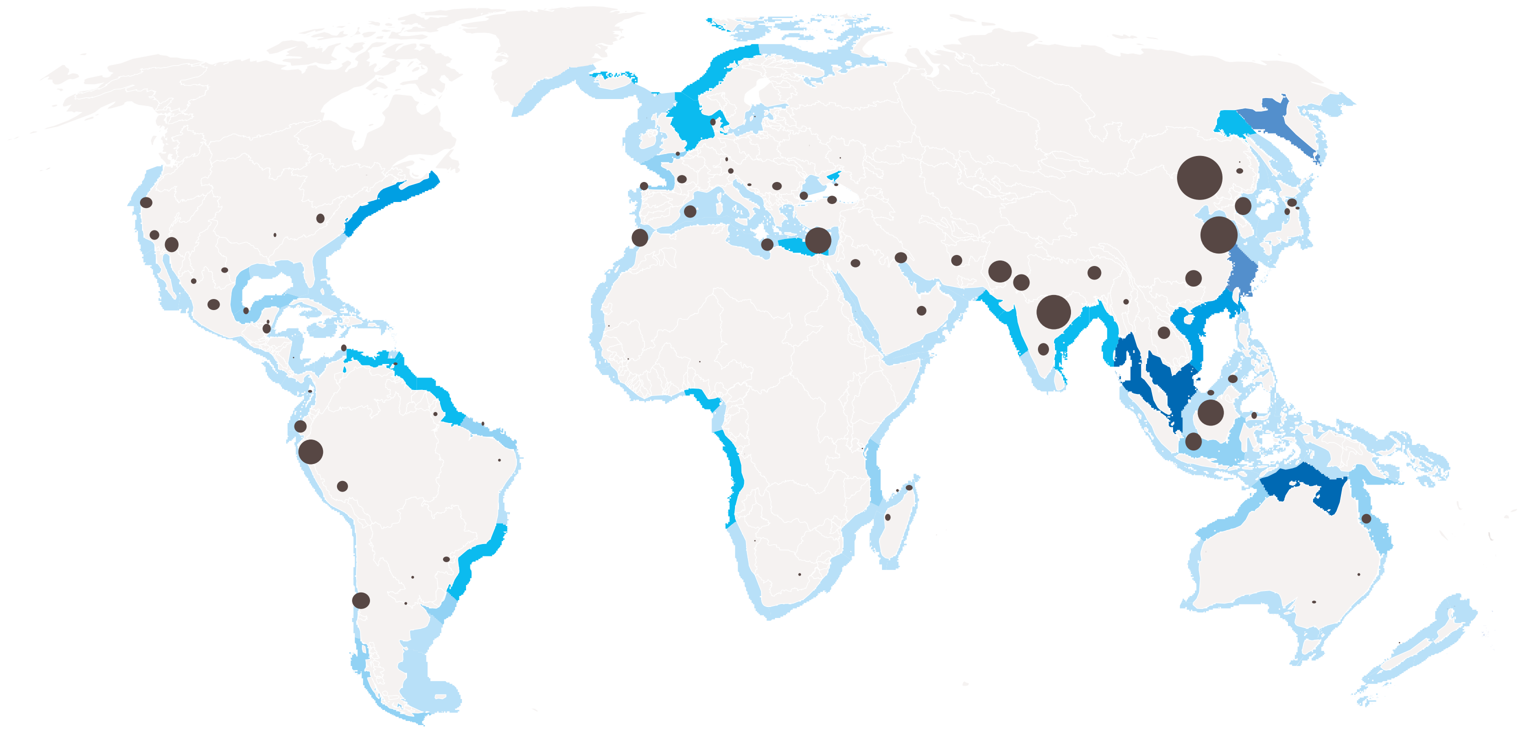
Source: Zamrsky et al., 2022

Groundwater abstraction 2020 in km³

- 5
- 50

Source: WEnR

Southeast and East Asia stand out, especially, as regions with both a high water demand and a potentially high availability of fresh offshore groundwater bodies. In these regions, offshore groundwater exploration may be a promising option to increase freshwater supply.

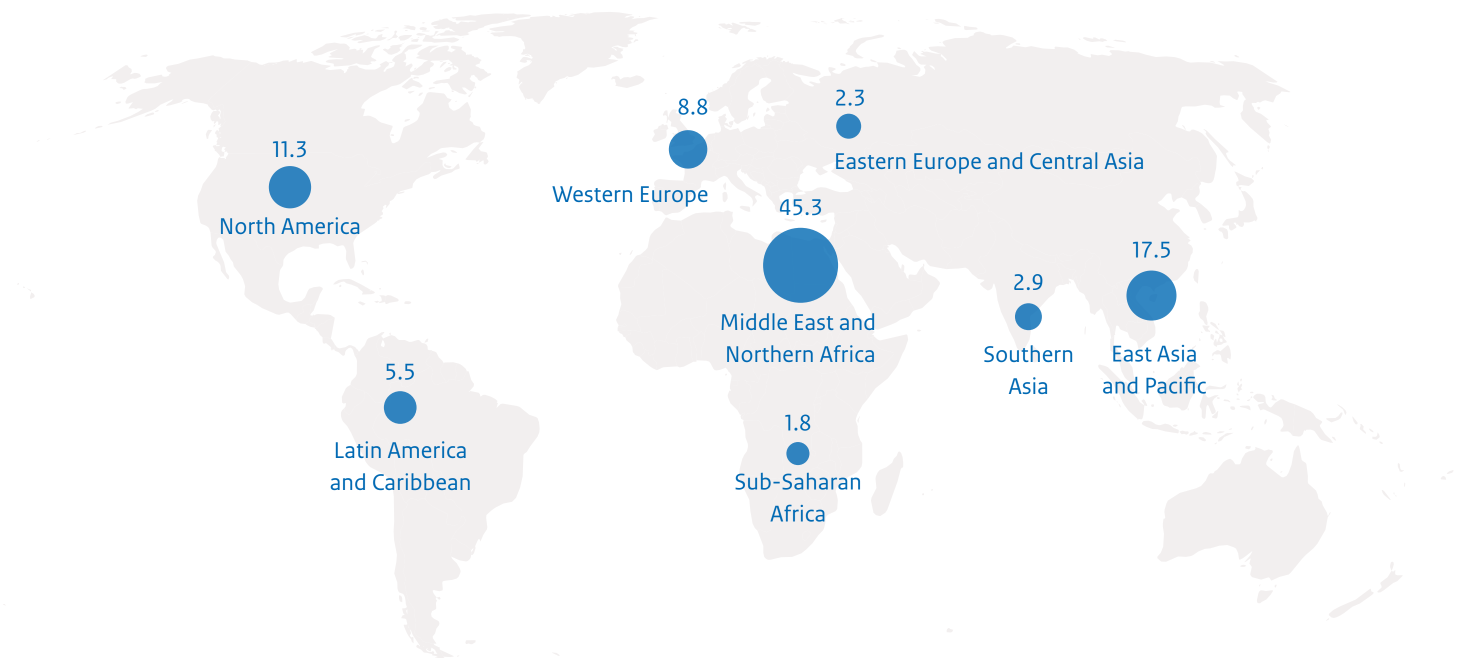


SUSTAINABLE FRESHWATER SUPPLY – BRACKISH AND SALT WATER RESOURCES

Desalination in combination with reuse systems can be sustainable solutions for freshwater supply. In some coastal countries with little freshwater resources, desalination and reuse may contribute by up to two-thirds to the freshwater supply.

Brackish and salt water are potentially infinite resources of fresh water
In the face of increasing water demand and water stress, developing efficient desalination plants that run on renewable energy may provide a fundamental solution for a stable water supply, rather than using — and overexploiting — fresh groundwater systems. According to the International Water Association (IWA), desalination currently provides only 1% of the world's drinking water. At present, there are around 16,000 desalination plants, with a total global installed desalination capacity of 95 million m³/day. Of this capacity, 70% is located in high-income countries and over 90% serves as the water supply of municipalities and industries.

Desalination capacity
in million m³/day

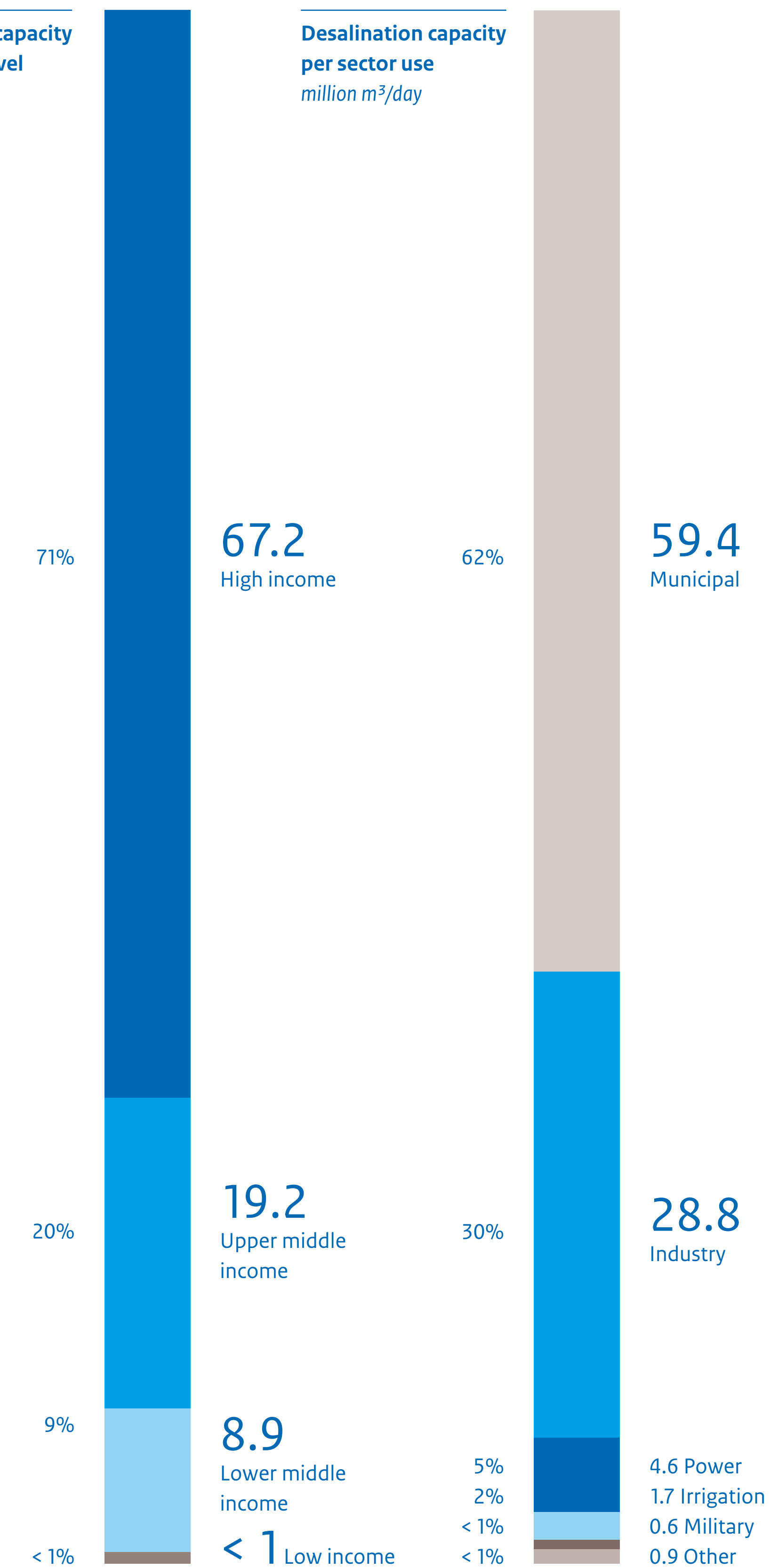


Jones et al., 2019

Prices are increasingly competitive
The price of desalinated water depends greatly on the energy price. Before the strong increase in energy prices in 2021, the cost of desalination had been decreasing steadily over time, making desalinated water increasingly competitive with other sources of fresh water. Under a further decrease in the relative costs of renewable energy, especially when using solar energy, desalination may become increasingly interesting for coastal populations and industries.

Desalination capacity per income level
million m³/day

Desalination capacity per sector use
million m³/day



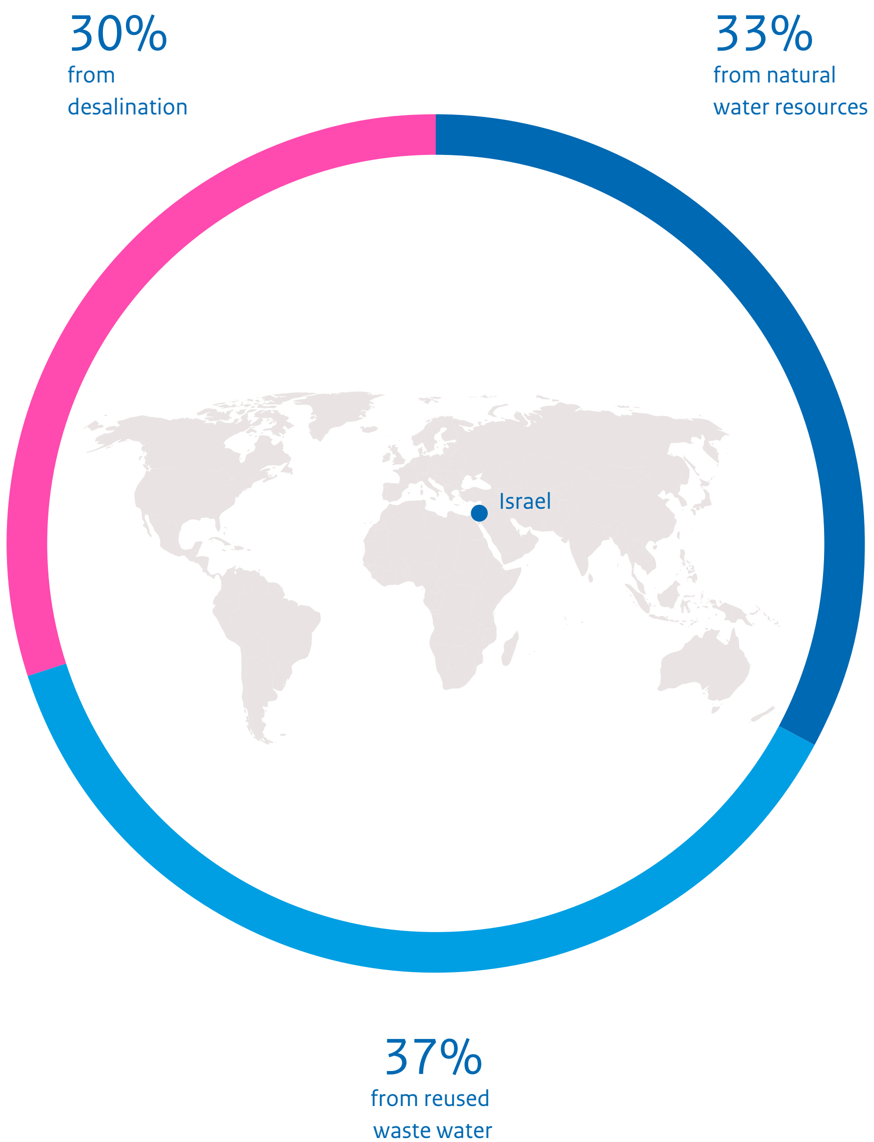
Source: Jones et al., 2019

SUSTAINABLY BALANCING FRESHWATER SUPPLY AND DEMAND

Reducing groundwater abstraction while facing an increasing water demand requires restructuring the water supply system and improving water use efficiency. Depending on the local situation and preferences, various combinations of water efficiency measures and developing new freshwater resources are possible: treated river water, off-shore ground water and desalinated water.

Desalination in combination with reuse: future perspective for coastal areas and deltas?
In high-income but water-scarce countries, such as in the Middle East, desalination and efficient reuse systems can already contribute to over two-thirds of the freshwater supply of today.

In Israel, in 2020, for example, the source of fresh water consisted of around 33% from natural water resources (groundwater/rivers/lakes); around 37% from reused wastewater (mostly used in drip irrigation and to replenish natural systems); and around 30% from desalination.



Important preconditions: renewable energy, just accessibility and reduced ecological impact
Desalination is an energy-intensive process that can only be implemented responsibly under a High ambition pathway if renewable energy sources are used. Also the highly salted return flow (i.e. brine) can damage the ecosystems in the receiving coastal waters if not managed well. From a social perspective, it is of critical importance to assure a just and equitable access to fresh water across regions and all of the population within them ('leave no one behind'). Desalination or the exploitation of offshore freshwater groundwater reserves are both climate-robust options. The use of river water may be hampered by water pollution and is more climate-sensitive as river water levels are projected to be substantially lower in the dry season because of more extreme droughts and less input from snowmelt and glaciers.

The costs, benefits and adverse impacts of various options to increase the freshwater supply

Option	Indicative cost (USD/m³)*	Relative cost (compared with option 1)	Contribution to land subsidence	Ecological impact	Climate sensitivity	Energy/ mitigation
1. Groundwater abstraction on land	0.40	1	High	Lower water tables and salinisation of groundwater	Depends on recharge	Fossil-based Renewable
2. Improving water use efficiency	No data	–	Less subsidence, depending on the resulting reduction in groundwater abstraction on land	Low	Low	
3. Using treated river water	0.40	1		Low	Increased risk of low river flow	Fossil-based Renewable
4. Desalination of brackish groundwater	0.68	1.7		Depending on the emission of brine	Low	Fossil-based Renewable
5. Desalination of seawater	1.95	4.8			Low	Fossil-based Renewable
6. Offshore fresh groundwater	0.86	2.15		Low	Low	Fossil-based Renewable

**Source: Kind and Bakker (2022)*

ADAPTATION MEASURES FOR COASTAL FLOOD RISK REDUCTION WILL PAY OFF

While dykes and levees are generally very effective in protecting communities against flooding, benefit–cost ratios show that alternatives can also be very promising on a local scale, under certain circumstances. Optimal combinations of dykes, water-robust construction and spatial zoning are very cost-effective in reducing flood risks.

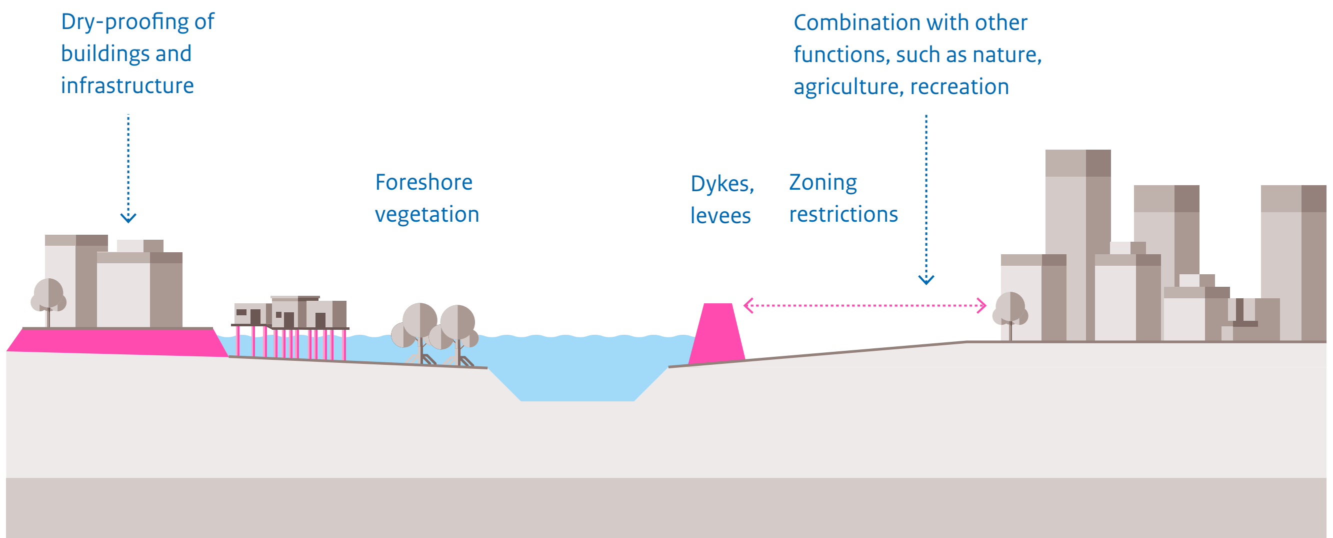
Tailor-made adaptation to coastal flooding: four options
Options to protect people and their assets against flooding and the related consequences include measures to reduce flood probability and severity (hazard), the exposure of people and assets to flooding, and their vulnerability for when flooding does occur. The combination of hazard, exposure and vulnerability defines the level of flood risk.

In addition to building dykes and levees, we explored three alternatives:
1. restoring foreshore vegetation, such as mangroves, to dampen waves and reduce hazard levels;
2. spatial zoning of new urban and industrial development out of harm's way to reduce exposure;
3. dry-proofing of buildings to reduce vulnerability for when flooding does occur.

We explored both the ability of these options to achieve a pre-established flood-risk reduction target — what we call effectiveness — and the benefit–cost ratio, or cost effectiveness of implementing these measures.

Source: Deltares & IVM

Measures to reduce flood risk



Source: PBL

Alternative measures can be a good starting point for flood risk reduction

On a global scale, performance levels between individual measures differ:
- all measures have a benefit–cost ratio of >1, indicating that all of them will pay off
- dykes and levees are the most effective way of achieving the risk-reduction target
- foreshore vegetation and spatial zoning are far less effective and cannot be implemented at all locations around the globe

In many regions, alternative measures are extremely cost-effective:
- foreshore vegetation in tropical regions
- zoning restrictions in areas with a projected large amount of urbanisation
- dry-proofing buildings in existing urbanised areas

Ambition pathways to reduce coastal flood risk

Effectiveness

Low
Moderate
High

Risk = hazard x exposure x vulnerability	✓ Type of measure	Measure effectiveness in terms of flood protection*	Measure effectiveness in terms of benefit-cost ratio (BCR)*	Types of measures in the Low ambition pathway	Types of measures in the Moderate ambition pathway	Types of measures in the High ambition pathway
Reducing hazard	Dykes and levees	High	Low		✓	✓
Reducing hazard	Foreshore vegetation	Low	Moderate	✓	✓	
Reducing exposure	Zoning restrictions	Low	High	✓	✓	
Reducing vulnerability	Dry-proofing of buildings, infrastructure	Moderate	Low	✓	✓	

** Effectiveness is determined for the local situation and then visualised at the global scale*

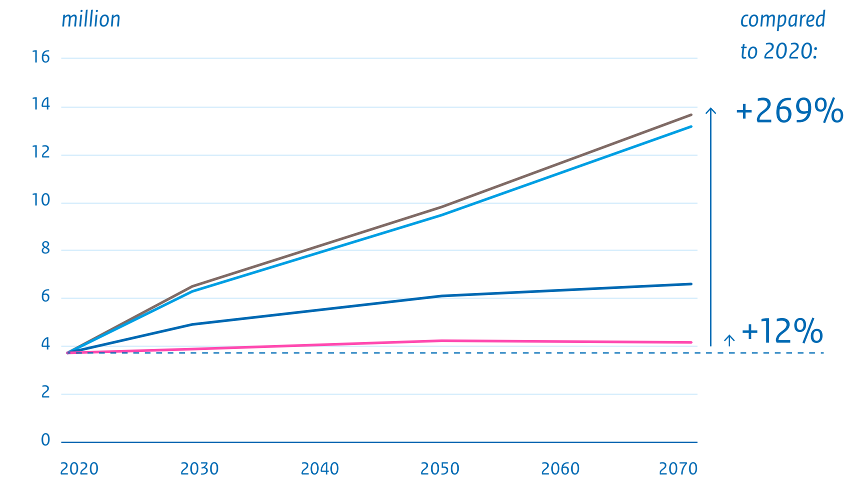
Source: PBL

OPTIMISING PROTECTION AGAINST COASTAL FLOODING

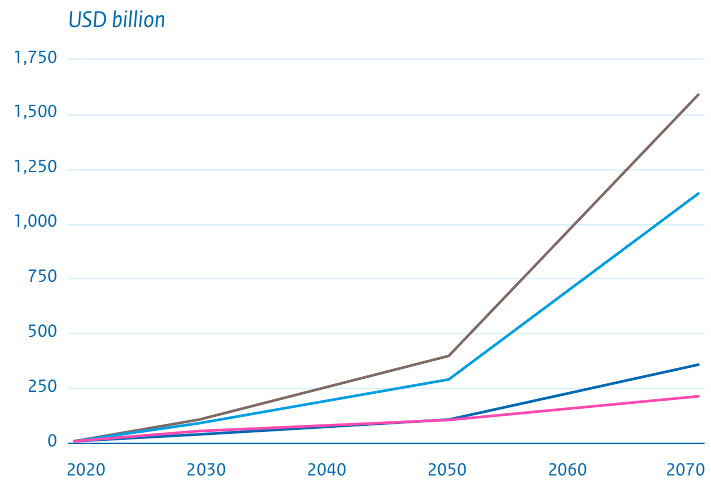
In many deltas and coastal zones, future annual flood risk in terms of expected exposed population and expected urban damage is projected to increase strongly without modifications to existing flood protection. Benefit–cost ratios for measures increasing the level of flood protection are greater than 1, justifying investment in flood-risk reduction.

Investments in reducing hazard levels, exposure and vulnerability will pay off
Large increases in coastal flood risk are projected for the coming decades. By 2070, under the Business-as-usual scenario, a threefold increase in the annually exposed population is projected, to almost 14 million, and the expected annual urban damage is projected to exceed USD 1.5 trillion. Flood risk under the Moderate and High ambition Pathway (see previous page) is substantially lower than under the Business-as-usual scenario, as a result of investments in dykes and levees (high ambition level) and in combination with alternative measures (moderate ambition level).

Annually exposed population



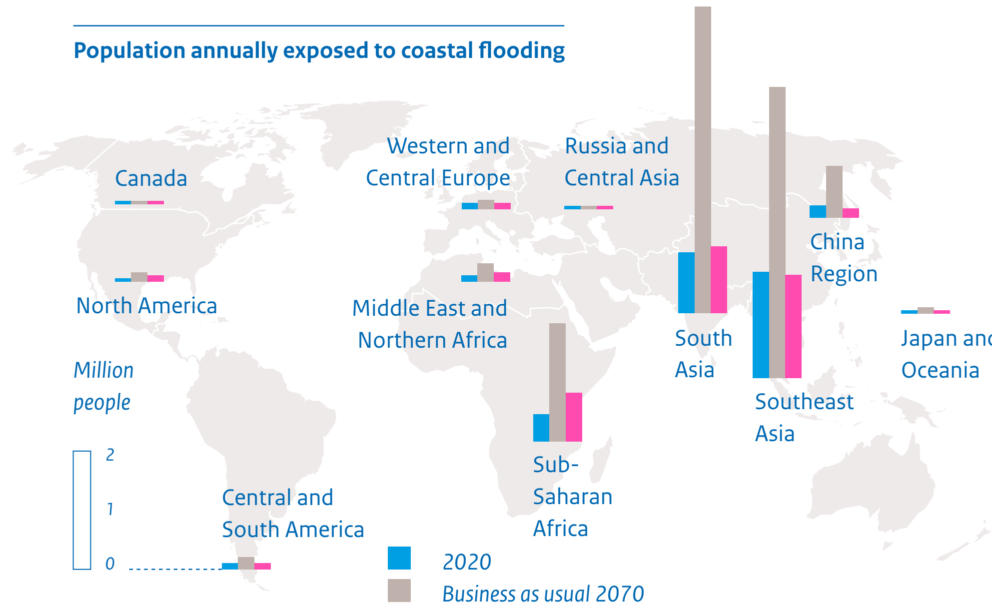
Annual urban damage



— Business as usual
— Low ambition
— Moderate ambition
— High ambition

Source: Deltares, IVM

Population annually exposed to coastal flooding



Source: Deltares, IVM

Projections clearly indicate that the share of the global population exposed to coastal flood risk in 2070 will predominately be located in South Asia, Sub-Saharan Africa and Southeast Asia. In absolute terms, substantial reductions in flood risk can be achieved in these regions if a High ambition pathway is followed. In many of these regions, though, the costs of creating dykes and levees could be high due to the lack of existing flood protection systems.

The locally most effective strategies in achieving flood-risk reduction towards 2070

Source: Deltares, IVM

- *Dry-proofing*
- *Dry-proofing + hybridisation*
- *Nature-based solutions*
- *Nature-based solutions + hybridisation*
- *Zonal restrictions*
- *Zonal restrictions + hybridisation*

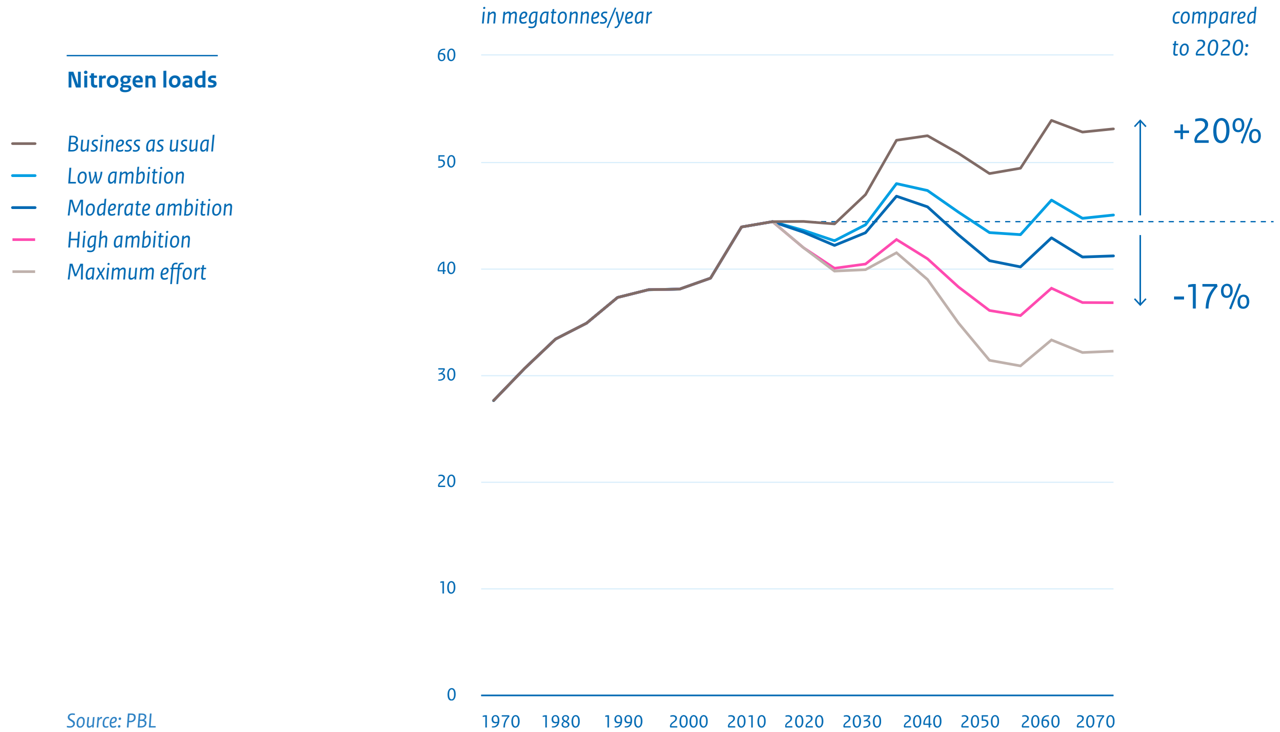
As with the risks of river flooding, the combination of restricting urban and industrial development in flood-prone areas and improving existing protection levels by dykes and levees are most effective in many areas. Dry-proofing buildings could be especially promising along highly urbanised coastlines, while nature-based solutions can work well in tropical and subtropical regions.

IMPROVING WATER QUALITY OF COASTAL SEAS

Most upstream pollution of surface waters ends up in the deltas and coastal seas. As deltas and coastal zones contribute 'only' about 16% to the total in nutrient emissions to coastal seas, improving the water quality of coastal waters will require great efforts in upstream areas, as well.

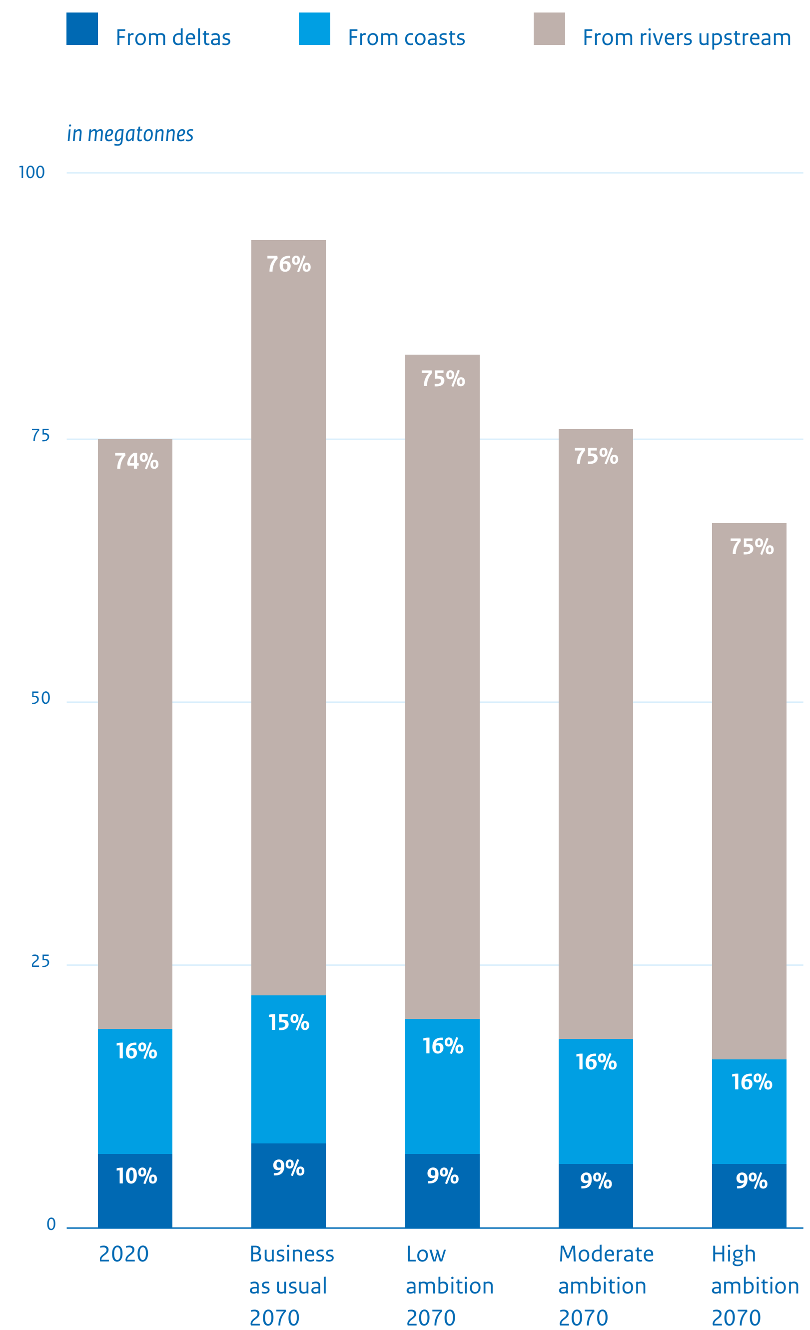
Level of nutrient emissions to coastal seas remains high, even under a High ambition pathway
Under a High and Moderate ambition pathway, total nutrient emissions from cities and agriculture can be significantly reduced to levels below that of 2020. For coastal seas, however, nutrient emission levels will remain high. This graph shows the trends for nitrogen, which is similar to that for phosphorus.

Nitrogen loads



Source: PBL

Contribution to total nitrogen loads in rivers



Rivers contribute 75% of nutrients in coastal waters
Coastal and delta communities contribute about 25% to the total in emissions to coastal waters, along all pathways. Constructive cooperation with upstream bureaucracies and communities will be needed to substantially reduce nutrient emissions to coastal seas.

Source: PBL

NUTRIENT EMISSIONS TO SEA SUBSTANTIALLY REDUCED UNDER HIGH AMBITION PATHWAY

The High ambition pathway projects a substantial decrease of nutrient emissions to coastal seas in many regions, contributing to reducing the risk of toxic algal blooms and oxygen depletion and improving the ecological conditions.

Quality of the coastal seas at risk of lasting high pressures
The projected high levels of nutrient emissions indicate that the risks of toxic algal blooms and oxygen depletion in certain waters will remain high, even along a High ambition pathway. The projected higher water temperatures due to climate change will increase these risks even further, with negative effects on biodiversity (including coral reefs) and economic sectors, such as fisheries, aquaculture and tourism.

Nitrogen load to coastal seas
2020

Absolute load in megatonnes
0.1
10

Percentage increase/ decrease since 1970
< -25
-25 – 0
0 – 25
25 – 50
50 – 75
> 75

Source: PBL

Business-as-usual scenario, 2070

Absolute load in megatonnes
0.1
10

Percentage increase/ decrease since 2020
< -25
-25 – 0
0 – 25
25 – 50
50 – 75
> 75

Source: PBL

High ambition pathway, 2070

Absolute load in megatonnes
0.1
10

Percentage increase/ decrease since 2020
< -25
-25 – 0
0 – 25
25 – 50
50 – 75
> 75

Source: PBL

RESTORING CONTINUITY OF SEDIMENT FLOW: A TOUGH CHALLENGE

New dam construction projects and large-scale sediment mining in rivers undermine natural sediment flow and river dynamics. Restoration of these sediment flows require huge interventions with an impact on hydropower development, and urban and infrastructural construction practices.

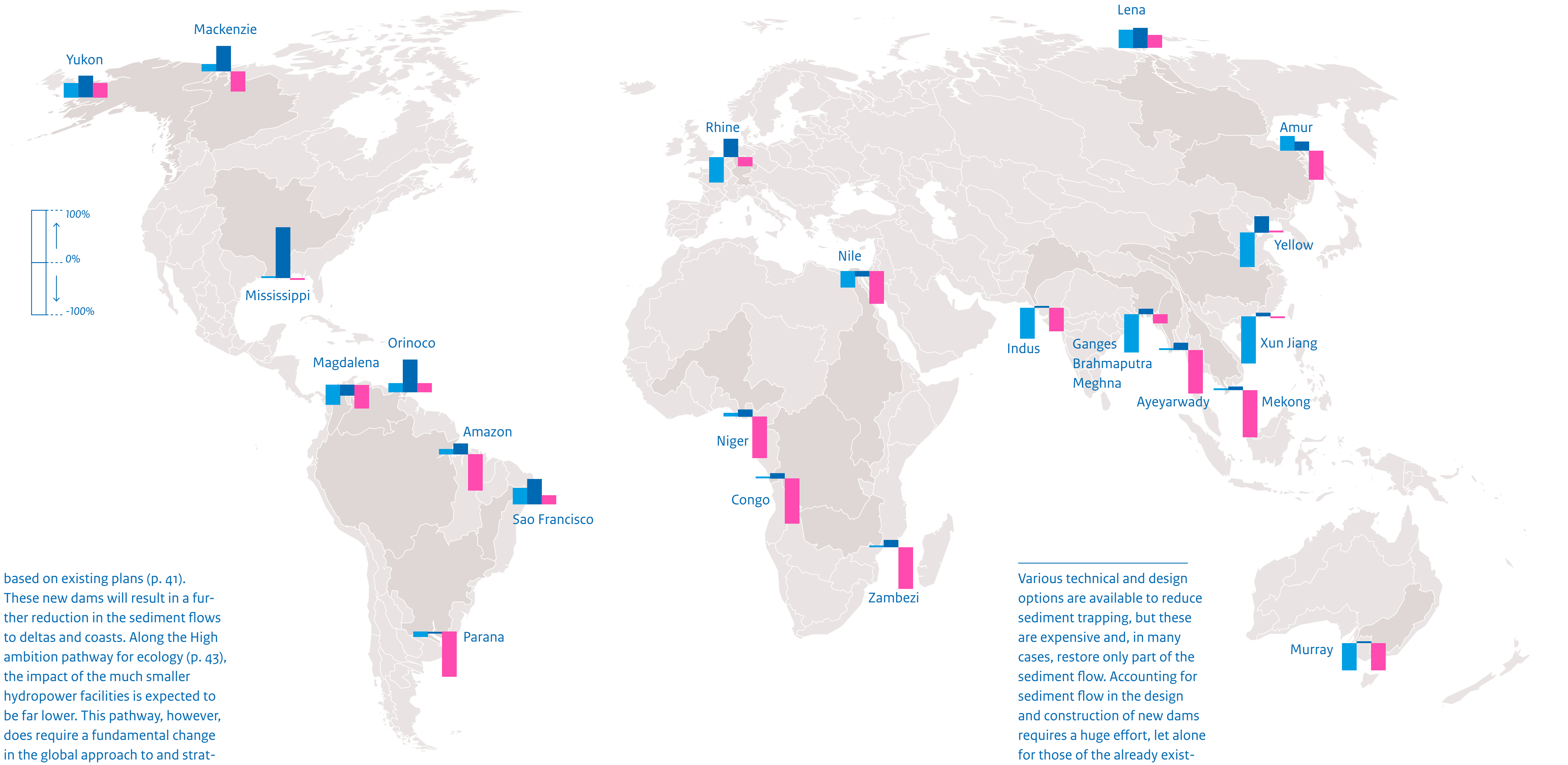
Changes in sediment flows in response to climate change and anthropogenic stress, for 23 of the world's largest river basins

Sediment flows to the deltas worldwide are changing due to:

- *Dam construction*
- *Socio-economic developments with land-use changes that affect soil erosion, because of deforestation, urbanisation and agriculture*
- *Intense rainfall due to climate change, increasing run-off to streams and rivers*

The combined impact of these pressures varies from one river basin to another.

Source: Dunn et al., 2019; Best, 2019



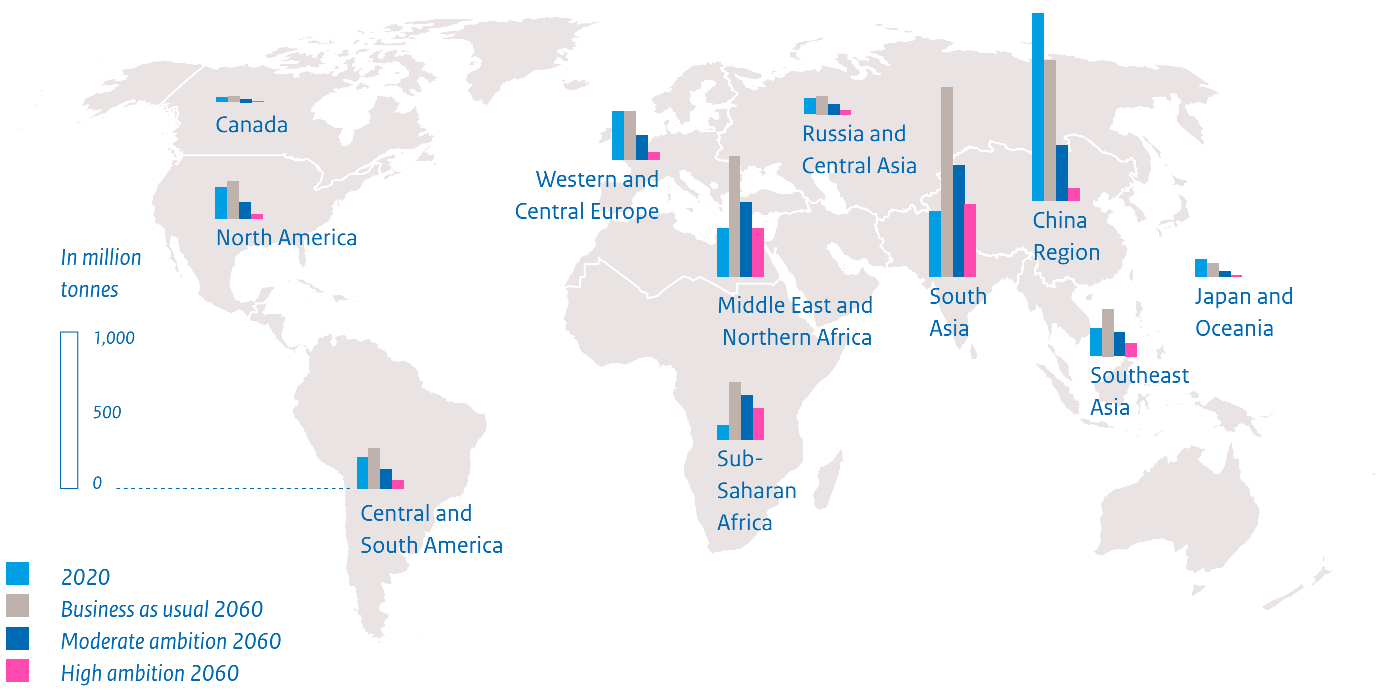
Reducing the impact of dams — an uphill battle?
Today, an estimated 50% to 75% of sediment flows from mountains to the rivers downstream are trapped behind dams (p. 40). The Business-as-usual scenario projects the construction of around 950 new traditional dams, while the High ambition pathway projects 3,700 new dams maybe constructed for hydropower, based on existing plans (p. 41). These new dams will result in a further reduction in the sediment flows to deltas and coasts. Along the High ambition pathway for ecology (p. 43), the impact of the much smaller hydropower facilities is expected to be far lower. This pathway, however, does require a fundamental change in the global approach to and strategy for hydropower generation.

Various technical and design options are available to reduce sediment trapping, but these are expensive and, in many cases, restore only part of the sediment flow. Accounting for sediment flow in the design and construction of new dams requires a huge effort, let alone for those of the already existing dams.

REDUCING SEDIMENT DEMAND AND MINING FOR URBANISATION

The high demand for sand and gravel for the construction of buildings and infrastructure is increasing sediment mining in downstream river reaches, negatively affecting sediment flows to the deltas and coasts. Especially in parts of Asia and Africa a combination of measures will need to be implemented to reduce sediment demand and mining.

Sand used for construction
(concrete, glass)



These numbers represent 1/3 – 1/2 of global sand use for concrete and glass

Source: Zhong et al., 2022

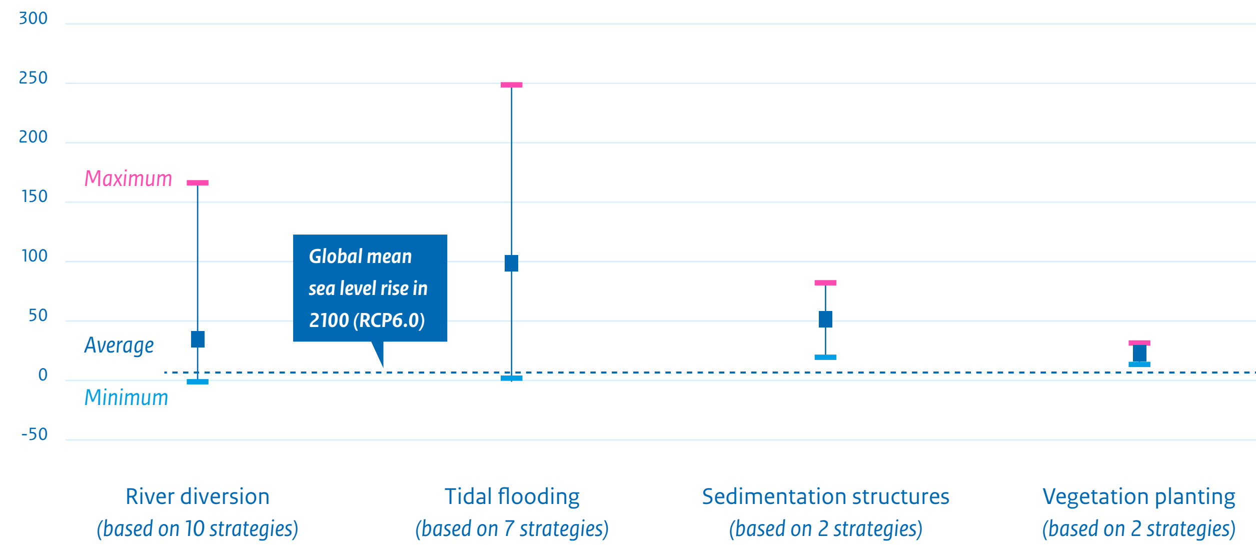
Keeping sediments in the river — reducing sediment mining
The high demand for sand and gravel for the construction of buildings and infrastructure increasingly disrupts sediment flows (UNEP, 2022). Zhong et al. (2022) explores 6 options to reduce such demand for sand, with widely varying effectiveness from one world region to another. Especially in Southern and Southeastern Asia and Africa, where cities are growing at a fast pace, a combination of measures will need to be implemented to strongly reduce the demand for sand used in construction and the related pressure of sand mining in rivers. These options will require fundamental restructuring of construction practices and innovative collaboration between partners in this sector.

Sedimentation in deltas is hampered by existing built-up area and infrastructure
Deltas used to be able to keep up with sea level rise, thanks to the deposition of sand and silt supplied by rivers. Today, reduced sediment supply and subsidence hamper these processes. Strategies to increase or restore sediment deposition, allowing deltas to keep up with sea level rise, are still in their infancy. Cox at al. (2022) explore the potential of four major accretion strategies:

1. diverting river sediment flows;
2. allowing tidal flooding;
3. building structures that increase sedimentation and
4. planting vegetation.

These strategies can significantly increase sedimentation rates, compared to sea level rise. However, the scale of current projects is very small, with them covering only 0.1% of the current global delta area. Scaling up these strategies will be seriously hampered by existing built-up areas and infrastructure.

Sedimentation rate of various sedimentation enhancement strategy types
mm/year

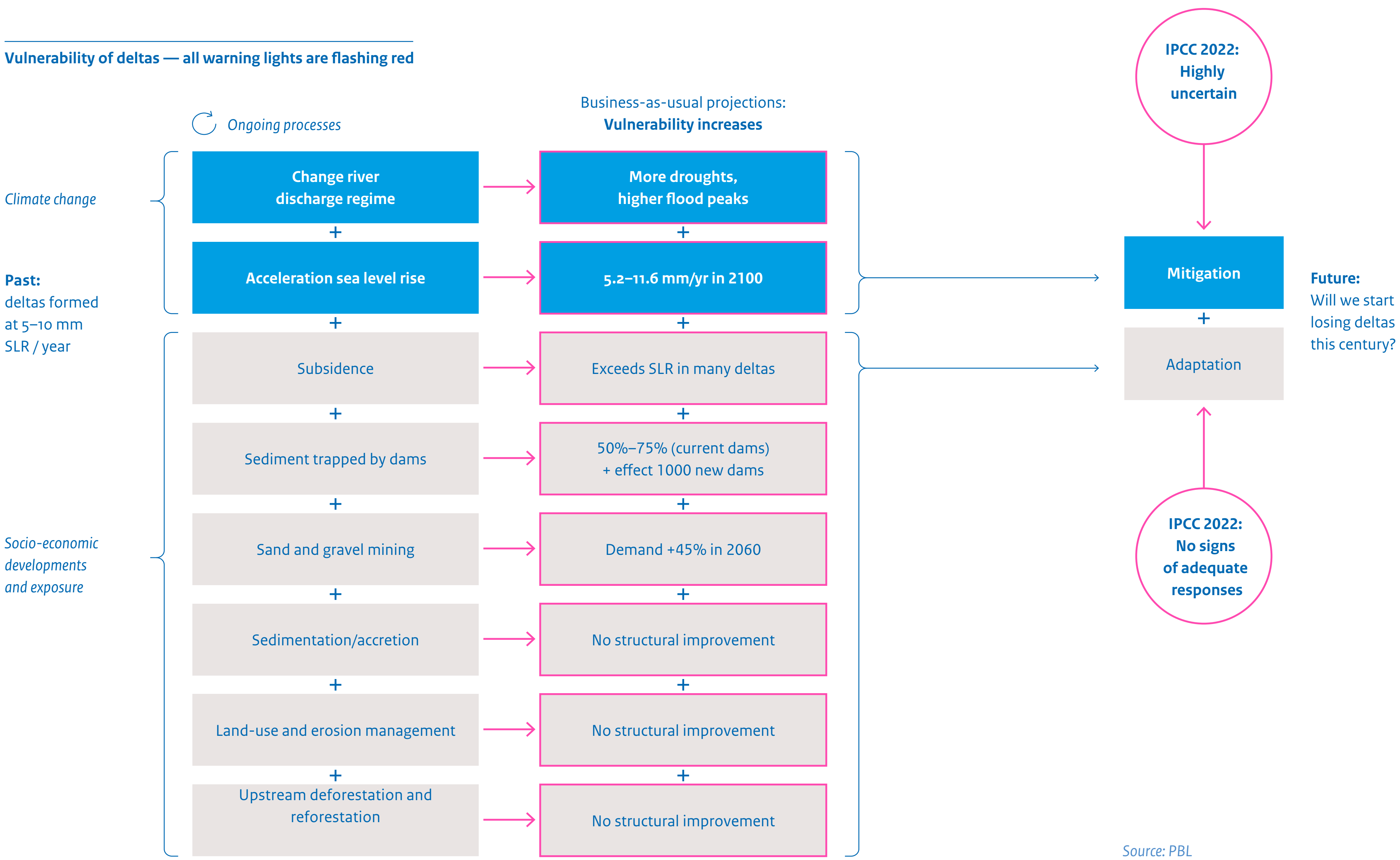


Source: Cox et al., 2022

THE FUTURE OF OUR DELTAS: URGENCY FOR ACTION IS HIGH

Low-lying coastal areas and deltas may face certain limits to adaptation, as they are facing sea level rise, subsidence that often exceeds sea level rise, and sediment starvation. Geological research into the origins of current deltas suggests it may not be long before critical conditions for the survival of these deltas are reached.

Vulnerability of deltas — all warning lights are flashing red



Source: PBL

An overview of future trends of the drivers that are crucial to a sustainable future for our deltas shows that, for many deltas, the situation is highly alarming and all warning lights are flashing red. However, in this section on deltas and coastal zones, we show that a High ambition pathway could bend the trend. The future of the world's low-lying coasts and deltas depends on the actions taken over the coming decades, not only in these areas themselves, but also in the upstream river basins.
This poses an enormous challenge for bureaucracies responsible for deltas and coastal zones and will require constructive interaction upstream, in both national and transboundary river basins.

National, provincial and municipal authorities, in collaboration with private sectors, social organisations and local communities, will have to come to a shared understanding of past developments and current and future challenges. Then they will need to develop a shared long-term adaptive strategy, aligning goals, targets and implementation efforts across all relevant sectors and on all scales.

WHAT IF THE PAST IS THE KEY TO THE FUTURE?

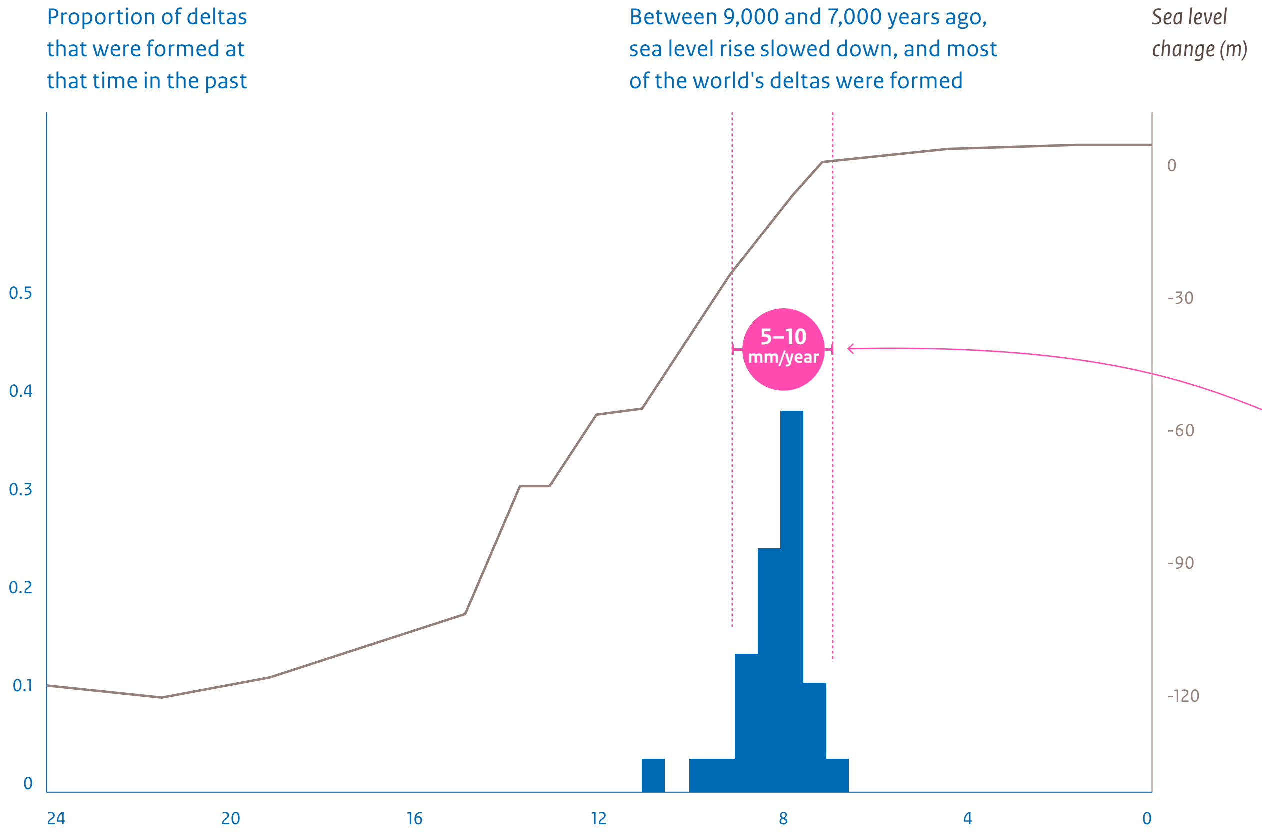
Most deltas around the world formed at a time when — after the ice caps of the last ice age melted — the rate of sea level rise slowed down to 5–10 millimetres per year. The accelerating sea level rise may exceed this range in the course of this century, seriously affecting the livability of the world deltas.

Urgency is high: some deltas may enter a critical phase in next 50 years
Geological research revealed that most deltas around the world formed at a time when — after the ice caps of the last ice age melted — the rate of sea level rise slowed down to 5–10 millimetres per year. Given the projected rates of sea level rise, this critical range of 5–10 mm/yr may be exceeded as early as in the next decades, depending on climate change and the resulting sea level rise. If this range has a predictive quality for the situation in the future, deltas may no longer be able to keep up with sea level rise through nature-based approaches and natural sedimentation processes.

Global sea levels are currently rising at an average rate of 3.6 millimetres per year. Based on recent IPPC projections, the tipping point to eroding and drowning deltas may already occur in the next 50 years.

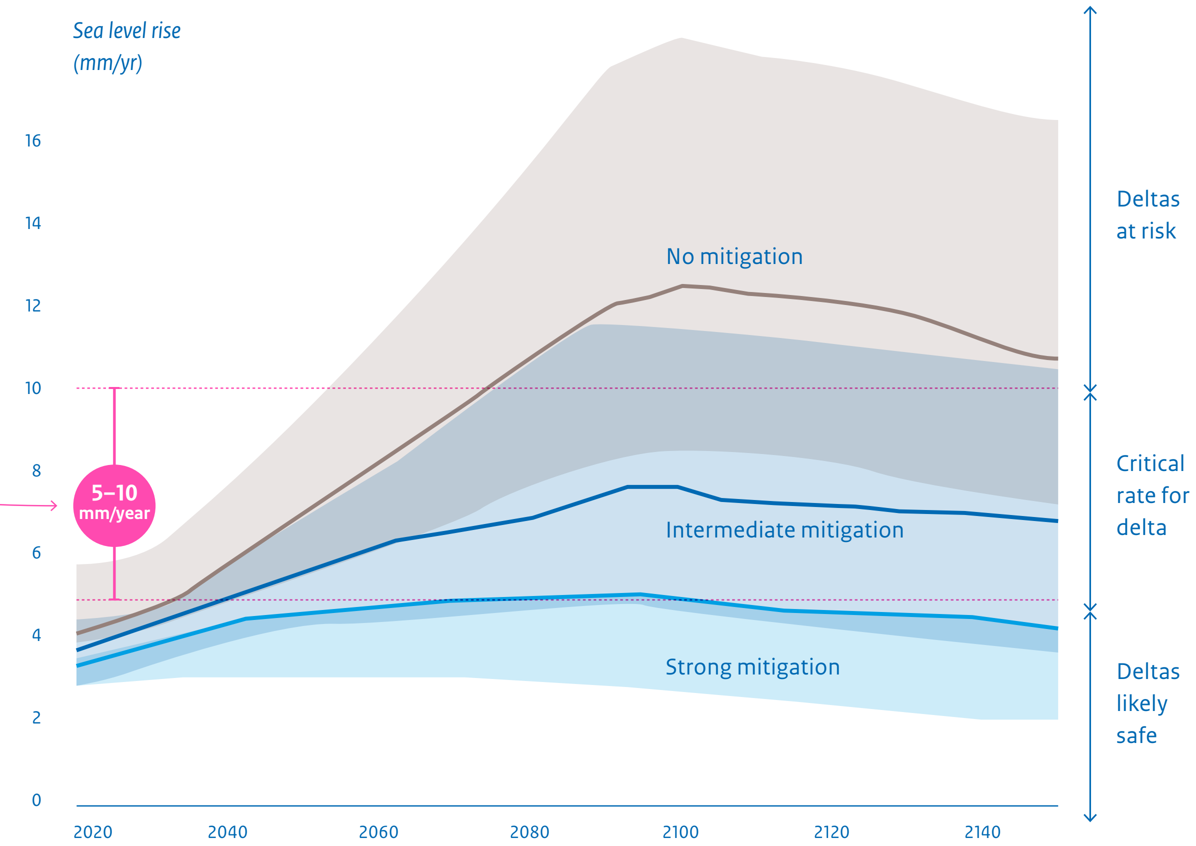
In addition to deltas, Small Island States are also highly vulnerable to sea level rise and are likely to lose more and more land.

We may start losing coastal deltas, 50 years from now



Source: Turner et al., 2018

Projected rate of global sea level rise



Source: NASA

THE VALUE OF WATER – SUPPORTING THE SDGs

Reducing water- and climate-related risks is projected to contribute in many ways to achieving the SDGs in all hotspot landscapes. A major challenge will be addressing inequality in future strategies.

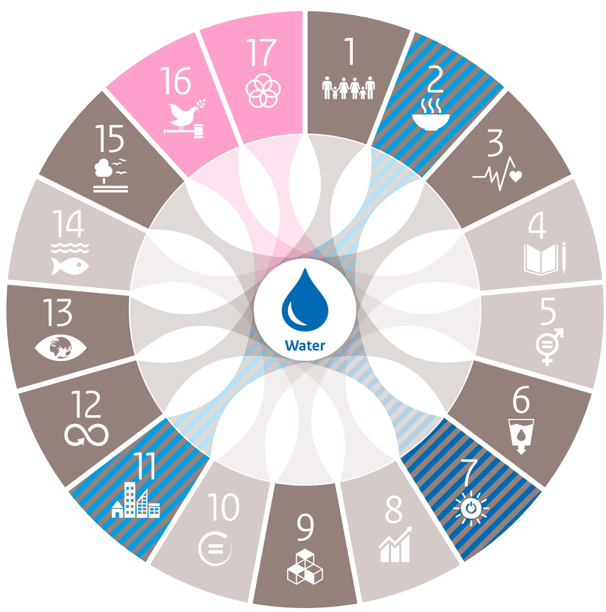
Projected improvement 2070 compared to 2020
- *based on quantified indicators*
- *qualitative appreciation*

Projected deterioration 2070 compared to 2020
- *based on quantified indicators*
- *qualitative appreciation*

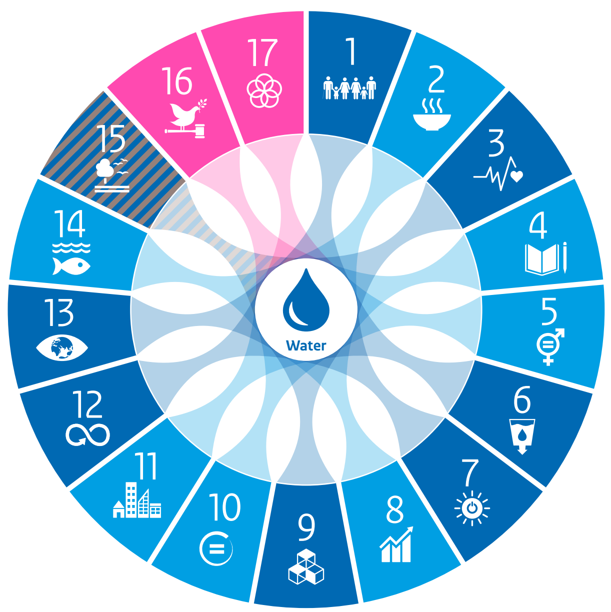
Important condition for transition
- *assumed to be fulfilled*
- *assumed not to be fulfilled*

partial improvement, partial deterioration or standstill 2070 compared to 2020

SDGs, Business-as-usual scenario 2070



SDGs, High ambition pathway 2070



The main differences in impact of the High ambition pathway on deltas and coasts, compared to the Business-as-usual scenario

SDG	
1	Environmental risks for the poor are reduced by effective management of potential increases in flood risk due to climate change and subsidence and improved water security.
2	Reduced subsidence and climate vulnerability and improved water and crop management improve crop production and food security.
3	Better human health conditions because of improved crop production and freshwater supply, and reductions in flood risks, climate vulnerability and polluting emissions.
4	A reduction in the number of children exposed to water-borne diseases and flood risk, and in the number of schools and schooling facilities disrupted by flooding events.
5	Safer living conditions for women and girls because of improved sanitation, increased food production, less pollution and more effective management of flood and drought risks.
6	Strong improvement in sanitation and wastewater treatment and effective management of flood and drought risks, water pollution and salinisation.
7	Lower risk of flooding disturbing the energy supply under a 70% increase in hydropower production.
8	Highly effective flood risk management, strong reductions in water pollution and greater water use efficiency prevent deterioration of the conditions for water-dependent economic activities.
9	Transformational innovations geared to reduce subsidence, restructure freshwater supply and improve flood protection in combination with nature-based solutions.
10	Efforts to reduce inequality are integrated in development strategies for deltas and coastal areas from global to local levels, especially contributing to SDG1.
11	Contribution to the development of sustainable cities and communities by reducing subsidence, improving freshwater supply, flood protection, sanitation, and water use efficiency.
12	Greater water use efficiency, less pollution and desalinisation due to the use of renewable energy, thus contributing to responsible consumption and production. Progress is lacking under the Business-as-usual scenario.
13	Implementing adaptation measures in a system-based development strategy, anticipating long-term climate change and sea level rise, and including upstream–downstream interactions.
14	Ecological quality of coastal seas improves by maintaining the continuity of freshwater and sediment flows, reducing nutrient emissions and applying nature-based solutions in coastal flood-risk protection.
15	Improvement in the water flow to and ecological quality of deltas and coastal zones due to ecosystem-friendly hydropower facilities, less water use upstream, fewer nutrient emissions and more wetland restoration.
16	Strong improvement in institutional capacities across scales enables a long-term ecosystem-based approach and improves upstream–downstream policy regulations.
17	Effective collaboration between public, private and societal actors and local communities results in new partnerships and coalitions that support innovation and transformation.

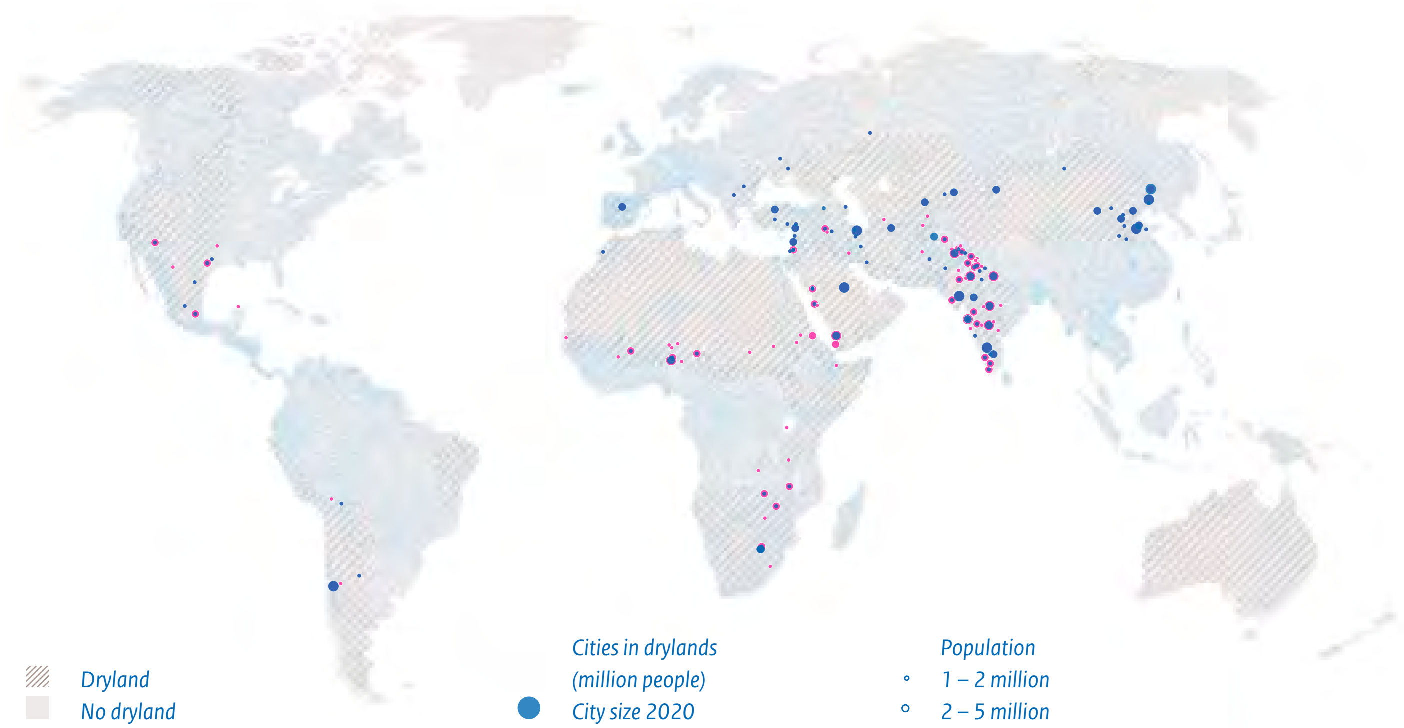
DRYLANDS

A CHALLENGING ENVIRONMENT WITH A GROWING POPULATION

Large parts of the drylands are located in low-income countries that contribute very little to climate change while, in the coming decades, they will face increasing water stress and deteriorating livelihood conditions. In regions with a growing population, in particular, this can affect migration and the risk of conflict.

Drylands host 3.1 billion people in 2020
Drylands make up 40% of the earth's surface and, in spite of the challenging water conditions, encompass 44% of all cultivated land and host 3.1 billion people, 90% of whom in low-income countries. The drylands population is projected to grow to 4.4 billion by 2070, especially in India and Sub-Saharan Africa. An increasing share of young adults in a population will change migration patterns. In many dryland locations, the population depends on rainfall and groundwater for its water supply. Locally, rivers provide water for irrigation and fertile wetlands. Well-known examples of rivers running through dryland areas are the Niger, the Colorado river and the Nile.

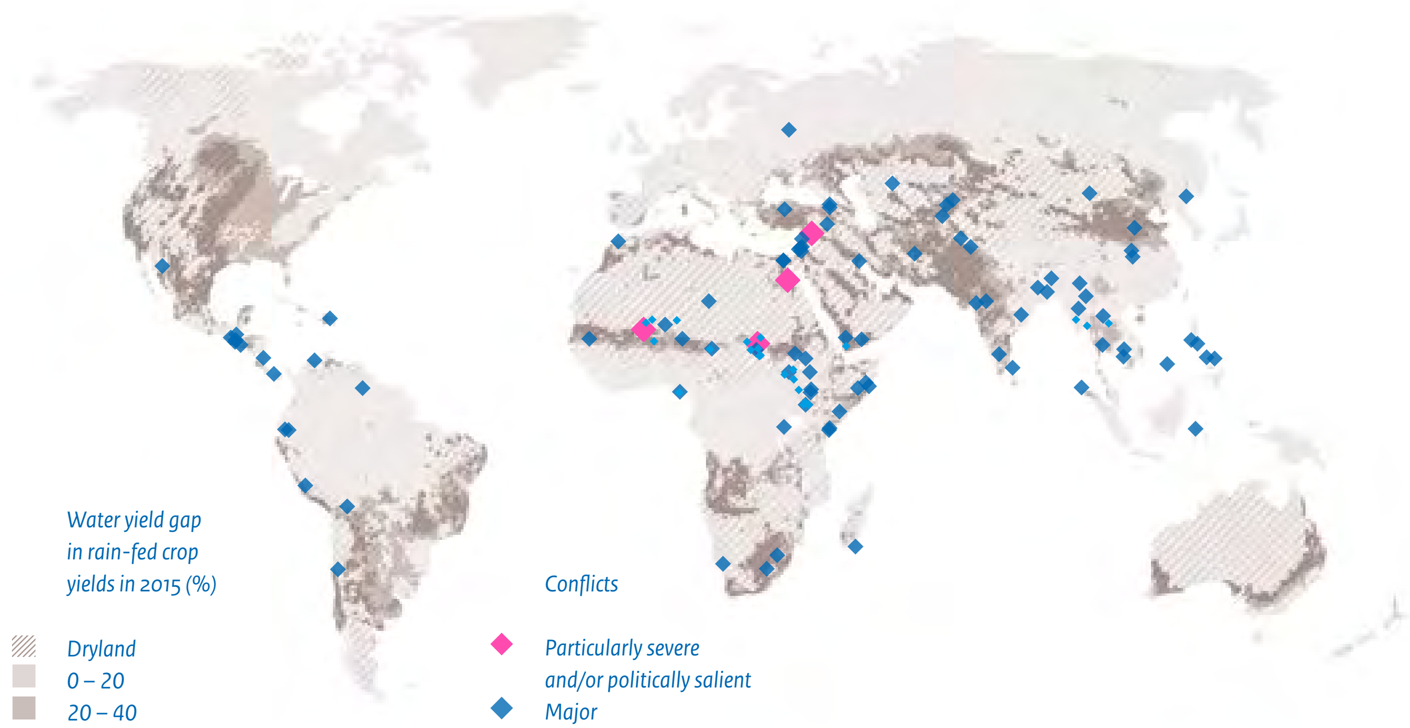
Drylands of the world in 2020



Source: PBL/IMAGE

Water stress can lead to migration and local conflict
Local or regional water stress can lead to a wide range of issues, such as decreases in agricultural yield and farm income, with negative effects on food insecurity and poverty. Water stress alone may not cause migration or local conflict but it does compound the risk in already vulnerable regions where livelihood dependencies on natural resources are high. Migration – within countries and cross-border – and local conflict can be affected by both slow-onset processes, such as population growth, climate change and land degradation, and frequent climate-related disasters, such as drought.

Conflicts over water, 1944–2016

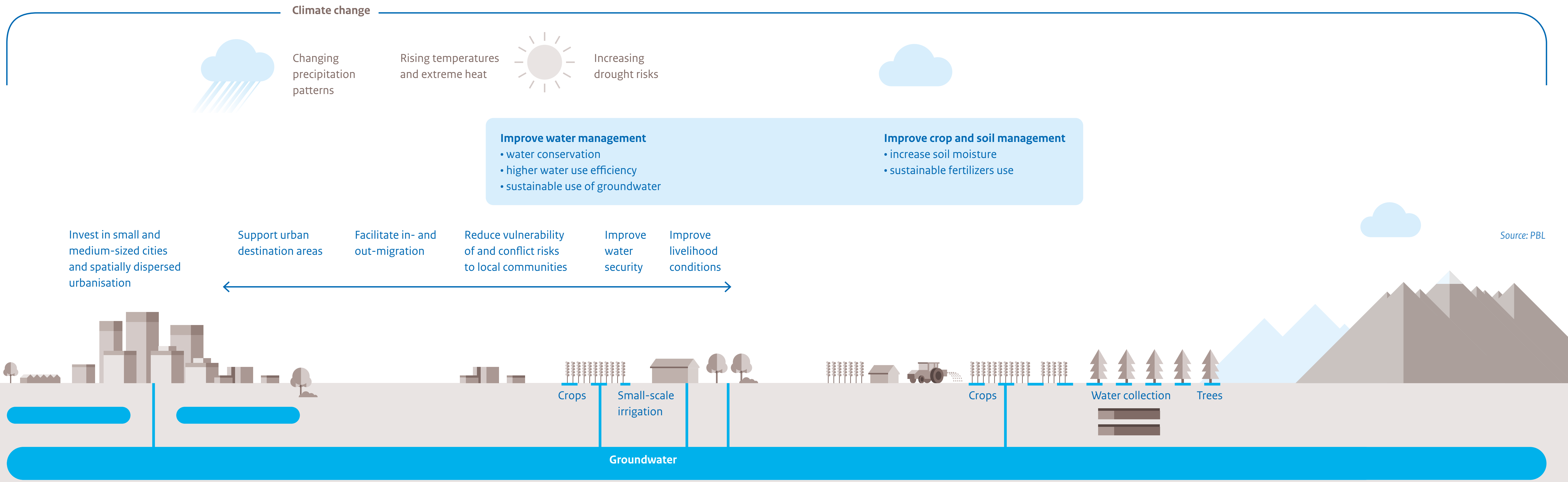


Source: Adelphi, PBL, WEnR

WATER AND CROP PRODUCTION WILL BE CRITICAL

Agriculture is the main economic sector in many drylands, providing food and a livelihood for billions of people. Improving water management and crop production and reducing climate vulnerability will be vitally important for improving the livelihood conditions, today and in the future.

Improving water and crop production conditions and security in dryland regions
In large dryland areas, there is a substantial gap between actual crop production and the level of production that would be possible if enough water would be available. In combination with the changing and increasingly uncertain rainfall patterns and increasing temperatures and heat risks, this calls for a structural improvement of water management and crop management. Improved crop management, higher crop production and stable incomes with lower water use will contribute to improving livelihood conditions and reducing climate vulnerability. At the same time, improving governance processes will be required to reduce the – potential negative effects of – migration and the local risk of conflict. On another level, investing in small and medium-sized cities rather than further expanding large cities can contribute to improving rural livelihood conditions and access to services for local communities. These combined efforts may contribute to breaking vicious circles of vulnerability caused by population growth, poverty and increasing climate stress.



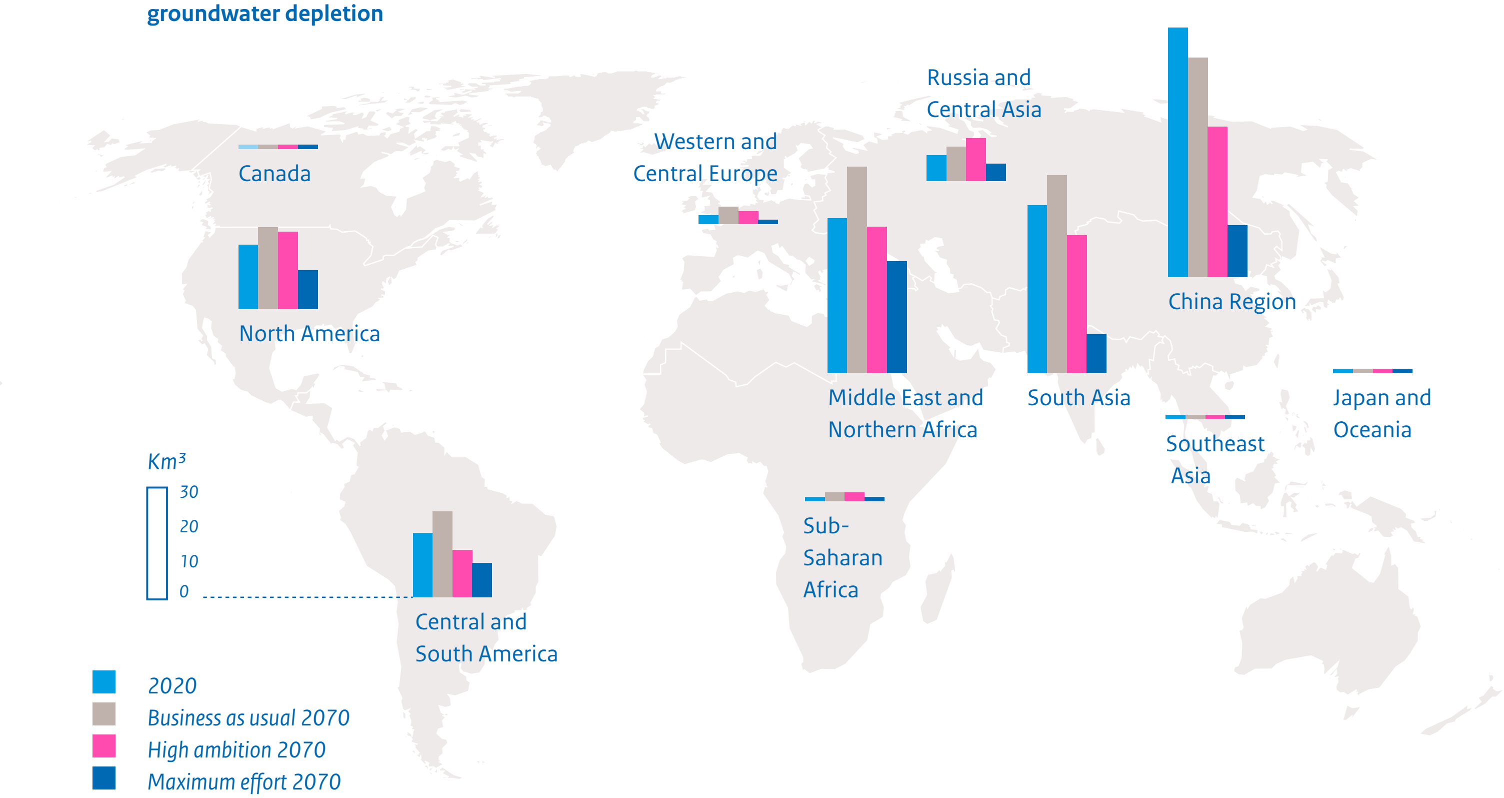
Source: PBL

WATER MANAGEMENT AND CROP PRODUCTION – MUCH TO GAIN

Under the Business-as-usual scenario, crop production is projected to increase by 29% due to cropland expansion and intensification. Water use increases by 15%. Under the High ambition pathway, water use can be halved while enabling doubling of crop production.

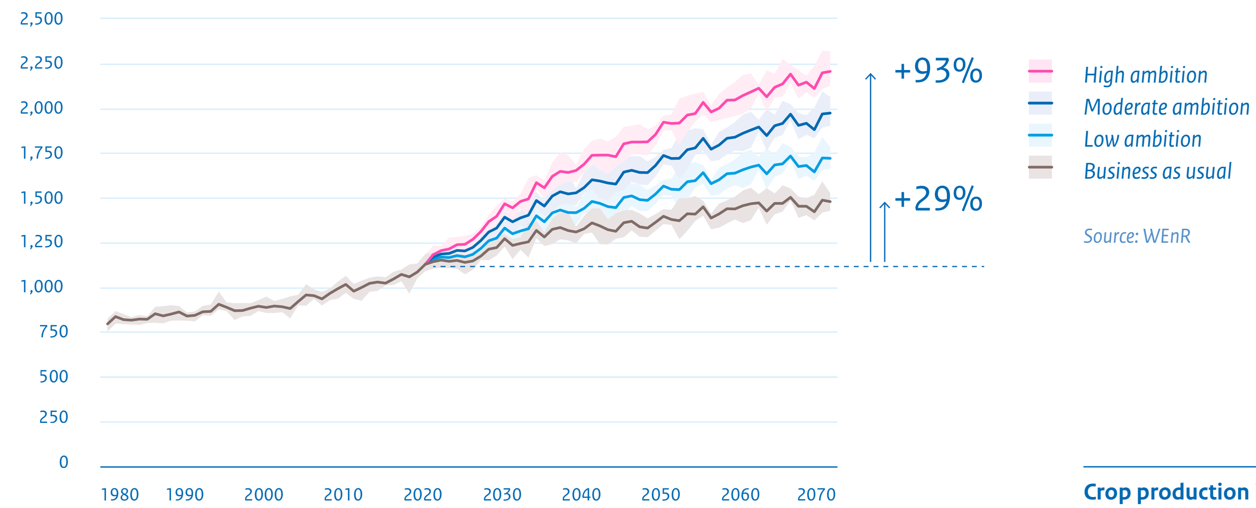
Overexploitation of groundwater systems can be substantially reduced
Globally, except for Sub-Saharan Africa, groundwater is used at unsustainably high levels for agricultural production in drylands. Under the Low, Moderate and High ambition pathways, non-renewable groundwater use can be reduced by 20% to 30%. The differences between these pathways in ground-water abstraction and depletion are small because all require large volumes of water for agricultural production. Groundwater abstraction also remains high under the High ambition pathway, because of the restrictions on the use of river water in order to retain a river's sufficient ecological flow. This then leads to a trade-off where groundwater is used instead.

Projected annual groundwater depletion



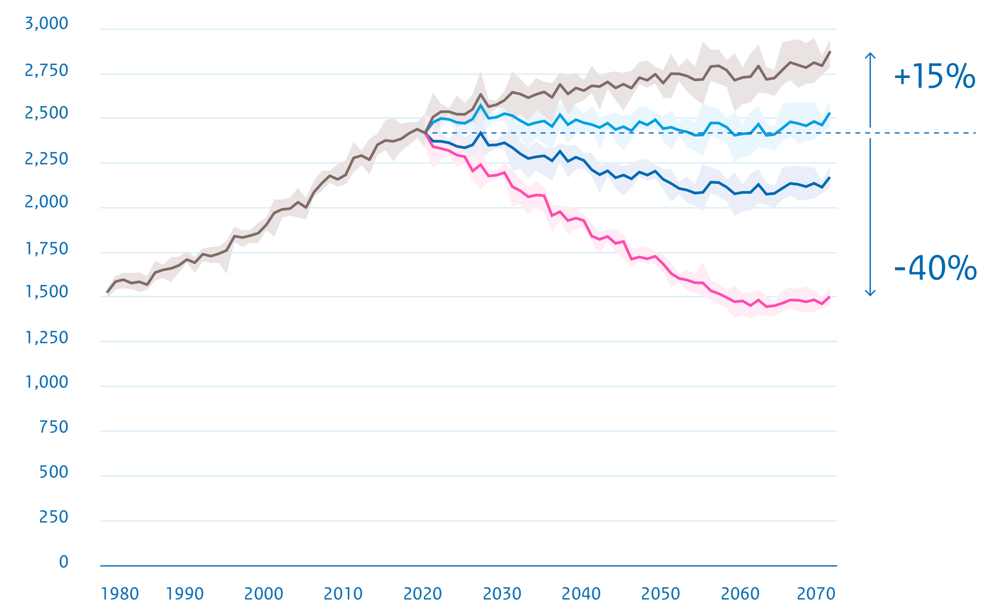
Source: WenR

Projected crop production in drylands
million tonnes dry matter



Source: WEnR

Projected water withdrawal in drylands
in km³



Crop production in drylands may double under the High ambition pathway, while water use decreases
Under the Business-as-usual scenario, dryland crop production is projected to increase by around 29% globally, compared to 2020, while the use of water increases by 15%, increasing climate vulnerability. The Low, Moderate and High ambition pathways show decreasing levels of water use while enabling further increase of crop production.

Under the High ambition pathway, water use efficiency increases by 55% compared to the Business-as-usual scenario. The combination of reducing water withdrawal for irrigation and increasing water use efficiency in rainfed crop production results in a strong reduction in the water yield gap in many regions.

CROP PER DROP MAY INCREASE SUBSTANTIALLY

Both irrigated and rainfed agriculture benefit from improving crop, soil and water management. Globally, crop productivity — in kcal per litre of water use — may increase by about 70%, on average. It is especially important to improve rainfed agriculture to support local communities in developing countries.

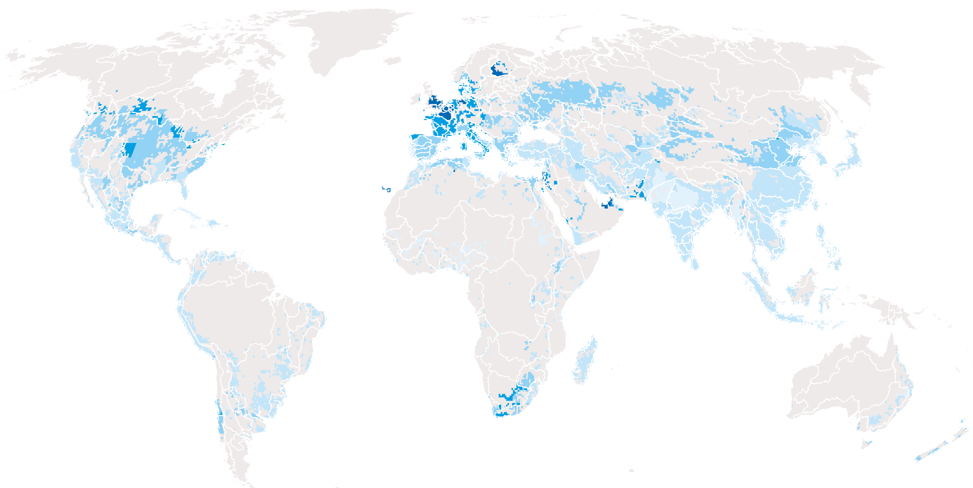
Crop water productivity of irrigated agriculture, 2070

Kcal/litre

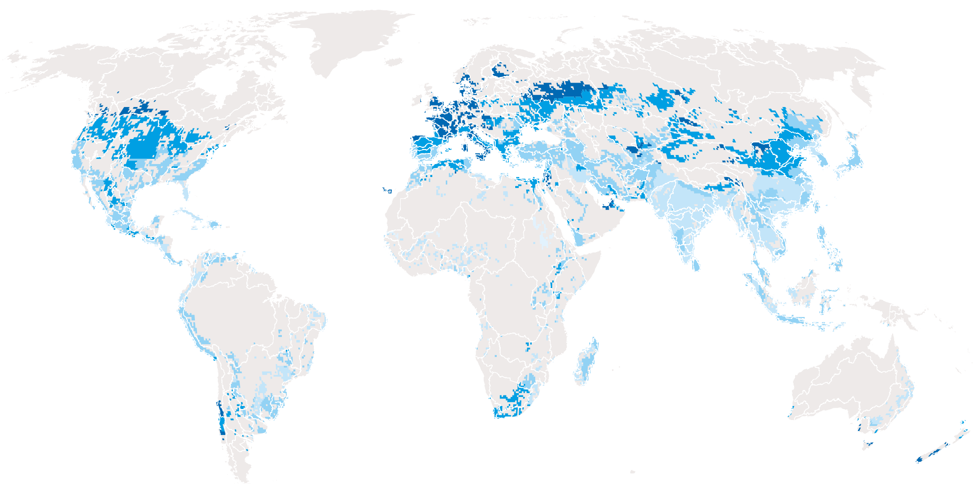
< 2
2 – 4
2 – 6
6 – 8
> 8

Source: WEnR

Business-as-usual scenario



High ambition pathway



Higher ambition levels increase crop per drop
Global mean crop water productivity increases under the higher ambition pathways. Rainfed crop productivity is projected to increase from 3.8 kcal/litre under the Business-as-usual scenario to a maximum of 6.5 kcal/litre under the High ambition pathway. Irrigated crop productivity is projected to increase under these pathways from 3.8 to 6.6 kcal/litre.

As to irrigated areas, crop productivity under the High ambition pathway increases in North America, Europe, Russia and the Middle East, while it remains at the current level in India and Southern China. The area of irrigated agriculture is relatively small in Africa.

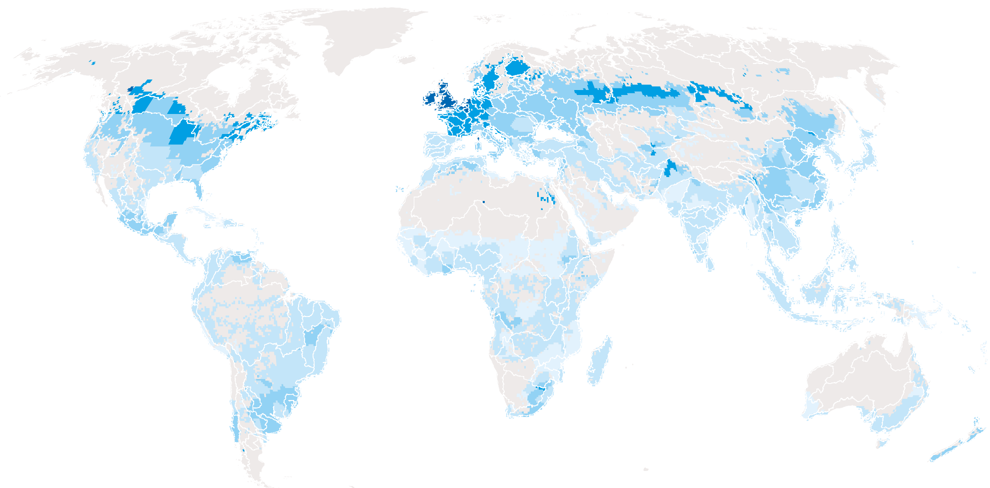
Crop water productivity of rainfed agriculture, 2070

Kcal/litre

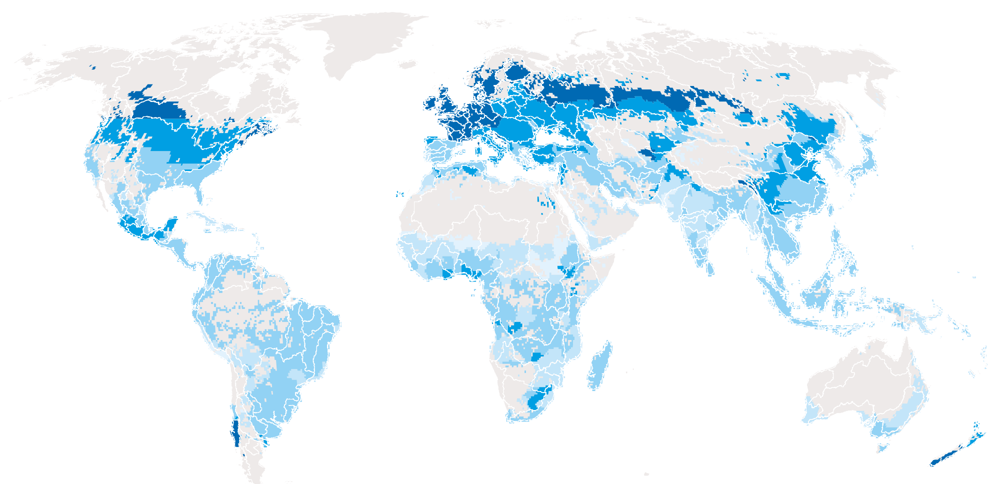
< 2
2 – 4
2 – 6
6 – 8
> 8

Source: WEnR

Business-as-usual scenario



High ambition pathway



Increase rainfed crop water productivity under the High ambition pathway
Under the High ambition pathway, rainfed crop productivity is projected to increase in many regions across the globe, also in parts of Sub-Saharan Africa.

As rainfed agriculture provides much of the food to vulnerable communities in developing countries, it is very important that rainfed crop production is increased while water use is reduced. Globally, rainfed agriculture accounts for more than 95% of farm land in Sub-Saharan Africa, 90% in Latin America, 75% in the Middle East and North Africa, 65% in East Asia, and 60% in South Asia. These areas include large dryland areas.

REDUCING CLIMATE VULNERABILITY – USING UNUTILISED GROUNDWATER IN AFRICA

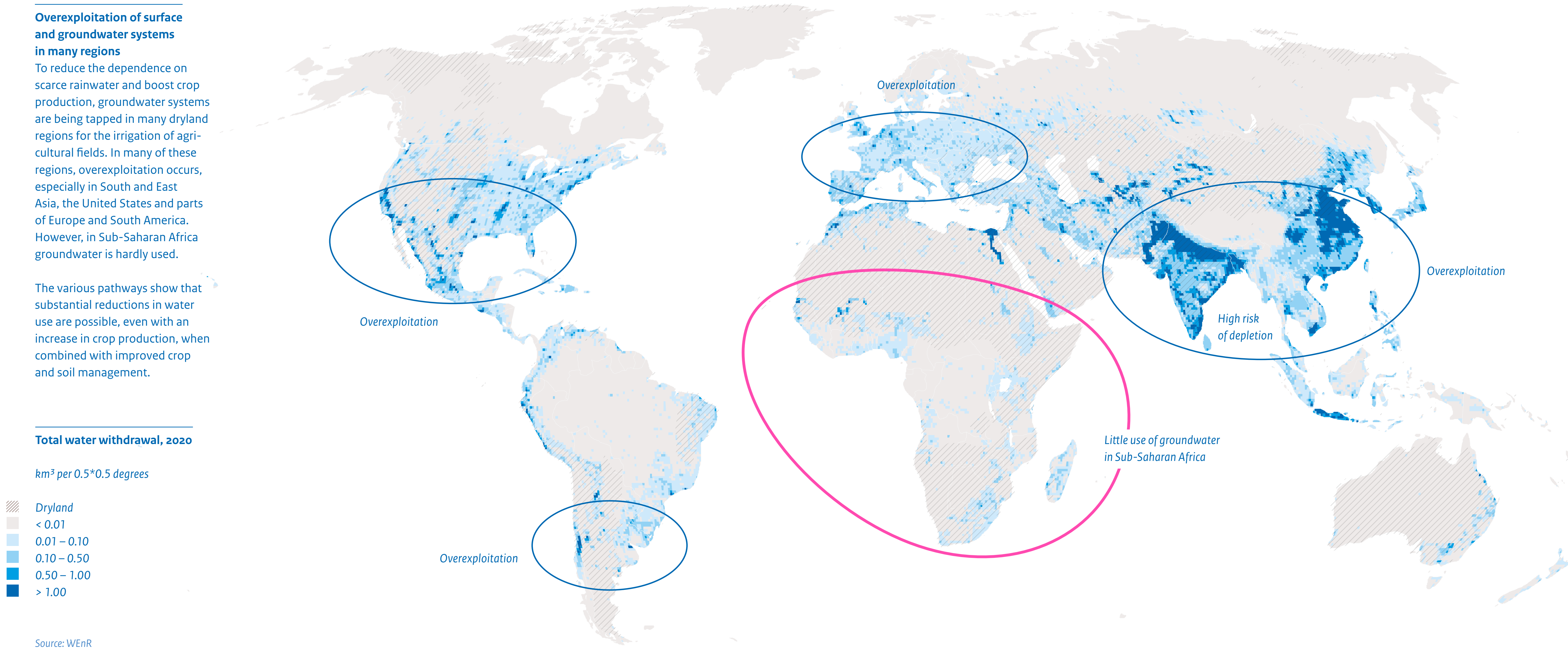
Groundwater systems in many dryland regions are overexploited, except for those in Sub-Saharan Africa. While in other regions increasing water efficiency is the way towards sustainable use of water resources, in Sub-Saharan Africa there seems to be potential for using more groundwater.

Overexploitation of surface and groundwater systems in many regions
To reduce the dependence on scarce rainwater and boost crop production, groundwater systems are being tapped in many dryland regions for the irrigation of agricultural fields. In many of these regions, overexploitation occurs, especially in South and East Asia, the United States and parts of Europe and South America. However, in Sub-Saharan Africa groundwater is hardly used.

The various pathways show that substantial reductions in water use are possible, even with an increase in crop production, when combined with improved crop and soil management.

Total water withdrawal, 2020

*km³ per 0.5*0.5 degrees*



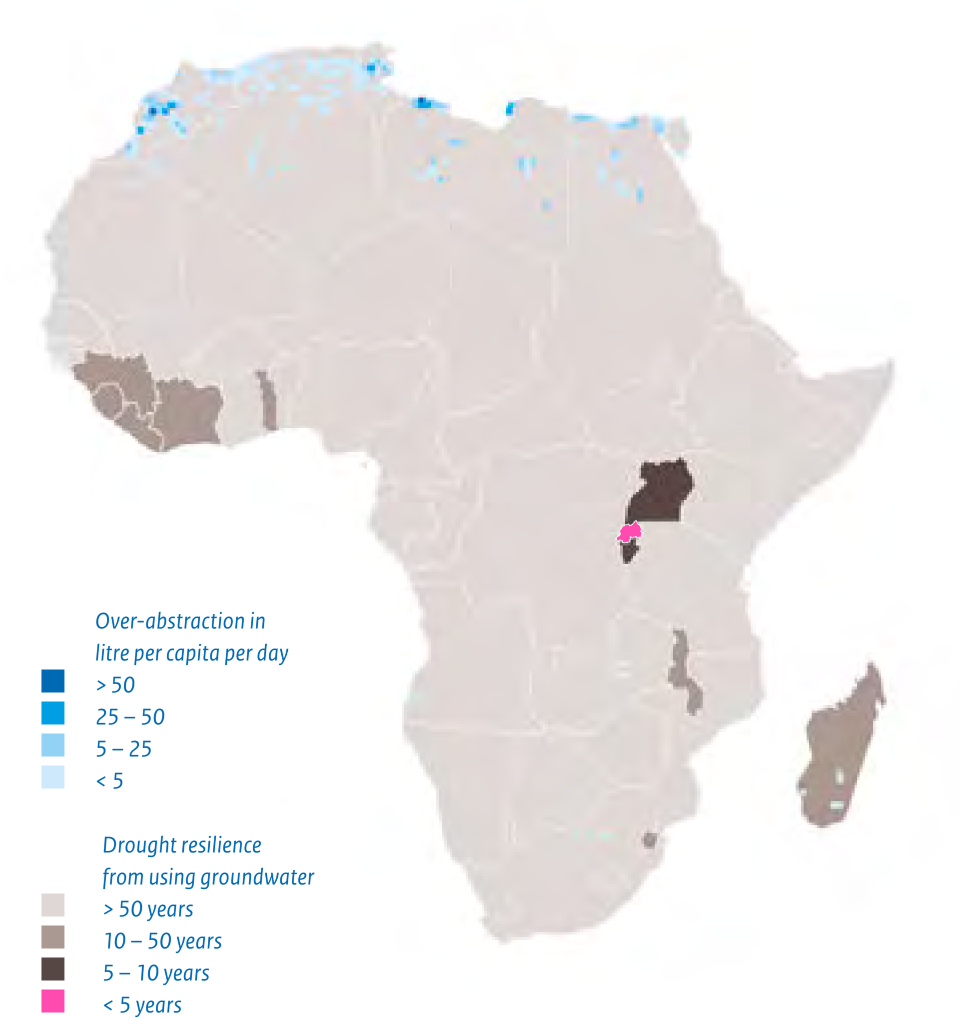
Source: WEnR

OPPORTUNITIES TO INCREASE WATER SUPPLY IN SUB-SAHARAN AFRICA

Sustainable use of available but unused groundwater resources in Sub-Saharan Africa may increase water availability with an additional 130 litres per person per day, corresponding to a doubling of the water that currently is available on average. This would significantly contribute to reducing climate vulnerability of Sub-Saharan African communities.

Unutilised groundwater resources in Sub-Saharan Africa — an opportunity to reduce climate vulnerability?
Recent African groundwater storage maps show significant reserves of potentially usable groundwater at a national level. Sustainable use of the resources may encompass current usage plus an additional 130 litres per person per day, assuming no active recharge of groundwater systems.

Drought resilience from using groundwater

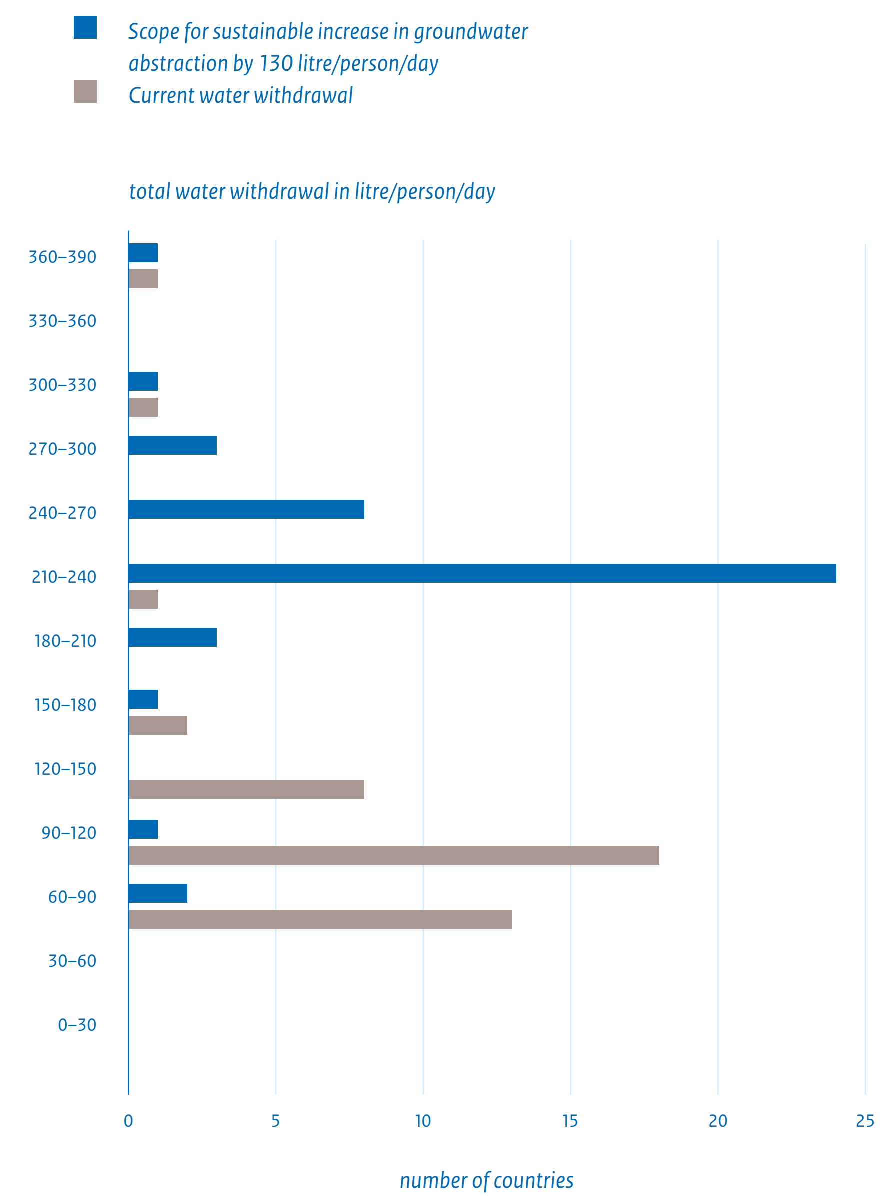


Source: British Geological Survey; WEnR

If the groundwater abstraction may be increased sustainably by 130 litre/person/day, this would correspond to a doubling of the water that currently is available on average, in many countries this is even more.
If this increase in use is indeed sustainable, this would be an important opportunity for improving and buffering the water supply of villages, towns, cities and efficient small-scale agricultural systems, as this would significantly reduce their climate vulnerability.

Source: WEnR, PBL

Daily groundwater abstraction for households and industries in Sub-Saharan African countries

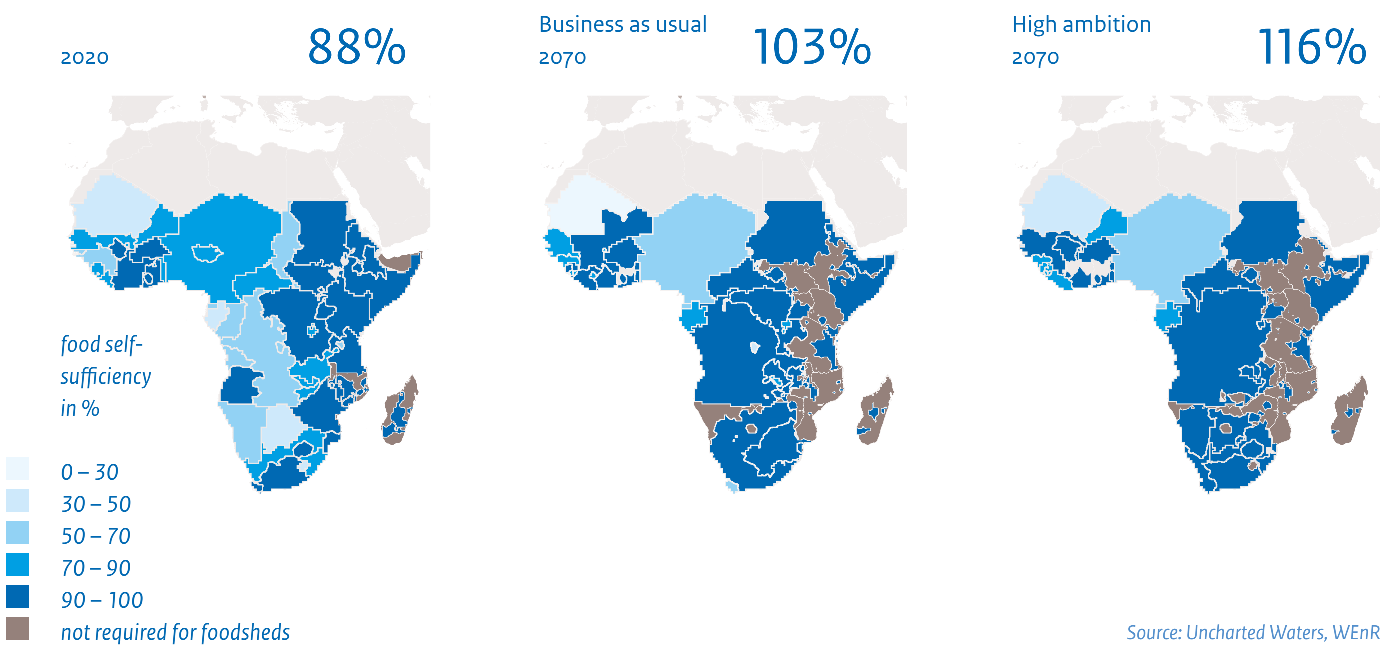


INCREASING CROP PRODUCTION CONTRIBUTES TO LOCAL FOOD SECURITY

Improved crop and soil management and water management measures are vitally important to maintain or improve levels of food self-sufficiency and reduce climate vulnerability of the urban and rural population in both Sub-Saharan Africa and South Asia.

Foodsheds: indicator of local food security based on local crop production
Foodsheds are a way of visualising the 'local aspect' of food production and the extent to which cities can rely on the surrounding rural areas to meet their food demand. Foodsheds are defined as self-sufficient areas with internal urban–rural dependencies, i.e., where supply matches demand (Kinnunen et al., 2020; Karg et al., 2016). Regional food self-sufficiency is a major issue in both Sub-Saharan Africa and parts of South Asia, due to the growing population and increasing risk of yield failure caused by increasing drought risks and overexploitation of groundwater systems, especially in South Asia.

The level of plant-based food self-sufficiency in Sub-Saharan Africa



Source: Uncharted Waters, WEnR

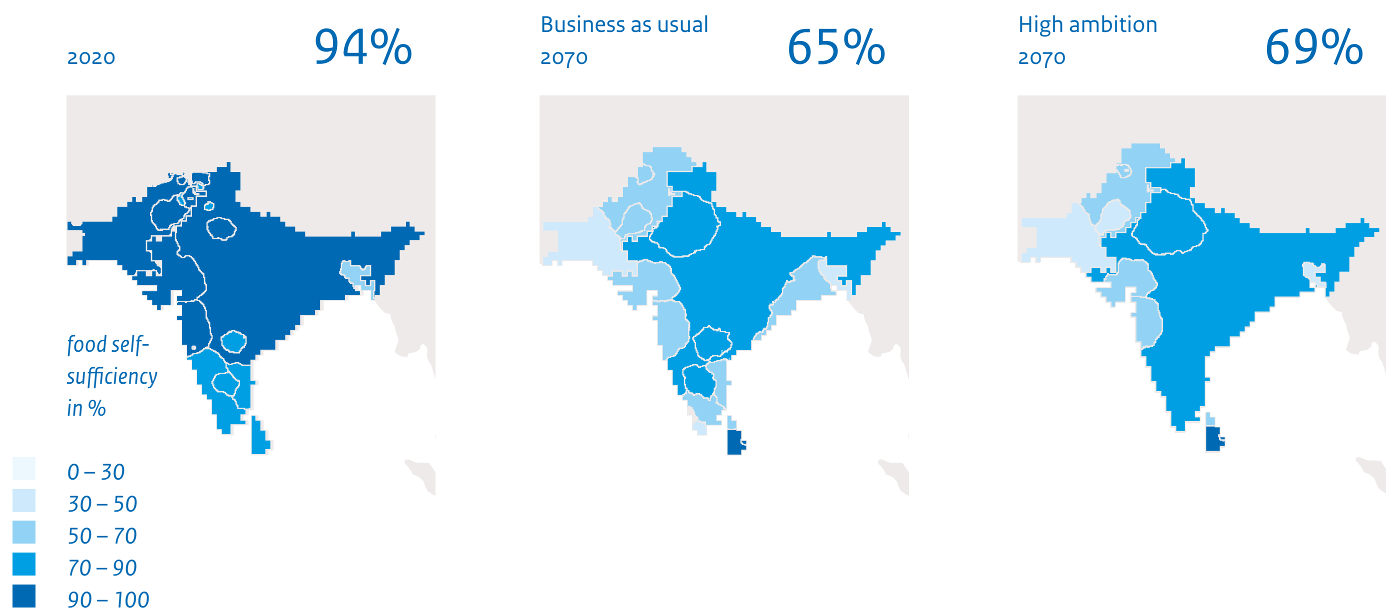
We focus on Sub-Saharan Africa and South Asia. Population growth towards 2070 is expected to increase food demand in Sub-Saharan Africa by almost 250% and in South Asia by almost 50%. Under the Business-as-usual scenario, food crop self-sufficiency in Sub-Saharan Africa is projected to increase from meeting 88% of the food crop demand by the surrounding foodsheds today, to about 103% by 2070. Under the High ambition pathway, a level of self-sufficiency of about 116% is projected. In South Asia, these two pathways project a decrease, from 94% today to 69% under the High ambition pathway by 2070. Here, the opportunity to expand crops lands is limited.

Source: Uncharted Waters Research

Increasing crop production – reducing poverty
Most farmers in Sub-Saharan Africa and South Asia (70%–80%) work plots that are smaller than 2 hectares, representing in total about 30% to 40% of the agricultural land in those countries (Lowder, Skoet and Raney, 2016). Poverty is high amongst these smallholders, making the need to keep investing in this group of pivotal importance for achieving the Sustainable Development Goals.

Source: De Bruin et al., 2021

The level of plant-based food self-sufficiency in South Asia



Source: Uncharted Waters, WEnR

FOOD SYSTEMS CONNECT URBAN AND RURAL DEVELOPMENT

The ways in which urbanisation is changing food systems and rural development are not only influenced by the dynamics of urbanisation and the environmental context — such as climate change, water availability and land degradation — but also by the political, social and trade context, including import/export dynamics, institutional capacities, education, skills and welfare distribution.

Urbanisation patterns affect rural opportunities
While the local agricultural sector could profit from the projected increases in food demand due to population and income growth towards 2070, potential yield increases or diversification will not automatically contribute to rural development. Instead, urbanisation could also increase inequality and poverty. Smallholders located close to expanding cities risk losing their land to urbanisation, while people living in rural areas far from growing urban food markets are at risk of losing out, due to lack of access to inputs, markets, services and information.

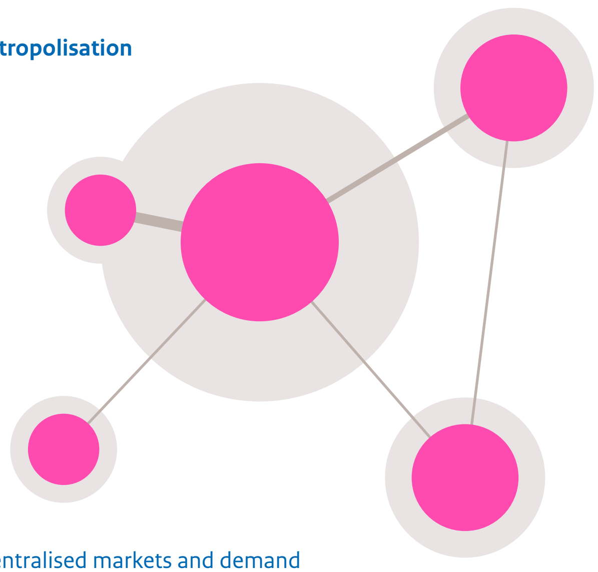
The development of smaller cities and towns tends to contribute more to regional poverty reduction than is the case with growing larger cities. Physical and communicative proximity to urban markets means better access to finance, inputs, information, a wide variety of services and off-farm employment opportunities. The clustering of the population in megacities (>1 million inhabitants) has had little effect on poverty reduction, and in some cases even led to an increase in poverty.

This implies that urban growth strategies that result in a trend towards centralised large cities could weaken future growth-wealth linkages in already vulnerable regions, such as in Sub-Saharan Africa and India.

Patterns of urbanisation

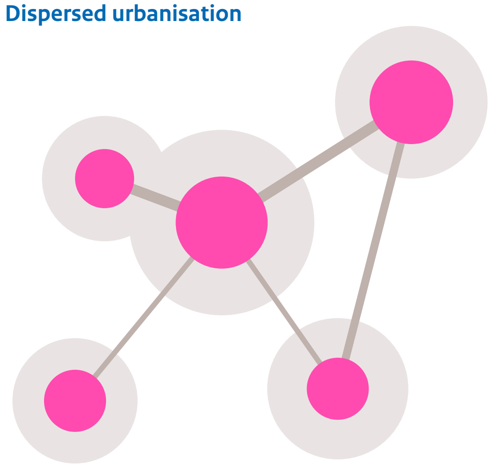
Connectivity
Urban area
Sphere of infuence

Metropolisation



- Centralised markets and demand
- More centralised economic growth
- Higher levels of economic inequality
- Increased risk of slums and urban poverty

Dispersed urbanisation

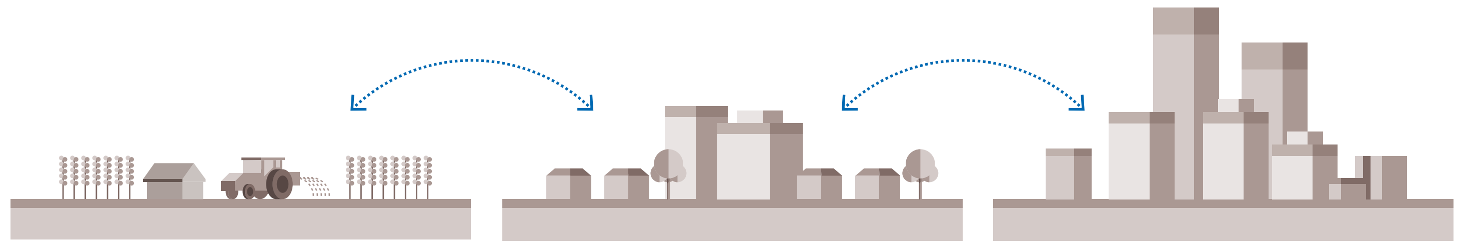


- Decentralised markets and demand
- Scattered centres of economic growth
- More dispersed non-farm employment
- More inclusive economic growth

Source: De Bruin et al., 2021

The importance of small towns and cities in rural development

Rural regions — Small cities — Big cities



Rural regions:
- Services and knowledge
- Income and employment
- Food and recourses

Food system functions of small cities
- Centres of demand/markets for their rural region
- Centre for the production and distribution of goods and services
- Centre for the development and growth of rural non-farm activities and employment
- Attracting rural migrants
- Processing and distribution centres

Big cities:
- Reduce pressure on big cities
- Provide processed foods
- Import and export

Source: De Bruin et al., 2021; PBL

LOCAL WATER- AND CLIMATE-RELATED CONFLICT RISK

Water stress can increase migration and the risk of local conflict. Improved water management and crop production, better access to water infrastructure and a higher level of adaptive capacities are found to result in a lower likelihood of conflict in relation to water stress.

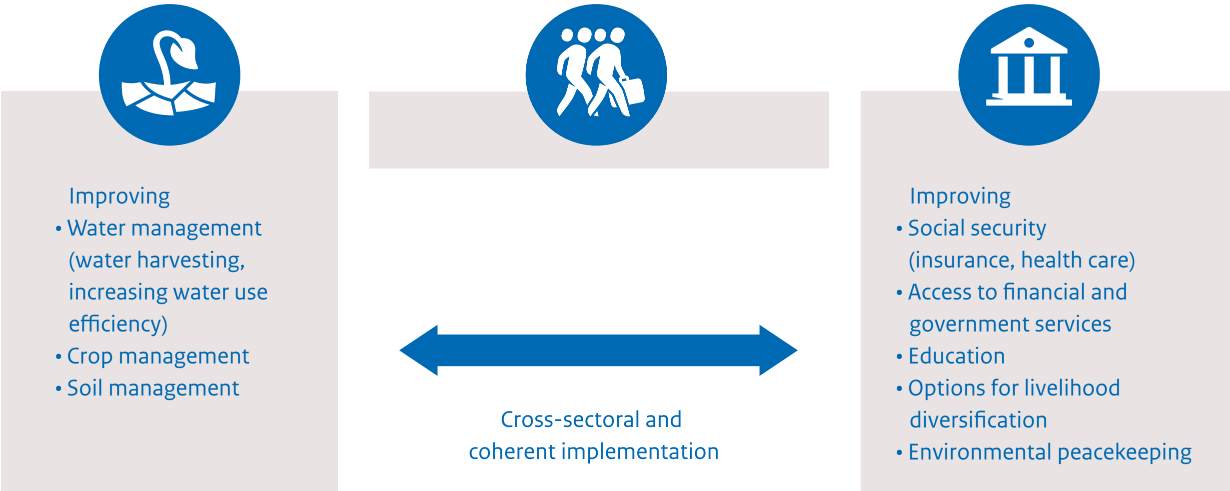
Droughts in regions depending on rainfed agriculture, can increase conflict risk
In areas where livelihoods highly depend on natural resources, both slow-onset processes (e.g. increasing water stress and land degradation) and sudden-onset events (e.g. drought) can affect migration patterns or social and political conflict. Especially in regions that depend on rainfed agriculture, sensitivity to civil conflict following drought is higher than in regions where irrigation is available. Conflict can occur between arable farmers and livestock farmers or between groups of livestock farmers.

Source: De Bruin et al., 2021

Reducing water-related migration and conflict

Improving water management and crop production to reduce vulnerability

Strengthen governance capacities to reduce vulnerability



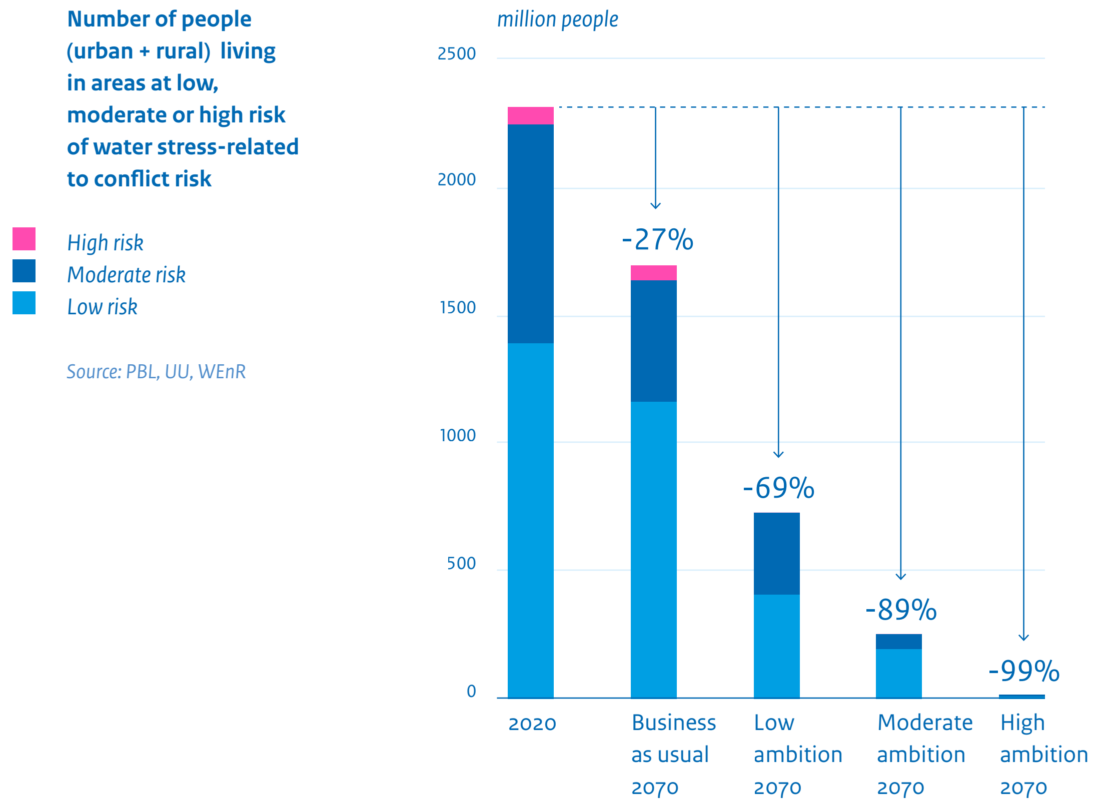
Potential changes in conflict risk are explored based on changes in water yield gap, GDP per person conform SSP2 scenario and governance quality (cf. worldwide governance index, (Kaufman and Kraay, 2021)).

Source: PBL

The population in areas with moderate or high risk of water-related conflict or migration could decrease strongly
Under the Business-as-usual scenario, the number of people living in areas with moderate or high risk of water-related conflict is projected to decrease strongly between now and 2070, because of high GDP growth. Under the Moderate and High ambition pathways, these risks further decline following an improvement in crop productivity.

Source: PBL, UU, WEnR

Number of people (urban + rural) living in areas at low, moderate or high risk of water stress-related to conflict risk



Source: PBL, UU, WEnR

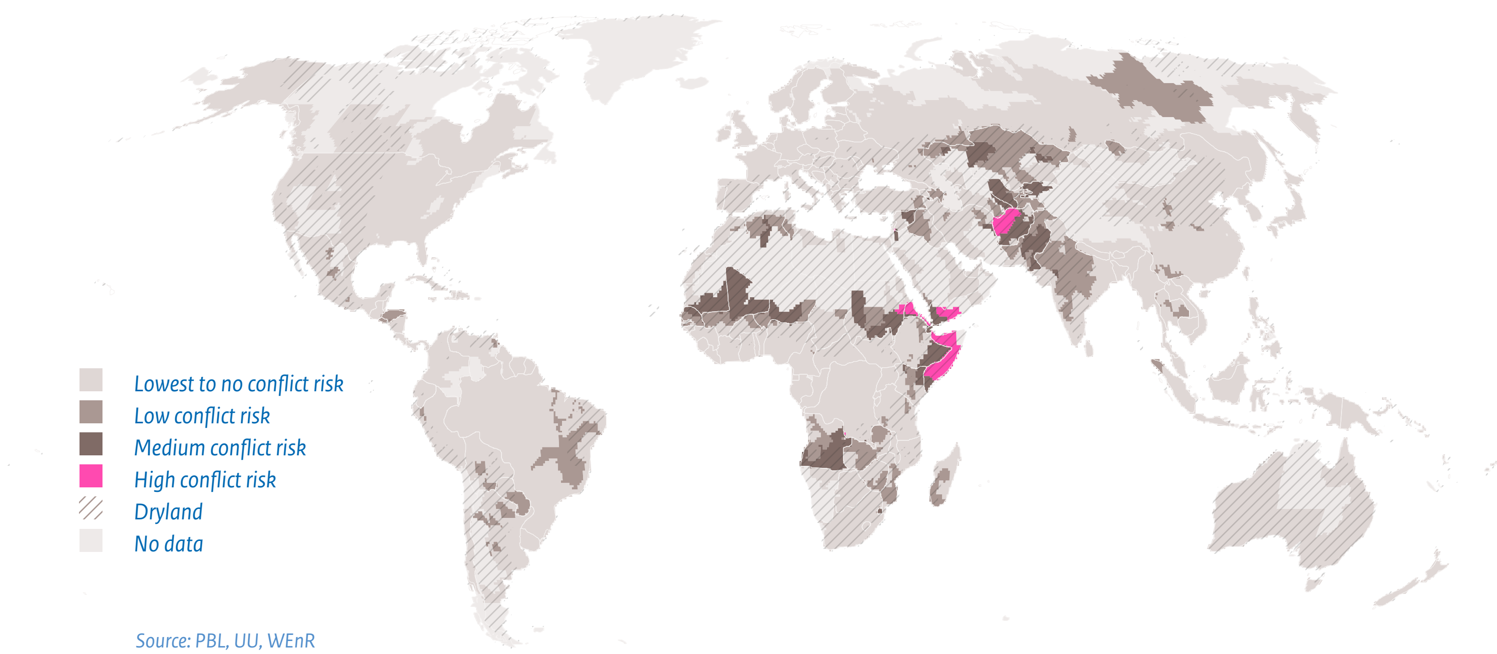
HIGH AMBITION PATHWAY: STRONG DECLINE IN CONFLICT RISK

The population in moderate- to high-risk areas is currently about 930 million. Under a High ambition pathway, this number is projected to decrease to 10 million by 2070, including only Yemen and Somalia.

Business-as-usual scenario
Under the Business-as-usual scenario, the most vulnerable regions are the Horn of Africa (Eritrea, Somalia), the Sahel (Niger, Mauritania, Mali), parts of Central/Southern Africa (Angola, Zambia), and parts of Central Asia (Afghanistan, Yemen, Pakistan).

By 2070, 520 million people are projected to live in moderate- to high-risk areas, compared to about 930 million people today. Strategies to reduce water stress-related conflict are based on water management as well as on a reduction in the vulnerability of populations at risk.

Areas with a projected risk of water-related conflict by 2070
Business-as-usual scenario



Source: PBL, UU, WEnR

High ambition pathway
Under a High ambition pathway, the population in moderate- to high-risk areas decreases to 10 million, including only Yemen and Somalia. This strong decline results from the strong reduction in the water yield gap, and the relatively strong increase in GDP per person and in the quality of governance under the SSP2 scenario.

Areas with a projected risk of water-related conflict by 2070
High ambition pathway

Source: PBL, UU, WEnR

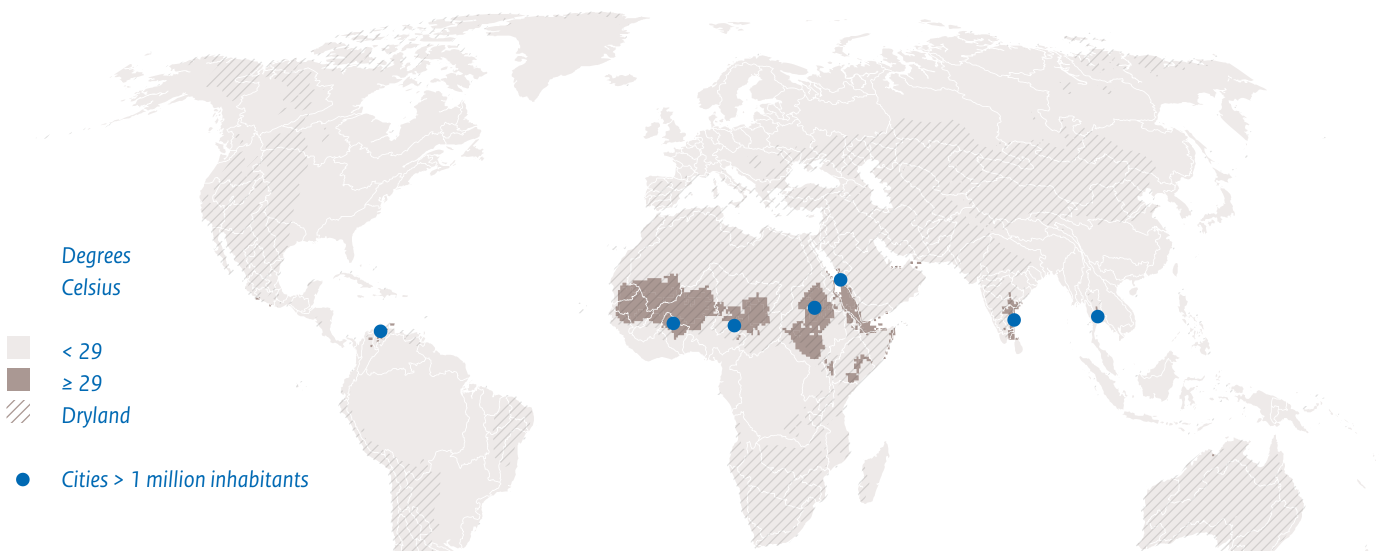
INCREASING HEAT – UNINHABITABLE AREAS IN DRYLANDS

Increasing temperatures are projected to affect the liveability in already warm regions, in particular in cities. By 2070, over 1 billion people may live in areas with mean annual temperatures more than 29 °C.

Temperature increase affects human habitat
Recent research reveals that living conditions for humans may become uninhabitable in areas with a mean average temperatures of more than 29 °C (cf. Xu et al., 2020). In addition, the increasing frequency and intensity of heatwaves and the urban heat island effects are increasing mortality and deteriorating living conditions, in particular in large cities. By 2070, 1.4 billion people may live in areas affected by high temperatures. About 200 million people are currently living in areas with an annual mean temperature of more than 29 °C, 60 million of whom in large cities of over 1 million inhabitants. The population in areas with an annual mean temperature of more than 29 °C is projected to increase to about 1.4 billion people by 2070, almost 700 million people of whom in large cities.

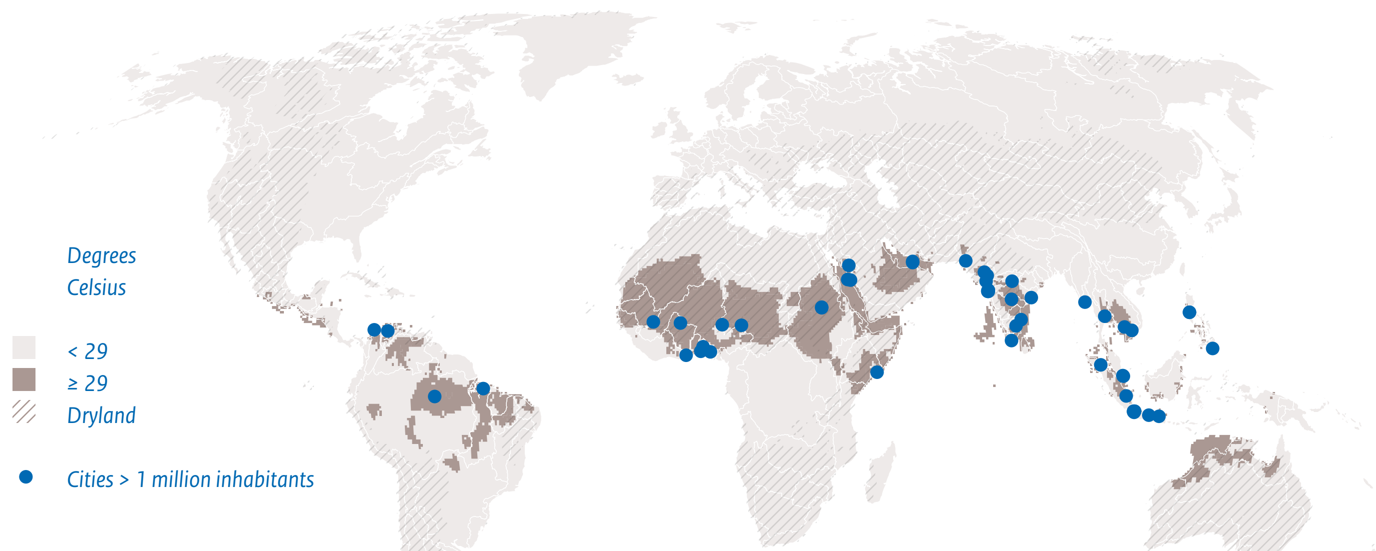
The Sahel region and parts of Central Africa are particularly at risk (i.e. Sudan and South Sudan). Also parts of Brazil, Saudi Arabia, India and parts of Southeast Asia may become too hot to sustain rural livelihoods. The potential impact of this increase in temperature under the RCP6.0 climate scenario underlines the high level of urgency for exploring options and strategies to sustain good livelihood conditions in drylands and vulnerable cities.

Areas and large cities with projected mean annual temperatures of over 29 °C
2020



Source: Lange and Büchner, 2017; PBL: the results are based on the projections of 4 climate models

Areas and large cities with projected mean annual temperatures of over 29 °C
2070



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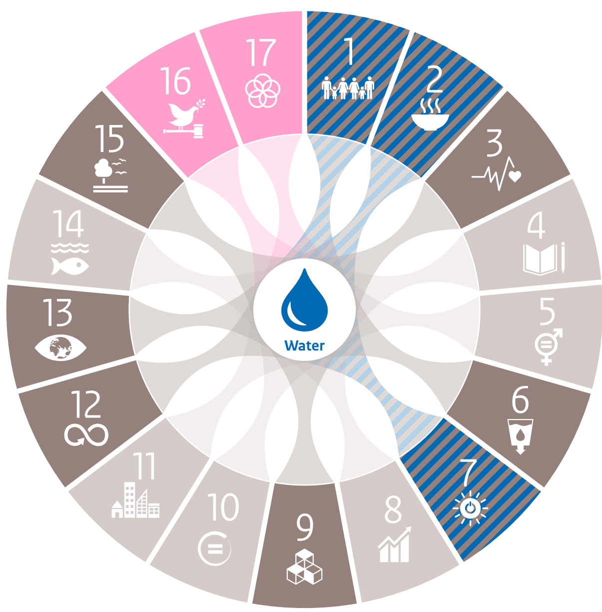
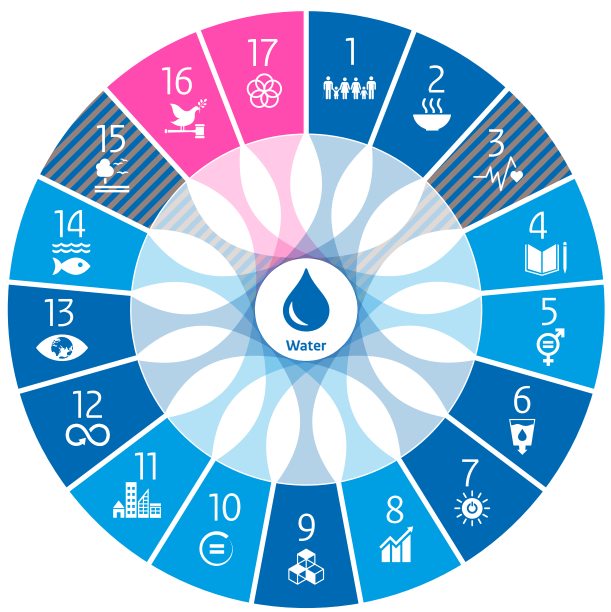
SDGs, Business-as-usual scenario 2070



SDGs, High ambition pathway 2070



The main differences in impact of the High ambition pathway on drylands, compared to the Business-as-usual scenario

SDG	
1	Livelihood conditions are improved in greater increase in crop production (100% vs 20%) in combination with higher water use efficiency, reducing climate vulnerability.
2	Greater increase in crop production (100% vs 20%) and reduced climate vulnerability structurally improve local food supply and security.
3	Improvement in health and well-being because of improved local food production and water use efficiency, and improved sanitation and wastewater treatment.
4	Improvement in the health and educational conditions for children because of improved local food production, and improved water supply and sanitation.
5	Improvement in the health and living conditions for women and girls because of improved local food production, and improved water supply and sanitation.
6	Strong improvement in sanitation and wastewater treatment and effective management of flood and drought risks, water pollution and salinisation.
7	Lower risk of energy supply disruption, due to flooding events disturbing the energy supply under a 70% increase in hydropower production.
8	Additional investments in agriculture and reduction in climate vulnerability provide better livelihood conditions with local crop production keeping up with population growth.
9	Investments in agriculture and in the infrastructure of small cities, towns and rural areas improve local livelihood conditions.
10	Structural investments in agriculture, sanitation and wastewater treatment and in the infrastructure of small cities, towns and rural areas reduce inequality and support especially SDG1.
11	Contribution to the development of sustainable cities and communities through structural investments in agriculture (local food security), sanitation, wastewater treatment and the infrastructure of small cities, towns and rural areas.
12	Greater water use efficiency (up to 50%) and a sustainable use of fertiliser contribute to responsible consumption and production. Progress is lacking under the Business-as-usual scenario.
13	Structural attention to climate change adaptation, improvement in water conservation and water use efficiency, and a structural increase in crop production efficiency.
14	Avoiding the adverse impacts of new dams and increased nutrient emissions to coastal seas by installing ecosystem-friendly hydropower facilities and stabilising nutrient emissions.
15	Improvement in wetlands protection and water use efficiency and a reduction in nutrient emission levels.
16	Strong institutions and inclusive policies greatly improve the conditions to enhance water management and crop production and reduce local conflict risks.
17	Effective collaboration across scales between public, private and societal actors and local communities results in new partnerships and coalitions supporting innovation and transformation.

CITIES

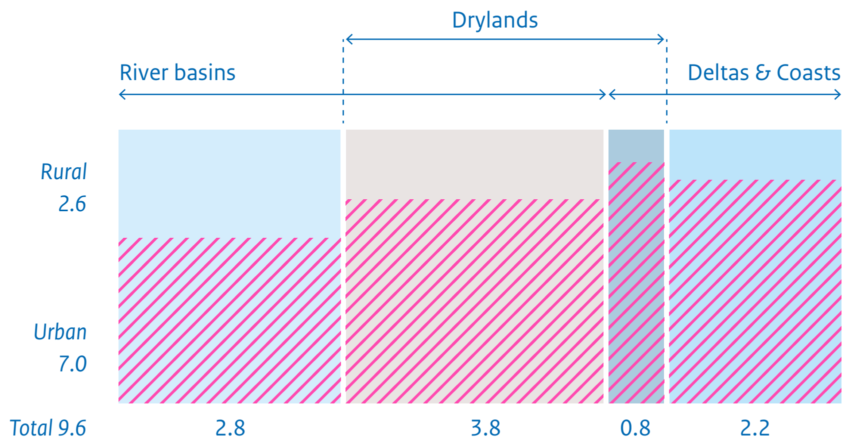
CRITICAL WATER- AND CLIMATE-RELATED HOTSPOTS

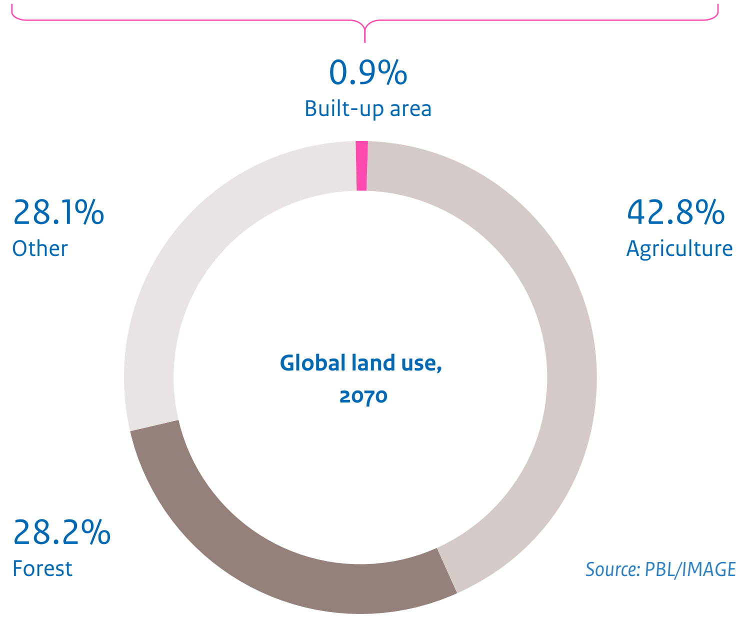
By 2070, an estimated 70% to 75% of the global population will be living in cities, either in a river environment, dryland region, delta or coastal zone. Municipalities and urban developers bear the critical responsibility of providing a healthy living environment with adequate water services and reduced water- and climate- related risks.

By 2070, 7.0 billion people are projected to be living in an urban environment
Cities are the main centres of population growth, economic development, innovation and cultural development. At the same time, especially in developing countries, they are on the front lines of climate change impacts, with serious consequences for human health, livelihoods and assets, especially for the urban poor — many of whom living in informal settlements — and other vulnerable groups. The urban population is expected to grow by 64%, from 4.3 billion in 2020 to 7.0 billion by 2070. Dominated by developments in Africa, with around 162% growth between 2020 and 2070, it is especially strong in the water-scarce dryland regions. By 2070, between 70% and 75% of the global population will be living on less than 1% of the global land area.

Fast urban growth, often more than doubling city sizes, is projected to occur especially in the developing countries of East and South Asia and Sub-Saharan Africa.

Population in the hotspot landscapes in 2070
in billions





Source: PBL/IMAGE

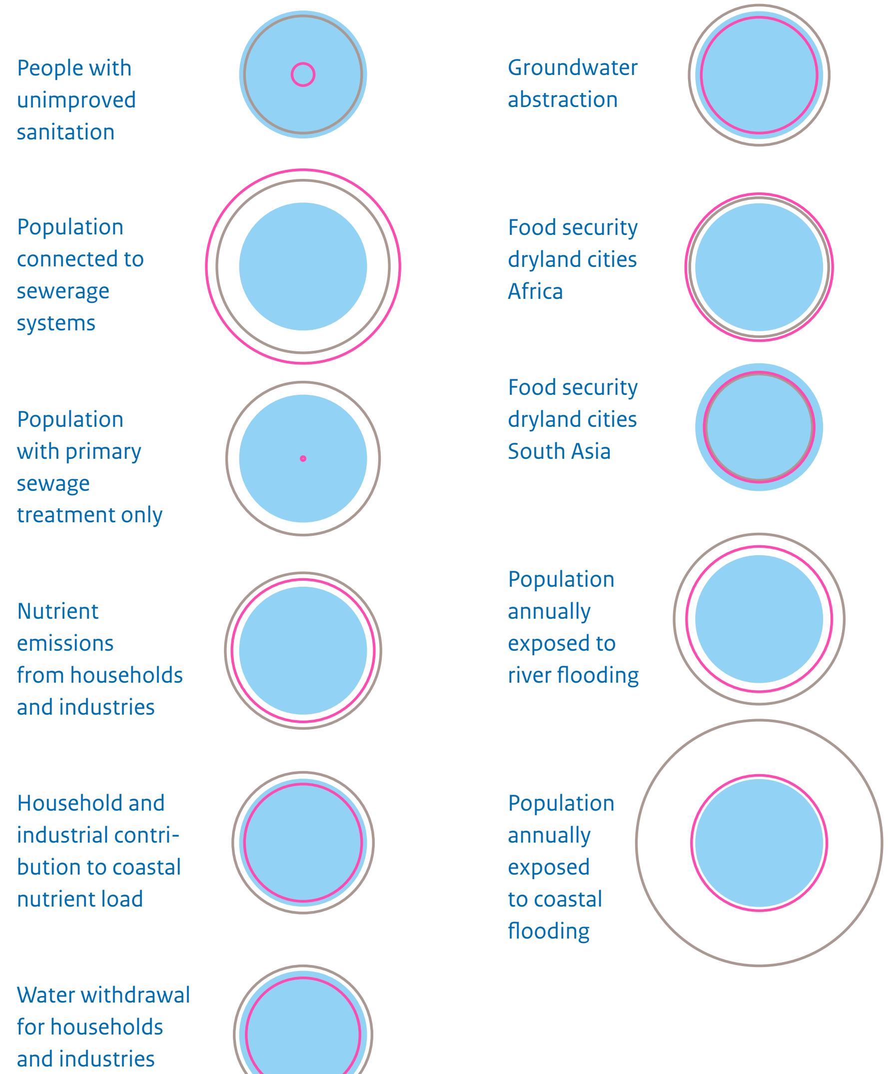
Water- and climate-related risks in cities

2020 (index)

Business as usual, 2070

High Ambition, 2070

Source: PBL



Promising perspectives need to be embedded in local urban strategies
Although our global exploration does not allow scaling down to the level of cities in specific situations, the outcomes in general show a promising outlook for cities under a High ambition pathway. To bend the trend in the high ambition direction, municipalities, urban developers and all other stakeholders involved in shaping the urban environment need to integrate the water- and climate-related challenges in their designs and development processes.

URBANISATION REQUIRES TAILOR-MADE SOLUTIONS

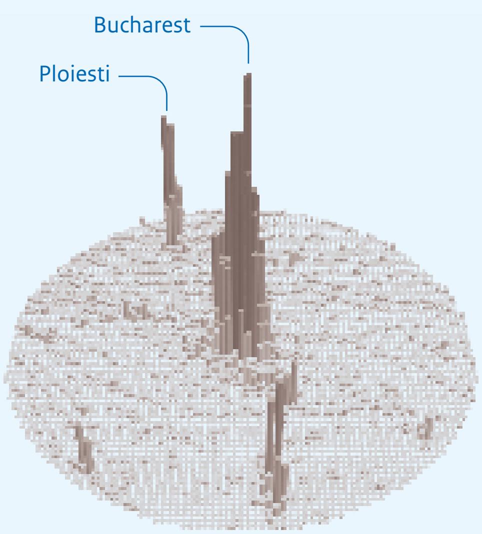
Apart from the geographical situation and climate-related risks, the challenges and potential pathways of solutions are also shaped by spatial morphology, history, demography, economy and the existing water infrastructure.

The diversity of cities calls for a diversity of solutions
It goes without saying that cities around the world and those in hot-spot locations are very diverse: apart from geographic location and water and climate change context, they can strongly differ from one another in demography, economic status and development level, existing spatial structures and quality of services, planning processes, and the pace and patterns of urbanisation. While some measures are common across landscape typologies, others are unique to certain landscapes, or even to certain clusters of cities. This illustrates how urban adaptation approaches to climate change and global development do not suit a 'one size fits all' approach. As to water- and climate-related risks, generally speaking, there are numerous ways of improving water services and reducing these risks, such as through behavioural and management measures, technical measures, and small- and large-scale blue and green measures.

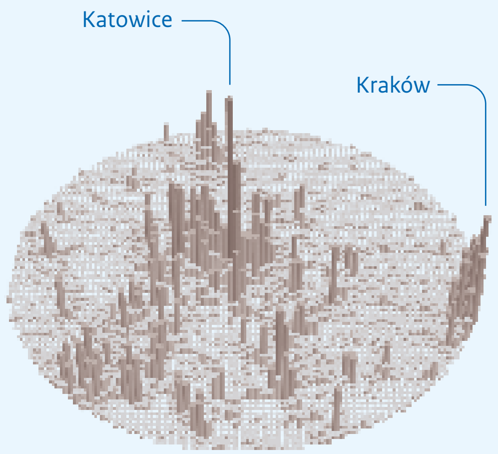
Spatial design and development determine options for a resilient development
Regardless of the type of landscape, the physical structure of a city is an important feature shaping its water and climate challenges and the types of spatial measures that can be used in future strategies. As to water and climate, the spatial structure defined by the amount of open space – including blue and green areas – versus the size of the built-up area of varying levels of density, strongly influences the applicability of potential spatial measures.

Four examples of the spatial pattern of urbanisation
Shaping the context for future strategies to improve water services and reduce water- and climate-related risks

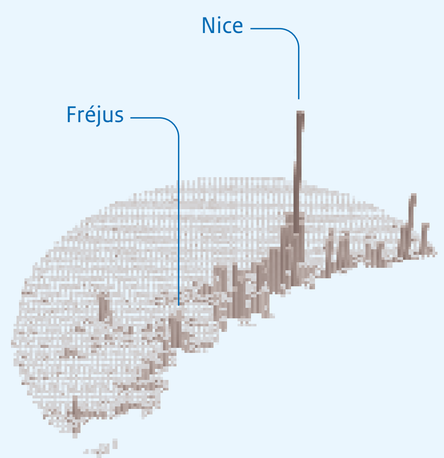
Monocentric urban pattern
Bucharest (Romania)



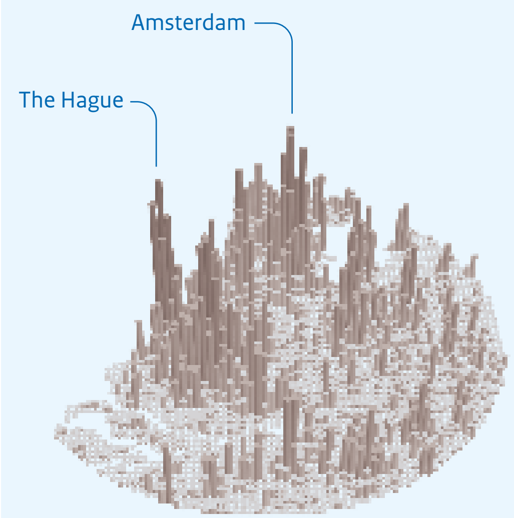
Dispersed urban pattern
Upper Silesia (Poland)



Linear urban pattern
Côte d'Azur (France)



Policentric urban pattern
Randstad (Netherlands)



Source: PBL

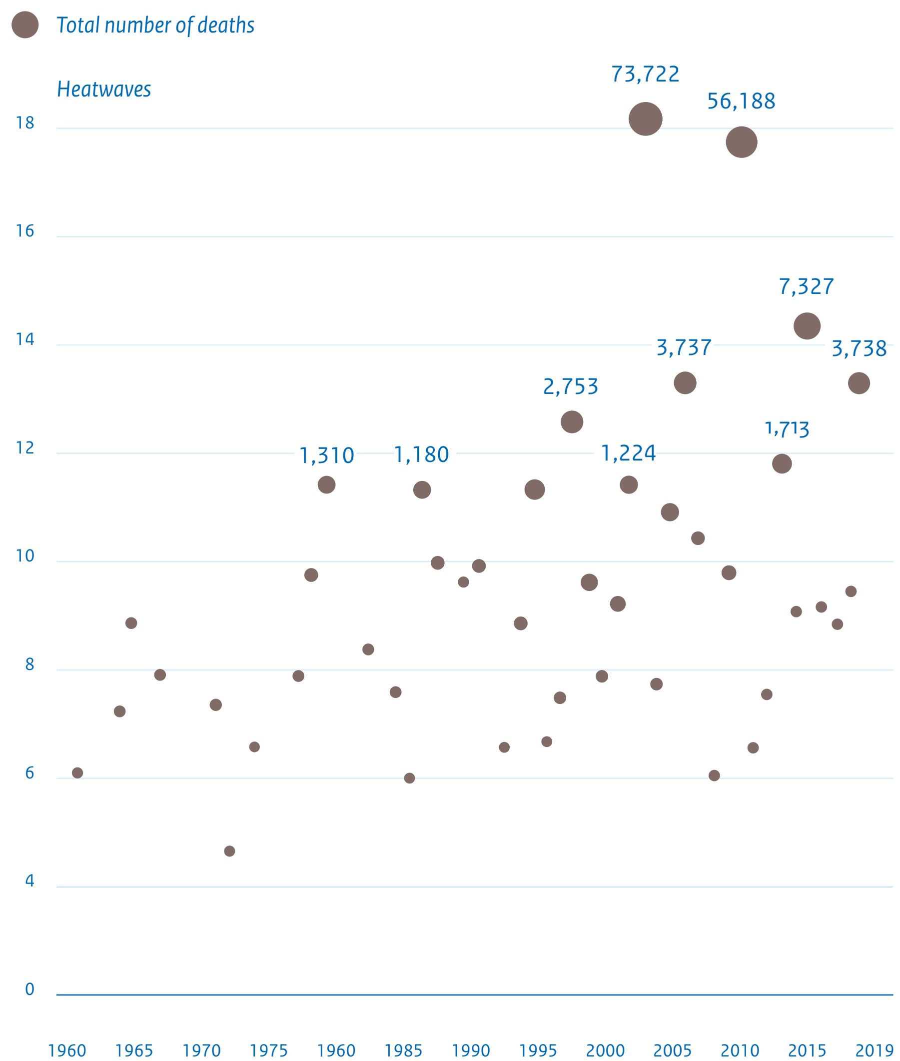
HEAT ISLANDS: ADDITIONAL CLIMATE STRESS IN CITIES

Cities also face higher temperatures than the surrounding rural areas, which is known as the heat island effect. In reducing water- and climate-related risks, cities simultaneously need to address the heat challenges and explore potential synergies, such as in blue-green infrastructural measures.

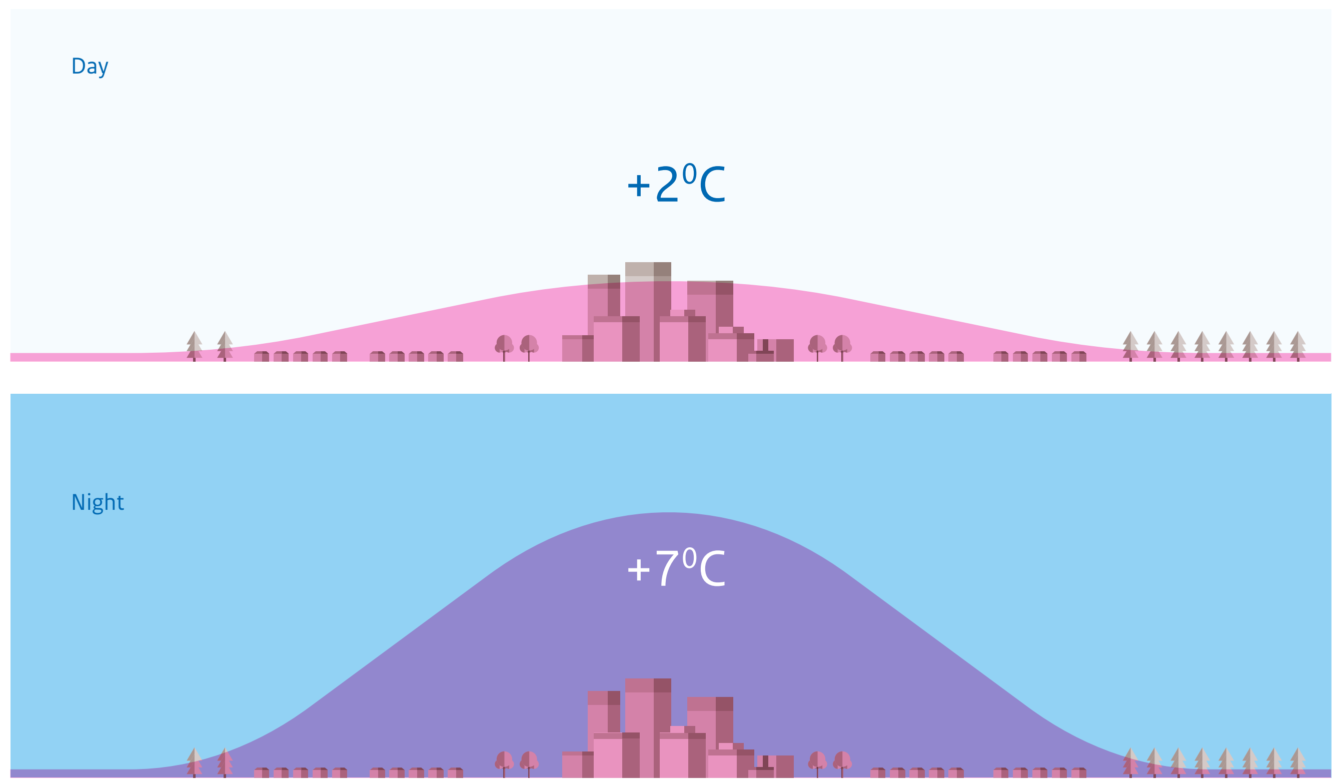
Heatwaves increase suffering and death
Increasing high temperatures are one of the more deadly consequences of global warming. Heatwaves increase mortality, in particular for vulnerable people, as well as overload energy grids, disrupting the electricity supply at times when people most need air conditioning or fans to survive in their overheated homes. Unprecedented heatwaves have scorched many parts of the world, in recent years, with record-shattering temperatures that have defied the expectations derived from climate models.

Source: United Nations Office for the Coordination of Humanitarian Affairs, the International Federation of Red Cross and Red Crescent Societies, and the Red Cross Red Crescent Climate Centre, 2022.

The global number of heatwaves and heatwave-related mortality, 1960–2019



Urban heat island effect increases mortality
The urban heat island effect is the phenomenon whereby the asphalt and concrete in cities trap an amount of heat during the day that is not fully released again during the night, causing cities to be warmer than the surrounding rural areas. In particular, the relatively high temperatures at night increase heat-related mortality, as people are unable to recover from the heat they experience during the day. In addition to water-related challenges and risks, increasing heat poses a serious additional climate challenge for cities. At the level of physical measures, green and blue infrastructure can contribute to reducing water-related risks, improving water conservation and reducing the heat island effect.



Source: Zhou et al., 2013; Schlünzen and Bohnenstengel, 2016; Huang et al., 2019

CONSERVING BLUE AND GREEN INFRASTRUCTURE IN FAST GROWING CITIES

Open spaces for water and vegetation can serve as blue and green infrastructure in cities and are of increasing importance in protecting cities against the impacts of climate change. Fast growing cities in Africa face the challenge of retaining sufficient areas of open space for blue and green infrastructure in the future.

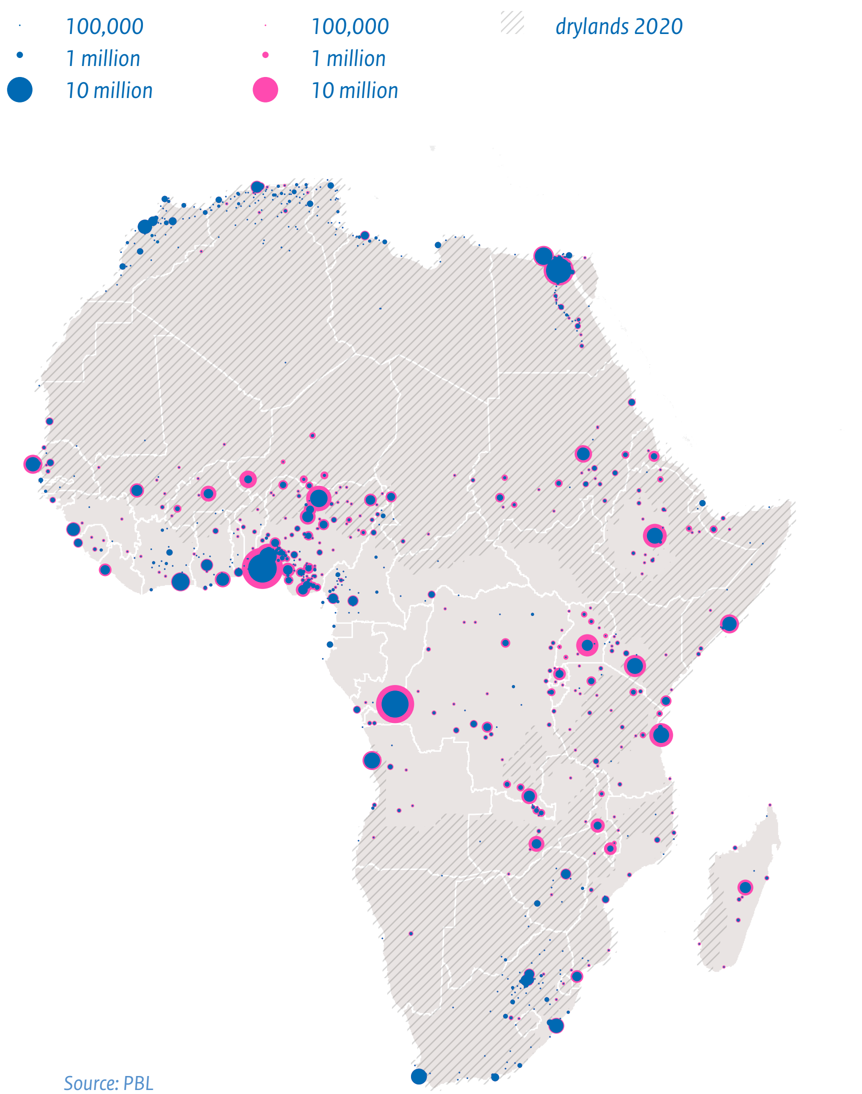
Blue and green open spaces should be cherished

Africa, especially, faces an unprecedented level of urbanisation, with cities projected to grow from a total of 370 million inhabitants in 2020 to 967 million by 2070 – a 162% growth.

Blue and green infrastructures in cities are water bodies and vegetated areas that can play a vital role in making cities water-robust and climate-proof, when integrated as essential elements in urban design. Blue and green open spaces are of increasing importance in reducing the impact of climate change. These areas are important for water storage during downpours and for water infiltration to recharge groundwater systems (i.e. sponge cities). Parks and trees temper the heat island effect.

Blue and green areas, in general, contribute to the quality of the living environment.

Fast growing cities in Africa

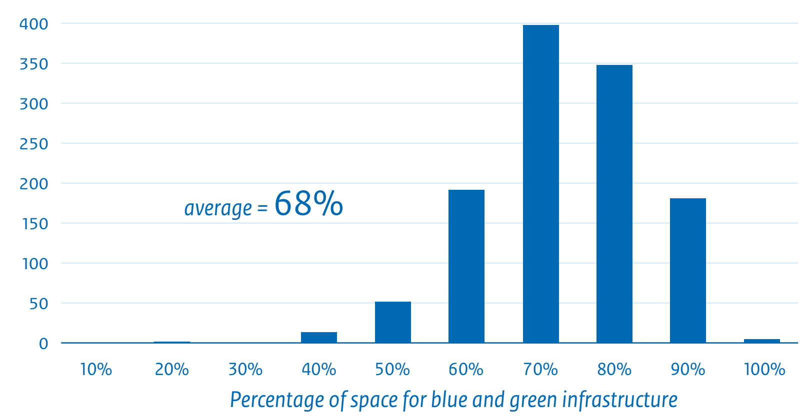


Source: PBL

Situation still favourable in many African cities

The urban footprint of cities constitutes the built-up area and the open land area in-between. An explorative statistical analysis for 1,190 African cities shows that, on average, these cities today include 68% of open space within their urban footprint area. Maintaining or creating sufficient blue and green infrastructure in the urban environment is a viable solution to protect cities against the impacts of natural hazards. Blue and green areas can store and absorb water and provide water and cool air during periods of heat and drought.

Percentage of open space for blue and green infrastructure in 1,190 African cities.

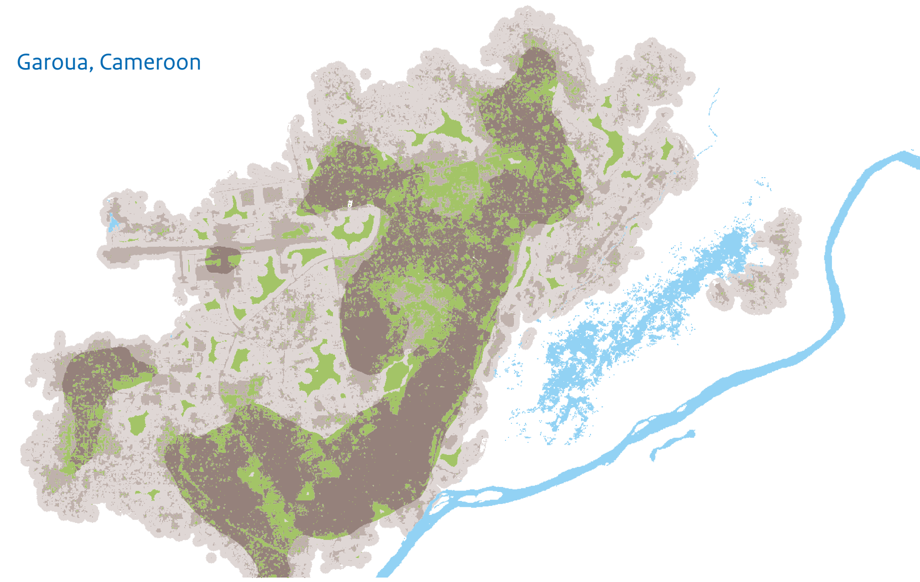


Source: IHE Delft

Preventing a Business-as-usual development

Under a Business-as-usual scenario, open and blue/green spaces tend to turn into built-up areas in fast growing cities. Under a High ambition pathway, the potential value of open and blue/green spaces should be acknowledged and adequately integrated in the future planning of horizontal and vertical urban development.

Open spaces in the city of Garoua (Cameroon) consist predominantly of large, vegetated clusters, a positive feature in the light of climate change



Urban built-up area
Suburban built-up area
Urban footprint
Captured open land
Water

Source: IHE Delft

BENDING THE TREND: A MULTI-FACETED DESIGN CHALLENGE

Bending the trend of increasing water- and climate-related risks in the urban environment is a phenomenal challenge. However, the high dynamics in the built environment and planned investments may provide a promising context for addressing these risks.

Urgent need to transform urban development
Globally, cities are pivotal areas of investments in vital sectors, urban development, infrastructure and industries. In 2018, the World Economic Forum estimated that, up to 2050, an annual USD 2.7 to 3.7 trillion will be invested in urban development. These investments will take place on less than 1% of the global area (p. 146). If these investments are being done in an innovative, green and inclusive manner, there is an unique opportunity to bend the trend.

Inclusive urban development: a major challenge
Today, there are about one billion people living in urban slums, often in the most risky locations (i.e. flood-prone areas near rivers and coasts) and/or with low-quality water services (i.e. water supply, wastewater treatment, exposure to polluted water). Reducing inequality in cities with respect to accessibility to adequate water services and protection against water pollution and flood risks is one of the major challenges on the path towards 2070.

Bending the trend in urban development

Starting conditions

- Position in the landscape
- Water- and climate-related challenges
- Age and quality of water infrastructure
- Adaptation deficit (flooding, drought, heat)
- Distribution of risks formal/informal city
- Demography
- Economic assets

Designing an adaptive future strategy

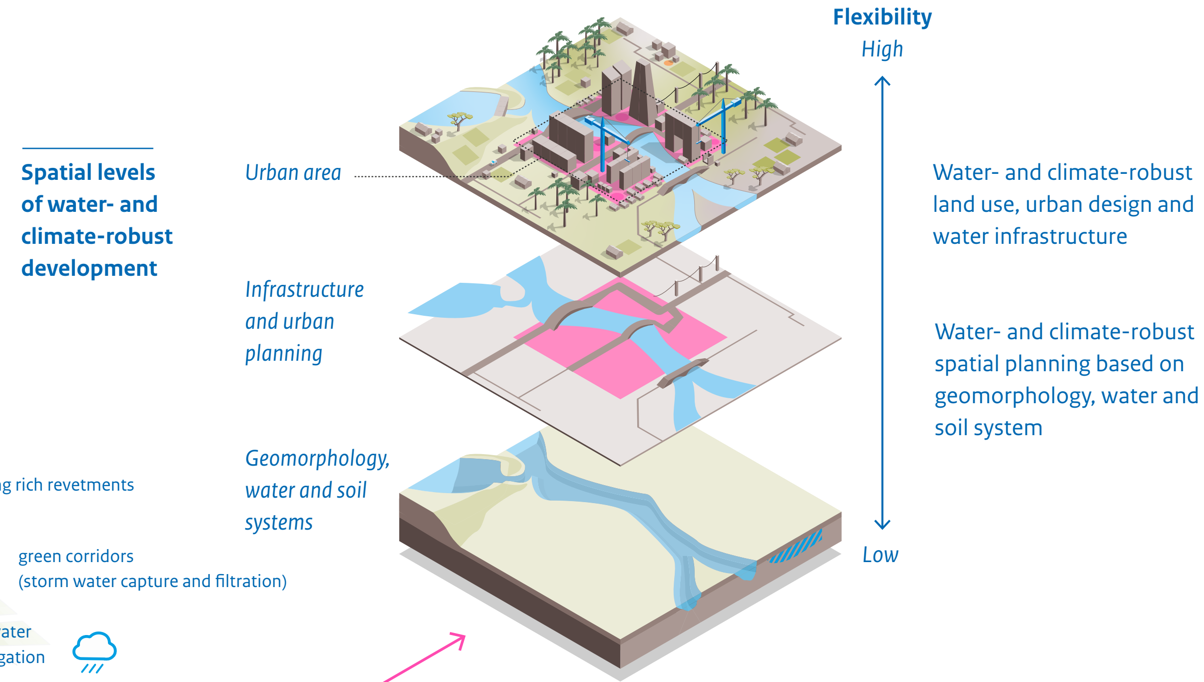
- Urban structure and densities
- Water- and climate-robust infrastructure
- Adequate water supply, sanitation and wastewater treatment
- Reducing water- and climate-related risks (flooding, drought, heat)
- Reducing inequalities formal/informal city
- Blue and green infrastructure

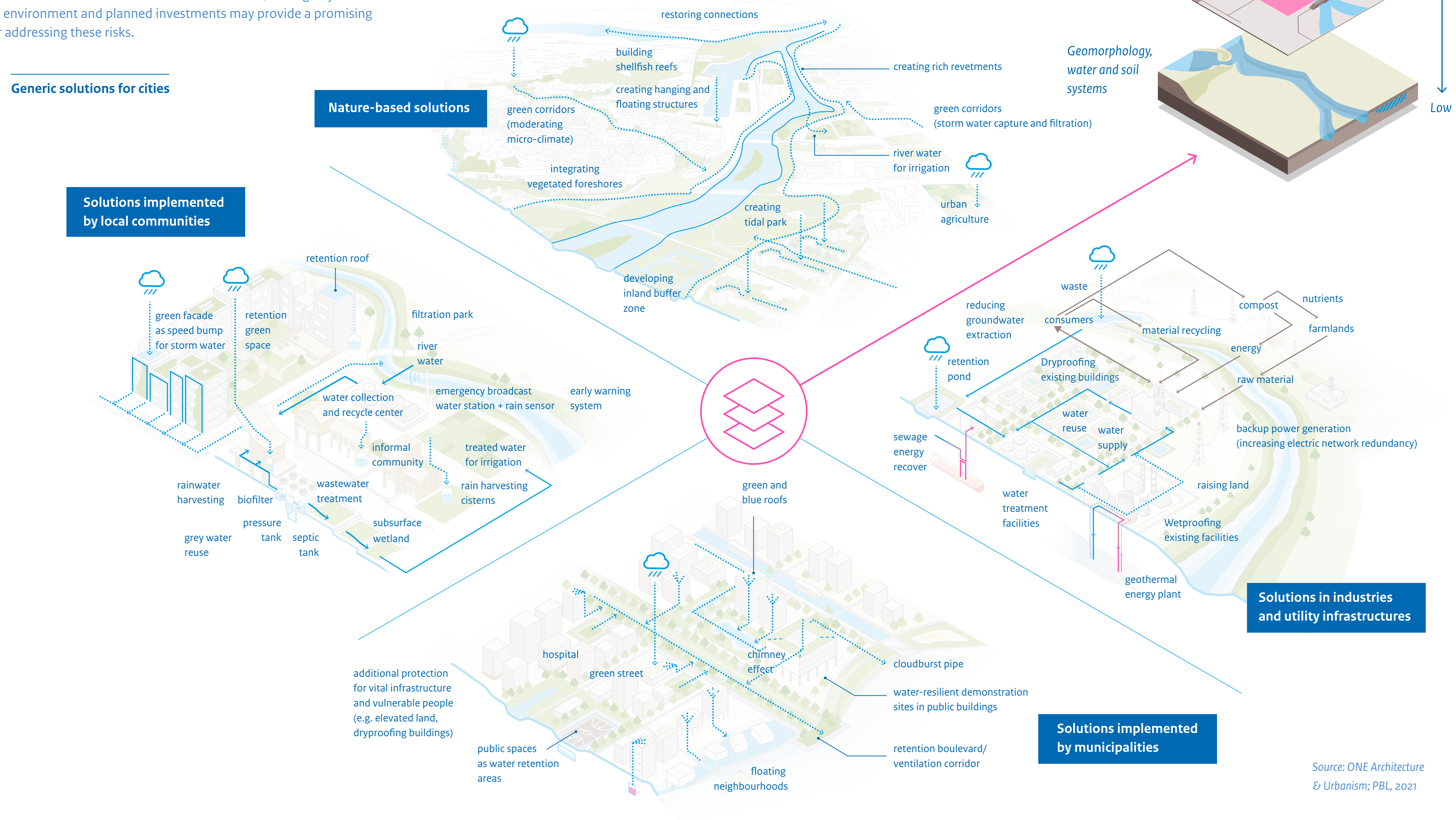
Integration of water- and climate-related risk strategy in urban development

Source: PBL

TAILOR-MADE SOLUTIONS IN THE URBAN ENVIRONMENT

It will be a phenomenal challenge to bend the trend of increasing water- and climate-related risks in the urban environment. However, the high dynamics in the built environment and planned investments may provide a promising context for addressing these risks.





Source: ONE Architecture & Urbanism; PBL, 2021

Integrated long-term plan for water- and climate-robust development

Mainstreaming the improvement in water services and climate adaptation in urban development calls for due attention in any development plan within the urban environment. To support the transition and motivate all sectors to address the water- and climate-related challenges in their work, an integrated approach and plan will be required, ranging from water- and climate-robust urban development on a city scale and determined by the physical geographical context, to the required design of neighbourhoods and buildings. While these are relatively flexible and can be adapted or even completely changed during reconstruction projects, the geomorphological and structural layout of cities has a low flexibility for adaptation strategies.

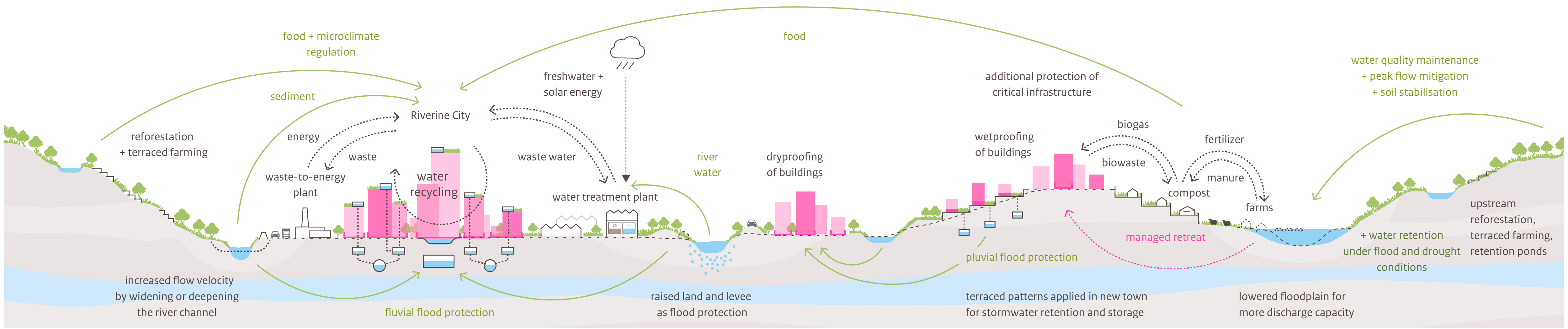
THE DESIGN CHALLENGE IN RIVER LANDSCAPES

For cities in river landscapes, it is vitally important to be aware of upstream developments influencing water and sediment dynamics and urban water quality, as well as the downstream impacts of cities themselves.

The city in upstream and downstream context
The river city landscape highlights the city itself, the peri urban areas and upstream–downstream interactions as key issues of water management.

In all zones, preserved green spaces provide a buffer for urban development, filter stormwater runoff, allow for local food production, and regulate the micro-climate. At the same time, it is of vital importance to be aware of cities' vulnerability to upstream developments affecting water availability and water quality for the urban population, and to be prudent about the downstream effects of these cities' own water use.

Cities in river landscapes: overview of potential measures

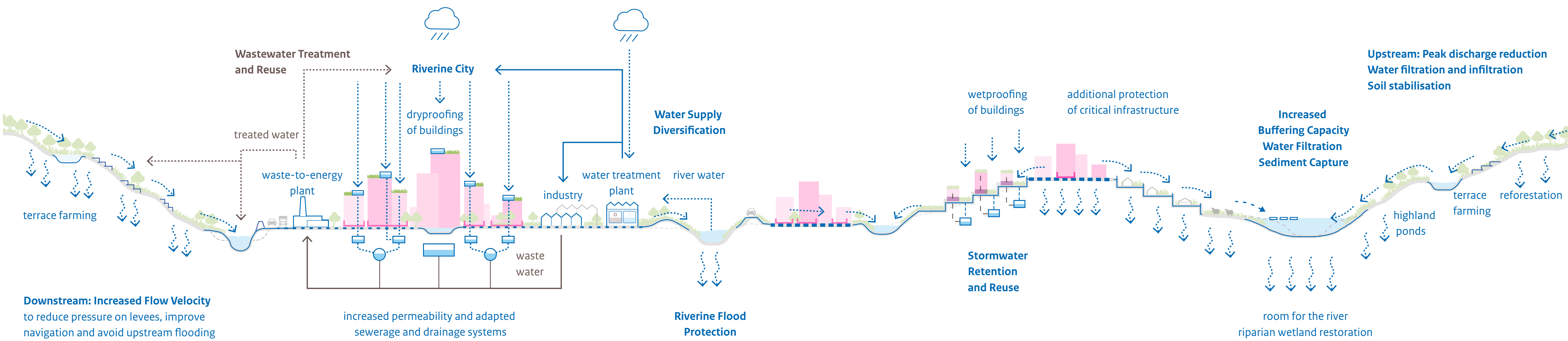


Systemic solutions for urban development and climate change

Occupation layer
Land use
Green infrastructure

Network layer
Grey infrastructure

Underground layer
Geomorphology, water and soil systems



Water Management Strategies

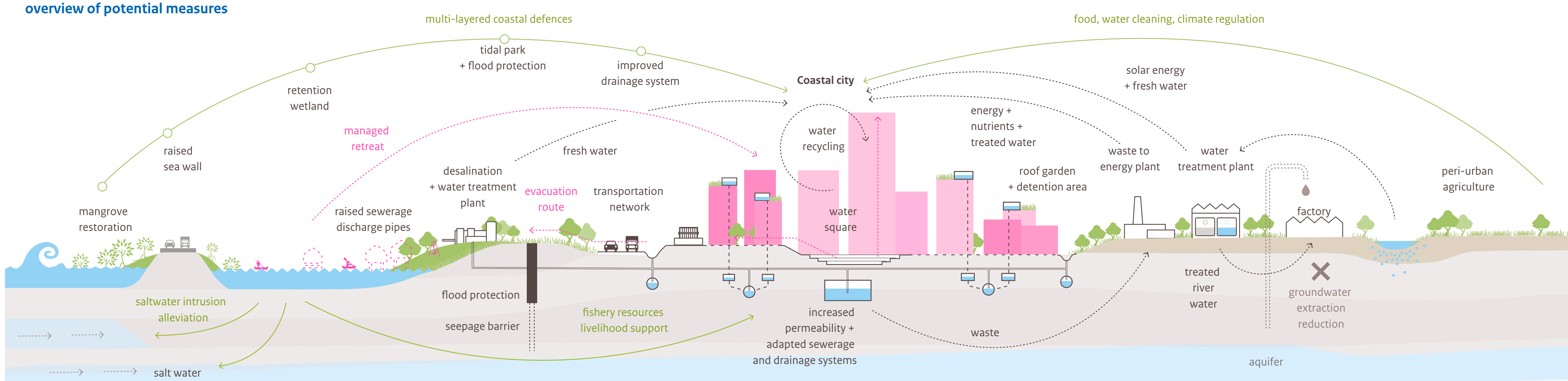
Waste water
Reused water
Water supply
Storm water/river water

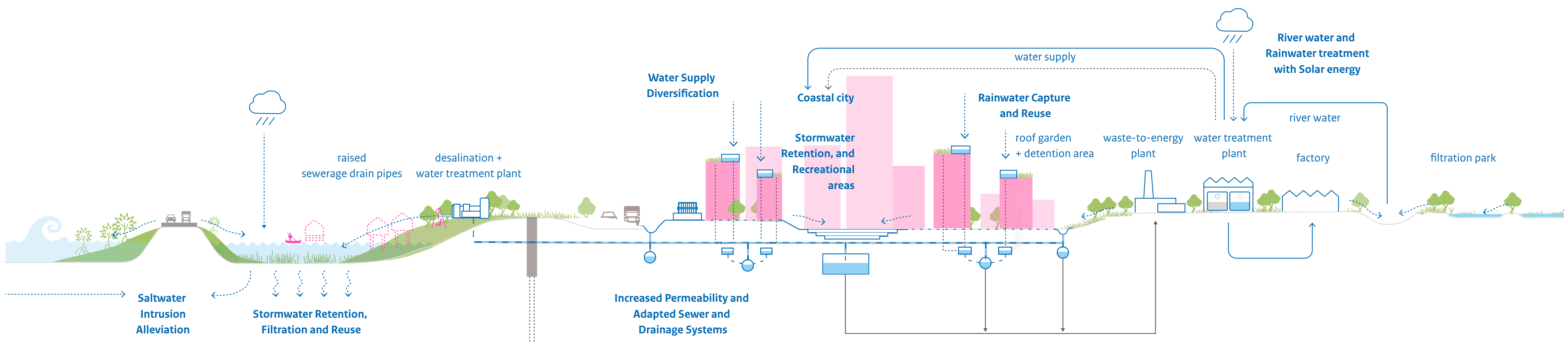
Source: ONE Architecture & Urbanism; PBL, 2021

THE DESIGN CHALLENGE IN DELTAS AND COASTAL ZONES

The major challenge for cities in deltas and coastal zones is that of managing the threat of sea level rise while improving water security and living conditions for the urban population. A high ambition approach will be needed, geared to restoring the natural processes as much as possible.

Cities in deltas and coastal landscapes: overview of potential measures





Cities threatened by sea level rise, subsidence and reduced water and sediment flows
Deltas and coasts are highly dynamic systems, shaped by local human interventions, upstream developments affecting water and sediment flow and water pollution, and the impacts of tidal action and waves. Management of subsidence and sediment dynamics is critical and ongoing sea level rise will challenge the limits of coastal protection systems. Inadequate strategies may result in the necessity to plan for a retreat. Bending the trend calls for using combinations of techniques and nature-based solutions, and restoring natural processes as much as possible.

Systemic solutions for urban development and climate change

Occupation layer
Land use
Green infrastructure

Network layer
Grey infrastructure

Underground layer
Geomorphology, water and soil systems

Water Management Strategies

Waste water
Reused water
Water supply
Storm water/river water

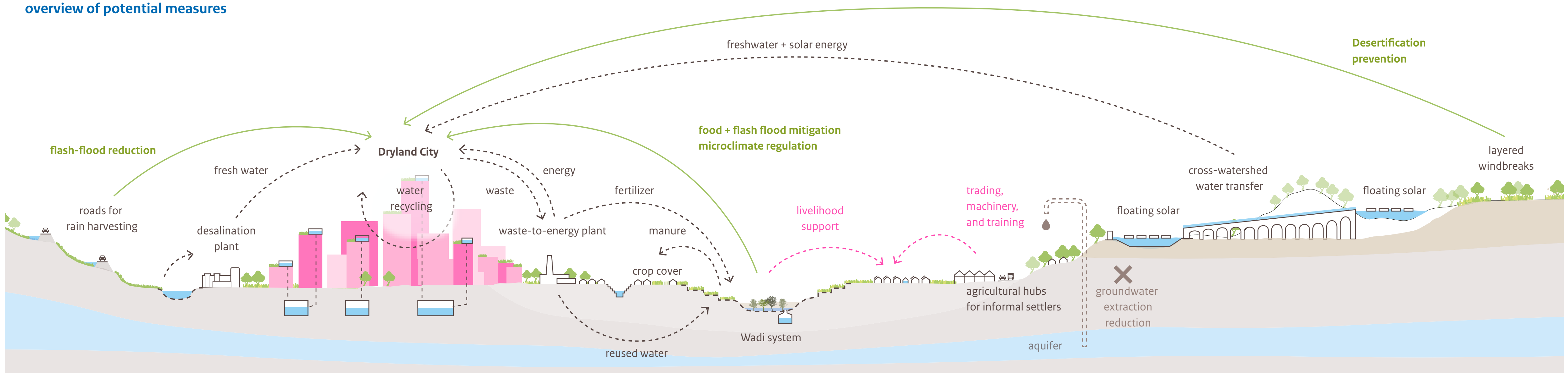
Source: ONE Architecture & Urbanism; PBL, 2021

THE DESIGN CHALLENGE IN DRYLANDS

Improving water security and reducing heat risks are the most prominent challenges for dryland cities. The High ambition pathway includes interaction into the rural areas to improve water and food security, access to services, and to facilitate in- and out-migration.

The city in a water scarce environment
A water management strategy for dryland cities is focused on securing water availability and efficient water use. The strategy must leverage the occasional occurrence of ‘too much’ water with a wide variety of measures to alleviate the times of ‘too little’ water, while improving sanitation, wastewater treatment and safe reuse systems to further improve human health conditions and water security. Constructive interaction between the cities and the rural environment can contribute to increased water and food security for both urban and rural populations, while reducing local conflict risks. Dryland cities inland differ markedly from dryland cities along rivers or coasts.

Cities in dryland landscapes: overview of potential measures

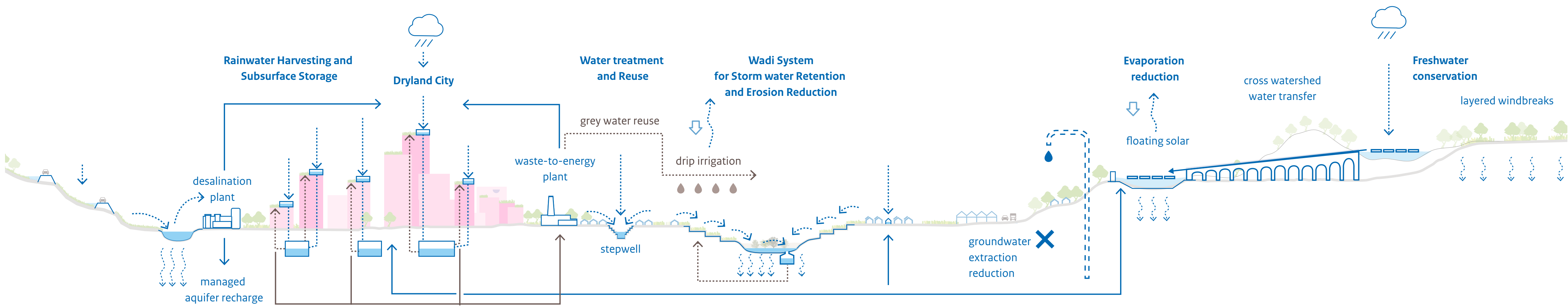


Systemic solutions for urban development and climate change

Occupation layer
Land use
Green infrastructure

Network layer
Grey infrastructure

Underground layer
Geomorphology, water and soil systems



Water Management Strategies

Waste water
Reused water
Water supply
Storm water/river water

Source: ONE Architecture & Urbanism; PBL, 2021

THE VALUE OF WATER – SUPPORTING THE SDGs

Reducing water- and climate-related risks is projected to contribute in many ways to achieving the SDGs in all hotspot landscapes. A major challenge will be addressing inequality in future strategies.

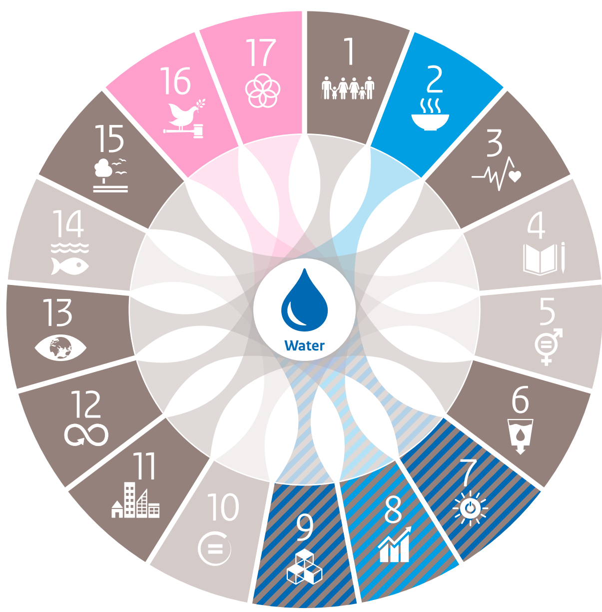
Projected improvement 2070 compared to 2020
- *based on quantified indicators*
- *qualitative appreciation*

Projected deterioration 2070 compared to 2020
- *based on quantified indicators*
- *qualitative appreciation*

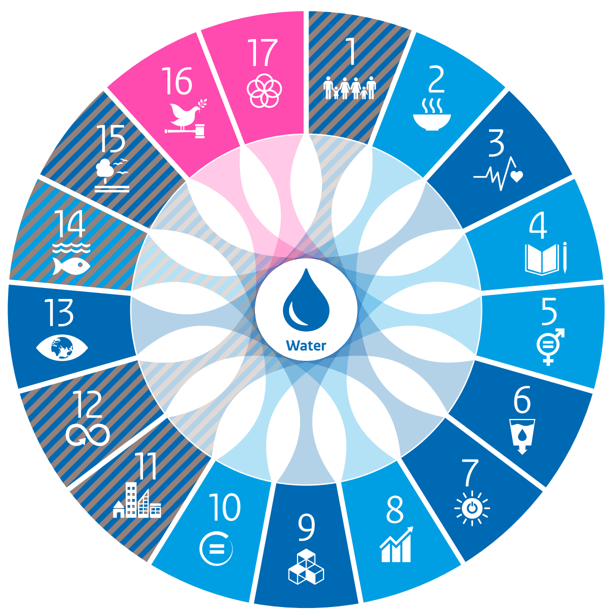
Important condition for transition
- *assumed to be fulfilled*
- *assumed not to be fulfilled*

partial improvement, partial deterioration or standstill 2070 compared to 2020

SDGs, Business-as-usual scenario 2070



SDGs, High ambition pathway 2070



The main differences in impact of the High ambition pathway on cities, compared to the Business-as-usual scenario

1	Only a small increase in the number of people annually exposed to flooding and reduced climate vulnerability and improved livelihood conditions in drylands.
2	A much higher level of self-sufficiency as a result of a larger crop production increase (100% vs 20%).
3	Improvement in sanitation and wastewater treatment, improved local crop production and a higher level of flood protection improve human health and well-being.
4	Improvement in sanitation and wastewater treatment, improved food security and a higher level of flood protection reduce the risk of disruption to educational processes and facilities.
5	Safer living conditions for women and girls because of higher water availability, improved local crop production and security, and lower flood risk.
6	Strong improvement in sanitation and wastewater treatment and a reduction in the risk of water pollution by flooding.
7	Lower risk of energy supply disruption due to flooding, under a 70% increase in hydropower production.
8	The higher GDP per capita is associated with a lower risk of local economic disruption by subsidence, flooding, drought and heat.
9	Innovations in industry and infrastructure are also focused on water use efficiency, reuse systems, reducing subsidence and a water- and climate-robust urban design.
10	Reduced inequalities in the access to water services and in the distribution of water- and climate-related risks as a result of dedicated policies, especially supporting SDG1.
11	Contribution to sustainable development of cities and communities by reducing subsidence, improving flood protection, sanitation and water use efficiency, and by conserving and developing blue and green infrastructure.
12	Greater water use efficiency and less environmental impact contributing to achieving the goal on responsible consumption and production.
13	Mainstreaming the adaptation to climate change in the improvement in water services and the reduction in water- and climate-related risks in urban development.
14	Reducing the increase in nutrient emission levels (from 48% to 25%) and including nature-based solutions as part of coastal flood protection.
15	Reducing the increase in nutrient emission levels (from 48% to 25%) and including blue and green infrastructure as part of urban development and flood control.
16	Strongly improved institutional capacity and performance with respect to water services and risk reduction, integrating adaptation in urban development and reducing inequalities.
17	Effective collaboration between public, private and societal actors and local communities results in new partnerships and coalitions supporting innovation and transformation.

3
THE GLOBAL PICTURE

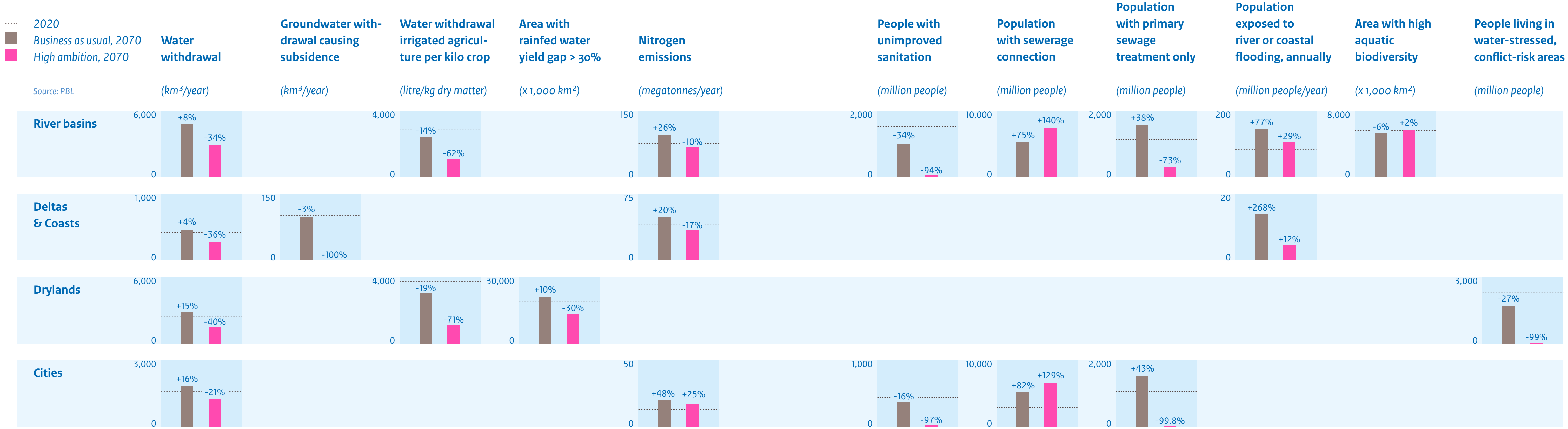
THE HIGH AMBITION PATHWAY MAKES THE DIFFERENCE

The water- and climate-related risks in the four hotspot landscapes can structurally be reduced under a High ambition pathway. Restoring the ecological quality of rivers and lakes lags behind, due to the high pressure of already existing dams and the still high level of nutrient emissions by 2070.

Water- and climate-related risks can be structurally reduced
This overview summarises the projected gains between 2020 and 2070 for the four hotspot landscapes — explored in Part II. The overview shows that the impact of human activities on water- and climate-related risks can be structurally reduced on a global scale, ranging from river and coastal flooding, water use and crop production in vulnerable dryland regions to subsidence in deltas and low-lying coasts. However, even under our High ambition pathway, the risks of river flooding and of cities' nutrient emission levels are projected to be higher in 2070 than in 2020, due to population growth and economic development. In combination with improved governance, the migration and local conflict risks in dryland regions and the transboundary conflict risks are projected to decrease.

Pressures on ecological quality remain high
While there are large regional differences, on a global scale, the ecological gains of the various ambition pathways are limited. The pressures on river systems also remain high under the High ambition pathway; the reduction in nutrient emissions to rivers and lakes and the ecological solutions for hydropower barely compensate for the projected loss under the Business-as-usual scenario. These findings suggest that more fundamental interventions will be required for substantial ecological restoration, such as increasing mitigation efforts to combat global warming, additional wastewater treatment systems, reduction in cropland area in combination with structural changes in human protein consumption to reduce nutrient emissions, and dam removal and large-scale wetland restoration to restore natural ecosystem dynamics.

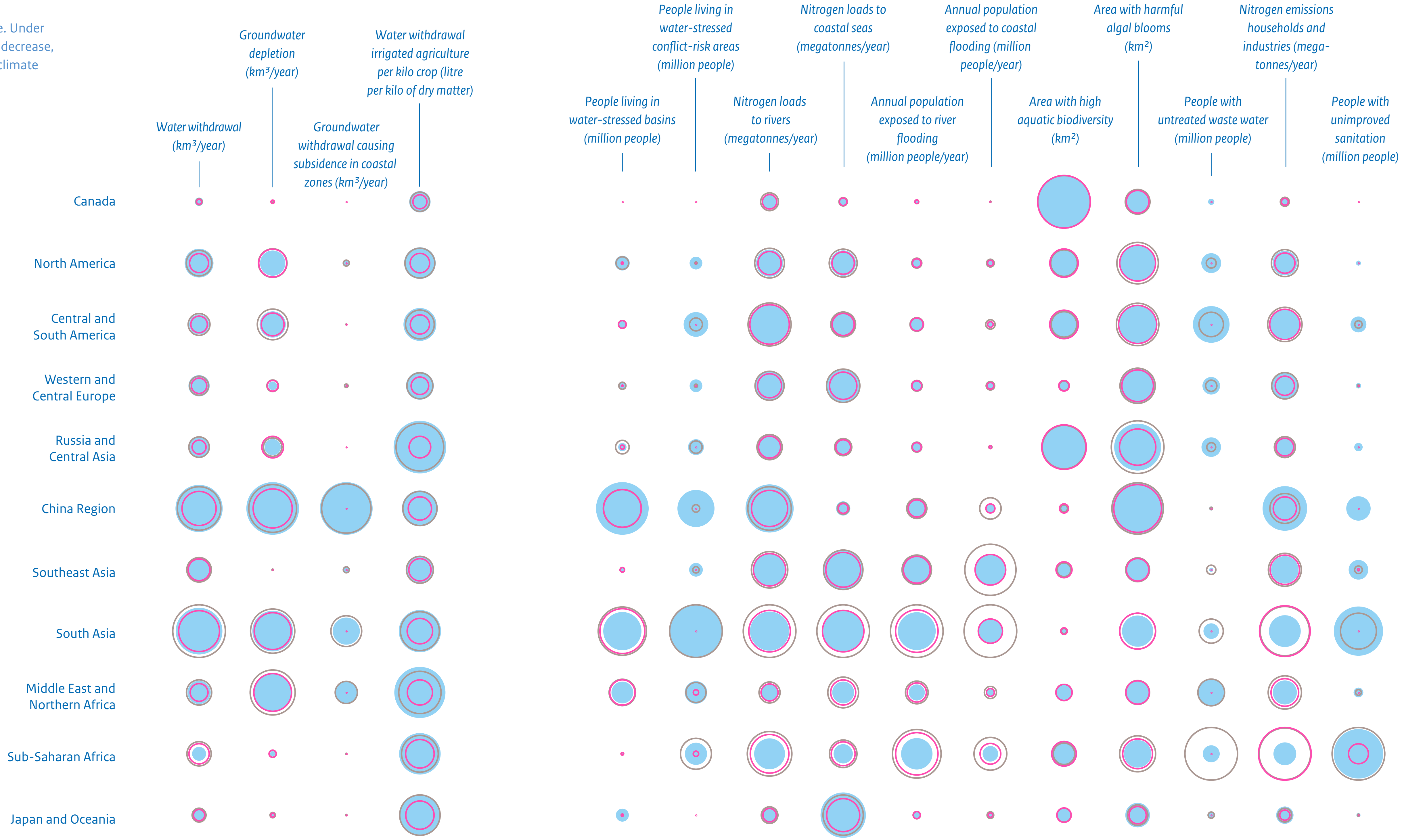
Selection of global water and climate challenges



LARGE REGIONAL DIFFERENCES

The water- and climate-related risks vary widely across the globe. Under the High ambition pathway, these risks are projected to strongly decrease, also in regions with relative high socio-economic pressures and climate vulnerabilities.

Under the High ambition pathway, the most substantial improvements are projected for South Asia, Sub-Saharan Africa, Northern Africa and Central and South America, and to a lesser extent, the Middle East. The potential increase in crop production while improving water management in especially Sub-Saharan Africa can be a major achievement in improving livelihood conditions and reducing climate vulnerability, migration and conflict risks. Groundwater abstraction and the resulting subsidence and flood risk can be structurally reduced, in many regions. For most regions, nutrient emissions to coastal waters will decrease because of reduced emissions to the rivers and natural retention processes in the upstream river basins. In combination with nature-based solutions, such as mangroves for coastal flood-risk reduction, this decrease will improve the ecological conditions for coastal seas.



2020

Business as usual, 2070

High ambition, 2070

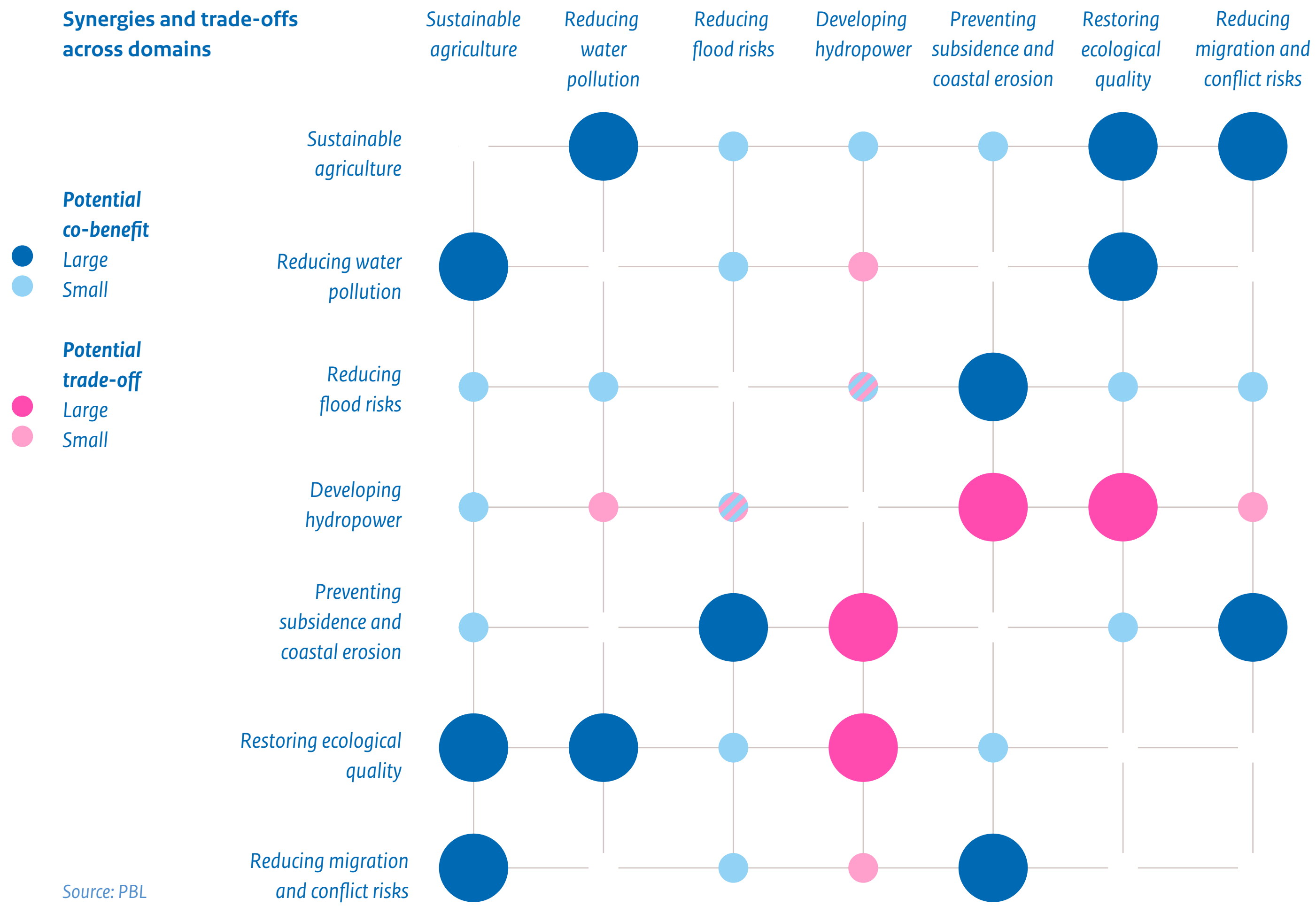
Source: PBL

MANY SYNERGIES – AND A WICKED PROBLEM

Under the High ambition pathways, there are many synergies in different domains, as well as sharp trade-offs — and a wicked sustainability problem — between further hydropower development and ecological quality and coastal erosion.

The High ambition pathways in this study show that adopting integrated approaches and systemic policies can result in adequately reducing trade-offs and creating many synergies between transformations across domains. Following the Paris 2015 Agreement, the pressure to strongly increase the renewable energy production, however, can have serious negative effects on ecology and sediment dynamics if this leads to a boost in hydropower development and the building of many more dams.

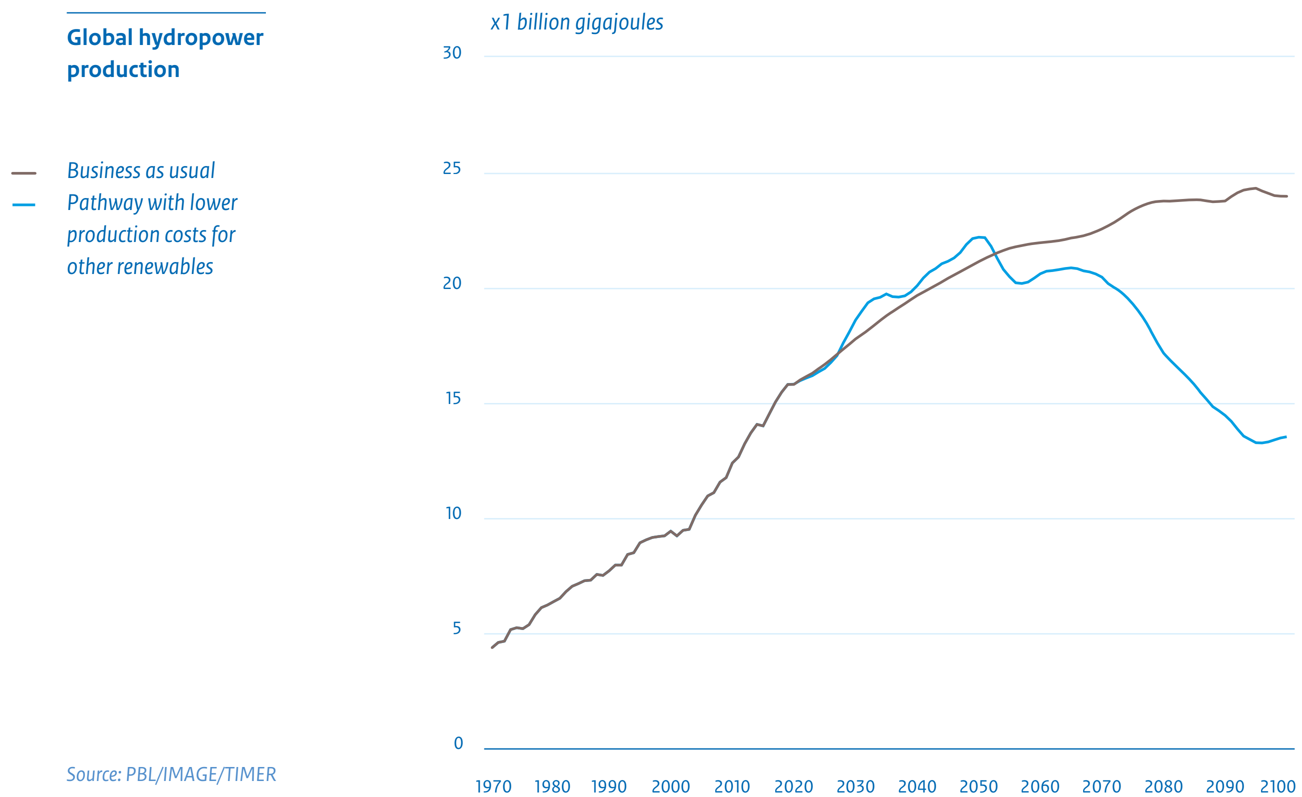
Synergies and trade-offs across domains



Source: PBL

A wicked problem: reconsidering hydropower?
The serious negative consequences of dams may warrant reconsidering the need for new dams, as a decrease in hydropower may be met by an equal increase in other renewables, especially solar energy. However, this varies per region. Some regions are more dependent on hydropower than others. Small-scale hydropower facilities can be the solution to the major adverse impacts of large dams, including them disturbing the continuity of water and sediment flows and fish migration as well as the resulting social disruption.
The demand for hydropower under the Business-as-usual scenario (SSP2/RCP6.0) is projected to gradually increase from the current 16 billion GJ/yr to almost 25 billion by 2100. Projections depend on assumptions about the future costs of electricity generation, however. If the costs of solar power, for instance, would drop faster than assumed, solar power may outcompete hydropower by 2050 and – as a result – the demand for hydropower by 2080 would drop to about current levels.

Global hydropower production



Source: PBL/IMAGE/TIMER

WATER-RELATED AMBITIONS STRONGLY SUPPORT THE SDGs

Reducing water- and climate-related risks is projected to contribute to the SDGs in many ways, in all hotspot landscapes. Addressing inequality in future strategies will be a major challenge.

The Global Picture of the main differences in impacts between the High ambition pathway and the Business-as-usual scenario, for the four hotspot landscapes combined

SDGs, Business-as-usual scenario 2070		SDGs, High ambition pathway 2070
1	The increase in GDP per capita is associated with a reduction in potential drivers of poverty, such as people's reduced vulnerability to water- and climate-related risks across the hotspot landscapes, and the limited increase in damage and number of people affected by flooding.	1
2	Food security is improved and climate vulnerability reduced, by increased crop production (100% vs 20%) and improved food self-sufficiency in especially drylands, under sustainable agricultural intensification and improved water management.	2
3	The limited increase in the number of people affected by flooding, reduced climate vulnerability and improved food security for dryland populations, and improved sanitation and wastewater treatment, contribute to improved human health and well-being.	3
4	Reduction in the number of children exposed to water-borne diseases and in the number of schools exposed to flood risk, thus improving children's health and reducing disruptions to educational facilities.	4
5	Safer living conditions for women and girls, in particular because of improved water supply and sanitation, increased food production and lower flood risk.	5
6	Strong improvement in sanitation and wastewater treatment and reduction in the risk of water pollution caused by flooding result in improved human health and living conditions for the poor, in particular.	6
7	Hydropower is projected to strongly increase, while the improved flood protection strategy results in a structurally lower risk of flooding disrupting and damaging the local energy supply and distribution systems.	7
8	Higher GDP per capita is associated with lower climate vulnerability due to strongly improved water use efficiency in agriculture, households and industries, and a lower risk of local economic disruption due to flooding and drought.	8
9	Innovations are geared to improve water use efficiency, reduce polluting missions to water and to water- and climate-robust design, including nature-based solutions, improving the living environment as well as ecological quality.	9
10	Dedicated policies result in reduced inequalities in the access to water services and in the distribution of water- and climate-related risks, particularly supporting the SDGs 1 to 6.	10
11	The development of sustainable cities and communities is supported by reducing subsidence, developing blue and green infrastructure, and by improving flood protection, sanitation and wastewater treatment, water use efficiency and local food security.	11
12	Greater water use efficiency and reduced nutrient emissions to water result in less environmental impact, contributing to achieving the goal on responsible consumption and production.	12
13	Mainstreaming and implementation of adaptation strategies and measures across the hotspot landscapes, reducing the risks of flooding, drought, long-term sea level rise, heat and ecological deterioration.	13
14	Avoiding the adverse impacts of new dams and increased nutrient emissions to coastal seas by installing ecosystem-friendly hydropower facilities, reducing nutrient emissions and implementing nature-based flood protection.	14
15	Halting a further loss of freshwater biodiversity and improving water flow to and ecological quality of deltas and coastal zones by ensuring ecosystem-friendly hydropower facilities, less water use upstream, reduced nutrient emissions and — although to a limited extent — wetland restoration.	15
16	Strong improvement in the institutional capacity across scales enables effective river-basin and ecosystem-based approaches as the basis for long-term sustainable policies reduces local and transboundary conflict risks and unequal distribution of water- and climate-related risks.	16
17	Effective collaboration between public, private and societal actors and local communities results in new partnerships and coalitions working on the SDGs and supporting innovation and transformation.	17

Projected improvement 2070 compared to 2020:
- *based on quantified indicators*
- *qualitative appreciation*

Projected deterioration 2070 compared to 2020:
- *based on quantified indicators*
- *qualitative appreciation*

Important condition for transition:
- *assumed to be fulfilled*
- *assumed not to be fulfilled*

partial improvement, partial deterioration or standstill 2070 compared to 2020

Source: PBL

THE WATER SECTOR CANNOT DO IT ALONE

Solutions to water- and climate-related risks cannot be found by working in silos. The required solutions in the hotspot landscapes call for developing broader narratives, for understanding and mastering complexity, and effectively involving various networks and layers of actors.

The functioning and quality of water systems strongly depend on land use, human activities and interventions to support economic developments

Source: PBL

Water supply infrastructure for agriculture, households and industries
- Reduce groundwater use and develop new freshwater resources
- Improve water use efficiency

Navigation and harbours
- Reduce pollution
- Reduce deepening of river stretches

Local communities
- Participation in development processes
- Livelihood perspectives
- Health and water securities
- Inequalities
- Cultural and social context

Construction/infrastructure sector
- Reduce sand mining demand by changing building practices
- Water-proof designs
- Integrate nature-based solutions

Cities and industries
- Reduce the use of groundwater and surface water
- Reduce polluting emissions
- Improve water conservation
- Reduce exposure to flooding
- Retain wetlands and green/blue spaces

Agricultural sector
- Reduce the use of groundwater and surface water
- Reduce polluting emissions
- Improve water conservation

Energy sector
- Develop the energy system based on renewables
- How many dams of which type where
- Adjust the construction and management of dams

Transnational collaboration
- Manage water use
- Reduce polluting emissions
- Manage high and low water flows
- Manage sediment flows
- Transnational adaptation strategies

Nature/biodiversity sector
- Conditions for nature and biodiversity goals
- Optimise ecosystem services
- Develop nature-based solutions

Connecting the dots
Goals and strategies with respect to improving the quality and functioning of water systems and adequately adapting to climate change and socio-economic developments need to be aligned with those in other sectors, both economic, ecological and social.

Connecting the dots will require new, integrative and collaborative approaches across sectors. The water sector cannot do this alone; this is an enormous challenge for all bureaucracies, private sectors, financing organisations and civil societies around the globe.

URGENT NEED FOR CLIMATE-ROBUST SOLUTIONS

The recent ‘extreme extremes’ of flooding events, droughts, wildfires and hurricanes have affected societies and economies beyond expectation and illustrate the urgency of robust solutions to water- and climate-related risks.

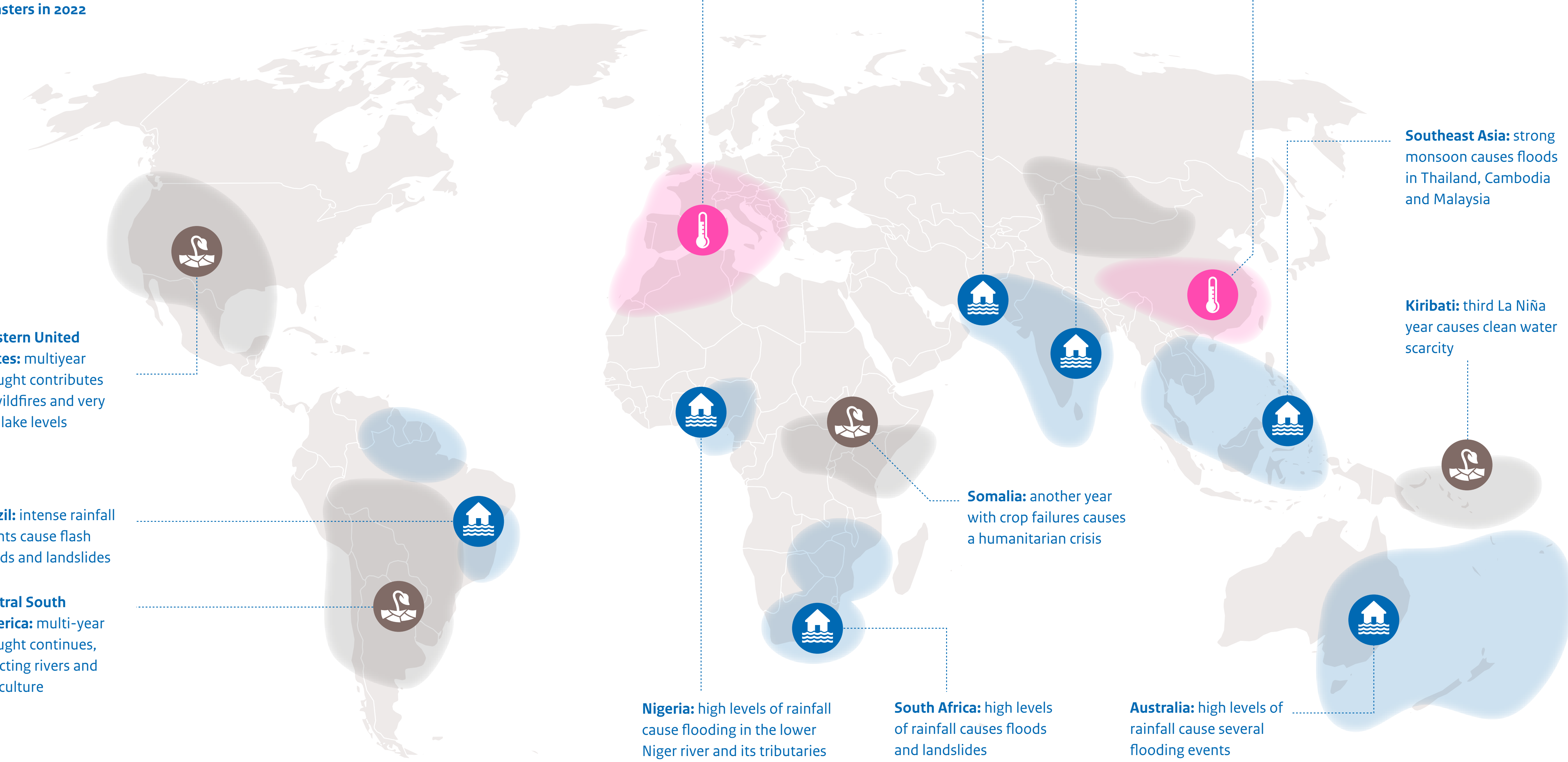
High level of urgency for structural water and climate adaptation strategies

Recent state-of-the-art research shows that tipping points may already be a possibility at current levels of warming and may become more likely within the Paris Agreement range of 1.5 °C to 2 °C maximum global warming. In this study, a gradual level of climate change underlies the future explorations towards 2070, but ‘extreme extremes’ are already happening and tipping points may interfere with this assumption.

Consecutive climate disasters require robust strategies

Countries are increasingly hit by different types of weather extremes, one after another; for instance, Pakistan that suffered under a heatwave and drought and some months later was hit by an enormous flood, affecting over 30 million people. Similar patterns have occurred in Australia, the United States, parts of Western Africa and Europe. These consecutive climate extremes increase the challenge of developing robust strategies to cope with water- and climate-related risks, today and in the future.

Major water-related disasters in 2022



Source: Global Water Monitor: Van Dijk et al., 2022

4
THE WAY FORWARD

BENDING THE TREND: CHANGING GEAR AND DIRECTION

The impacts of future developments around the world on our social, economic and ecological systems largely depend on political and societal decisions, values and regulations. Bending the trend with regard to future water challenges requires fundamental changes in water-related approaches, politics and economics.

From a Business-as-usual pathway to High ambition future pathways
We are living at the juncture of two epochs. The interrelated global water, climate and biodiversity crises show that current value systems, policies and economic practices are not suited to cope with the increasing pressures of socio-economic developments, and global warming on communities and ecosystems.

The world Is complex and water is not a silo. Given the complexities, there is no 'one size fits all' solution. Political will (a whole-of-government approach), and multiple cohesive actions across scales while engaging the society (a whole-of-society approach), will be required to break away from vested interests and business-as-usual developments.

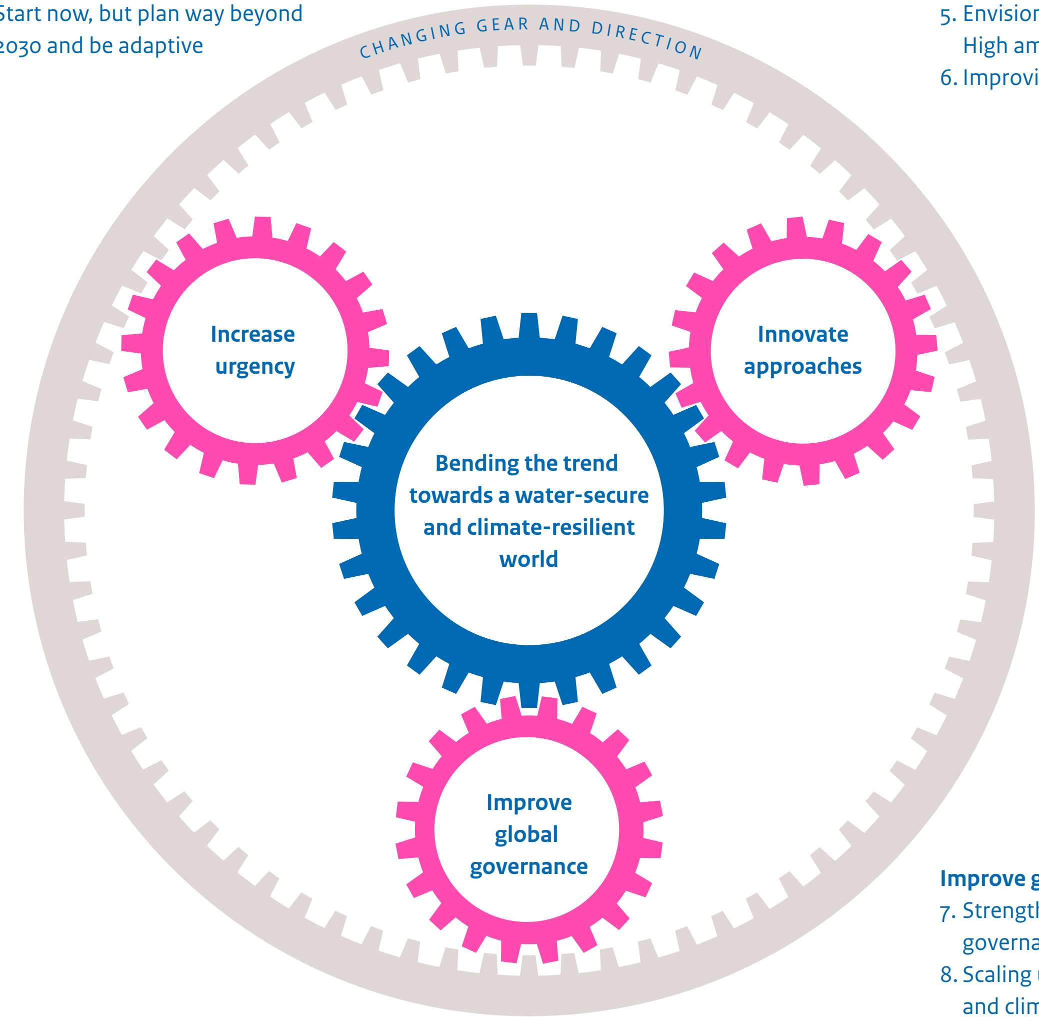
Three focus areas to bend the trend
Our study shows that, under a transformational approach and across the hotspot landscapes, the water- and climate-related risks can be managed much better than under a business-as-usual strategy (p. 168). This may also create opportunities for important contributions to the SDGs (p. 174).

We identify nine critical actions (turnarounds) to shift gear and guide the outcome of policy and investment strategies in the direction of water-secure, inclusive, climate-resilient and sustainable development.

These actions reflect three focal areas:
- increasing urgency
- using innovative approaches
- improve global governance

Increase the level of urgency
1. Acknowledge the importance and pivotal role of water
2. Valuing water: broaden the scope
3. Start now, but plan way beyond 2030 and be adaptive

Innovate approaches
4. Let water be leading: adopt a river-basin and ecosystem-based approach
5. Envisioning the future: develop High ambition pathways
6. Improving policy coherence



Improve global governance
7. Strengthening global water governance and capacity
8. Scaling up funding for water and climate adaptation
9. Building a shared water agenda and process to create perspective

Source: PBL

1

ACKNOWLEDGE THE IMPORTANCE AND PIVOTAL ROLE OF WATER

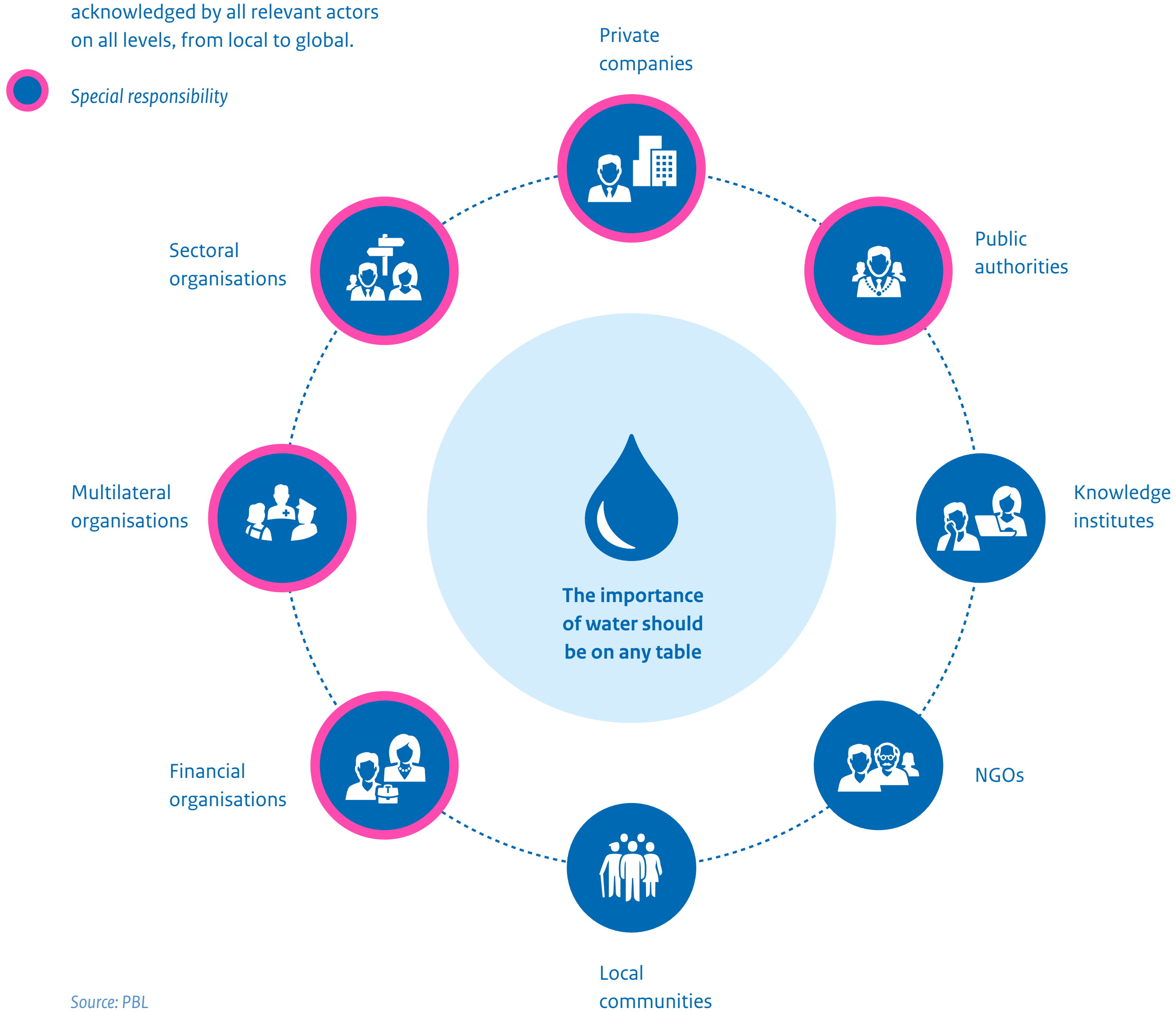
It needs to be recognised that the world, as a whole, is still only barely touching on solving the water-related problems and climate mitigation and adaptation challenges. The first urgent step towards bending the trend is to acknowledge the importance and pivotal role of water in climate mitigation, adaptation and sustainable development.

Urgency for change is high
The world already faces enormous water problems and a huge adaptation deficit. Rather than bending the trend, business-as-usual developments will increase future water and climate risks instead of decreasing them and carry a high risk of regrettable decisions and investments.
Every initiative, plan and project by every actor should be used as leverage for making the world more water-secure and climate-resilient. Climate change, population growth and economic development will not wait.

Building new coalitions
Water is linked to all of the sustainable development goals and cuts across all domains. Over time, because of these linkages and interdependencies, water has proved a source of collaboration rather than conflict. As water stress increases, on all levels and dimensions, water may once again form a basis for forging new coalitions, bridging interests, overcoming lock-ins and building a shared future.

Special responsibilities
All actors share responsibility for bending the trend. Influential and powerful actors, however, such as national, provincial and municipal authorities, multilateral organisations, sectoral organisations, private companies, developers and financing organisations, have a special responsibility in showing leadership and adapting their culture and practices to the requirements of both current and future challenges.

The importance of water
The importance of water should be acknowledged by all relevant actors on all levels, from local to global.



Source: PBL

2

VALUING WATER: BROADEN THE SCOPE

Water is undervalued. To structurally consider water and climate risks in policy development, investments and projects, we need to change the way we value water and measure success. In addition to the related economic gains, the focus should also be on a broader appreciation of the value of water for both human society and ecosystems.

Valuing water — a new logic for decision-making is needed
Water is everywhere and, as such, is connected to everything and everyone. It is the critical natural resource for all life on earth and, thus, for all societies and economies around the world. Nevertheless, its value is hardly recognised in policy development and economic valuations. As stated before, the 2015 Paris Agreement and, more recently, the 2021 Glasgow Agreement do not mention water at all, while the UNFCCC (2021) noted that 80% of countries identified water as the most urgent climate adaptation challenge.

In line with conclusions by Dasgupta (2021) and the thinking of Mazzucato (2022), water and climate adaptation goals, together with the SDGs, may provide a concrete framework for discussing the broader meaning of 'what constitutes value' and 'what counts in sustainable development'. We need to address and change the way water is valued as the basis of life, societies and economies — only then will policies change and contribute to sustainable development, rather than delaying or obstructing it.

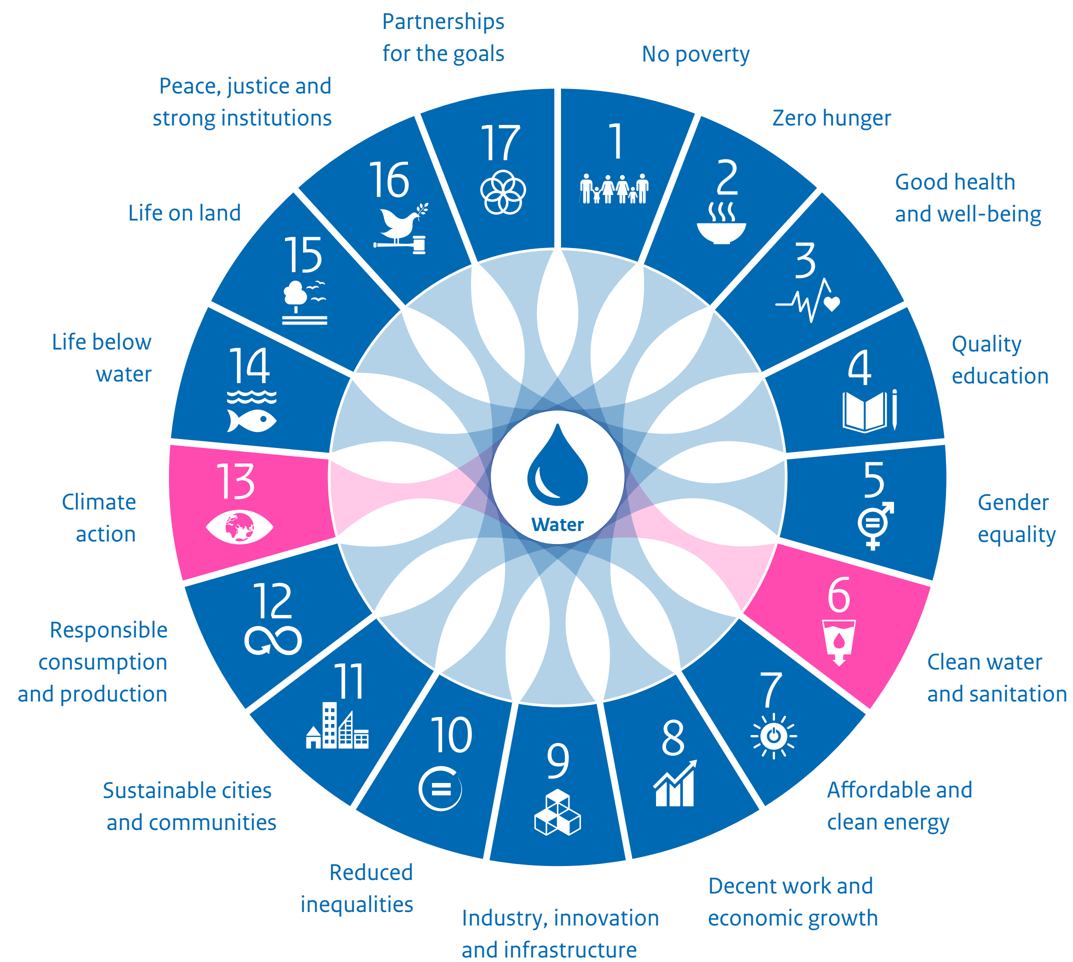
> *'Unlike most other natural resources, it has proven extremely difficult to determine water's 'true' value. As such, the overall importance of this vital resource is not appropriately reflected in political attention and financial investment in many parts of the world.'*
>
> – United Nations (2021)

> *'A new algorithm of measuring of success is needed to guide policies, investments and projects on a more sustainable path.'*
>
> – Dasgupta et al. (2021)

> *'The dysfunctions in markets today are not an accident, they are the result of decisions that we have taken in business and governments. If every person on the planet is to have access to enough safe water at an affordable cost, we must govern our economy in a radically different way.'*
>
> – Mazzucato (2022)

Broadening the scope
SDGs 6 and 13 are the most prominent SDGs with respect to water and climate adaptation, but water is basically linked with all SDGs, as this study shows. It is a critical factor in the economy, social equity and security, and in ecosystem functioning and quality. Achievement of SDG16 (Strong institutions) and SDG17 (Partnerships for the Goals) is vitally important if we are to bend the trend. Global commitments and objectives express the shared drive to make the world a better place. A major challenge is that of putting these global commitments into practice and transforming decision-making processes.

Valuing water – building on the SDGs



Source: PBL

3

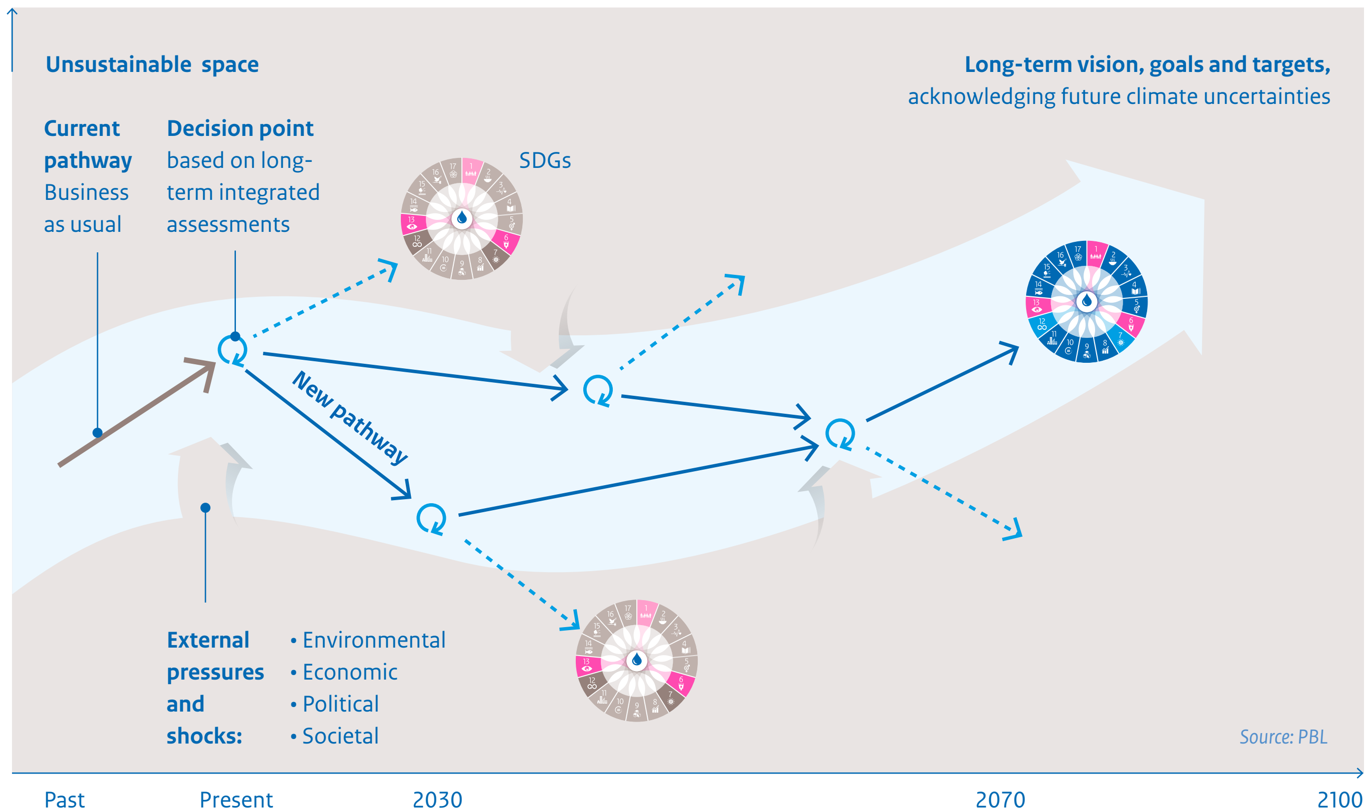
START NOW, BUT PLAN WAY BEYOND 2030 AND BE ADAPTIVE

Actions are urgent, but the transition to long-term policies, the often long lead times of plans and investments, and ongoing climate change call for a robust and adaptive long-term strategy that looks a century ahead.

A long-term and adaptive strategy will be needed to stay on track and adequately prepare for and respond to changes in external pressures and shocks in the face of long-term climate change and uncertainties with respect to precipitation patterns, and the risks related to flooding and drought and heat. Starting from the challenges related to water and climate adaptation and within the context of sustainable development, mission- and value-based objectives for the future can be formulated, relevant for societies across scales and landscapes.

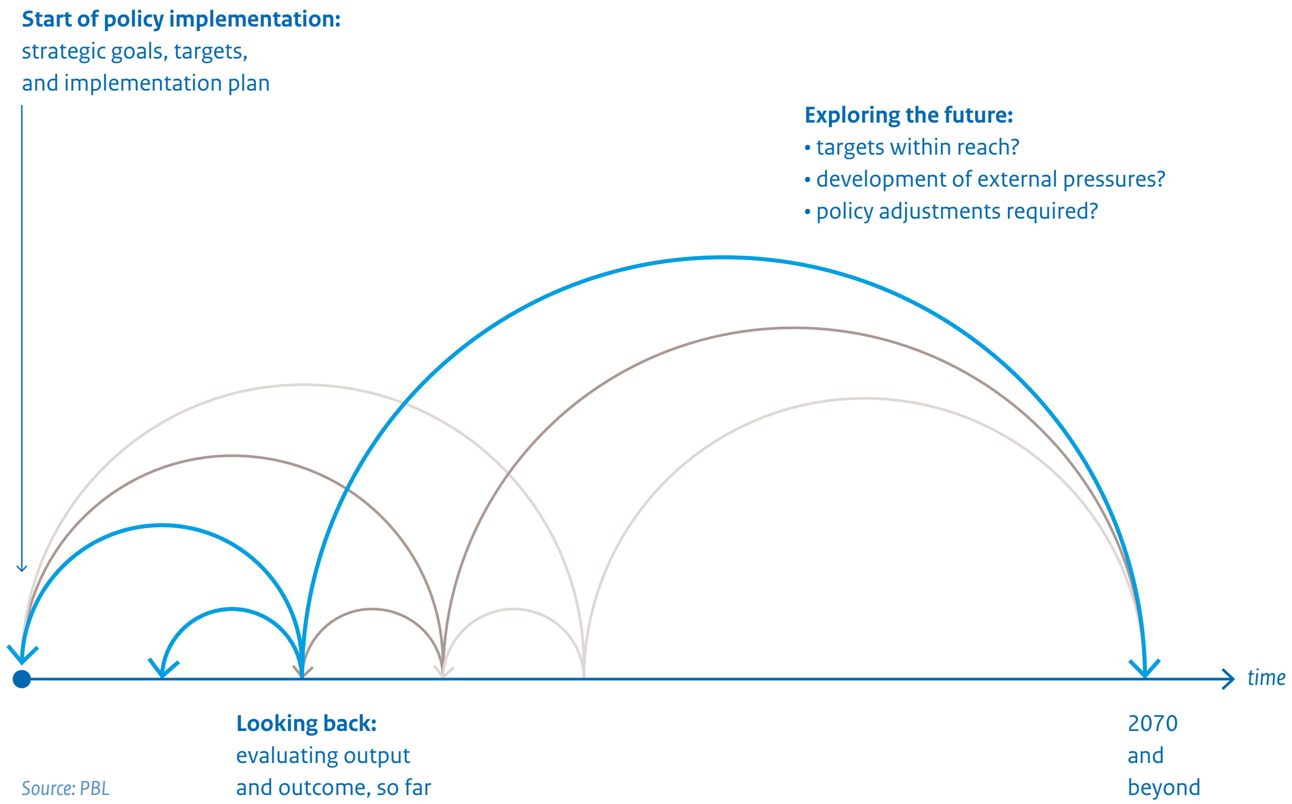
Creating a robust long-term development and adaptation strategy

Adaptive space



Planning, monitoring and evaluation are needed to support long-term adaptive strategies, to illuminate successes and identify failures, signal trends, and guide adaptive responses (Haasnoot et al., 2018; Higgins et al., 2021). This refers both to the present status and future changes in the conditions of the key ecosystem values of hotspot landscapes, to socio-economic developments, climate change and shifts in politics and policy. So far, monitoring and evaluation has remained poorly resourced and hardly implemented in most efforts to protect key ecosystem values of hotspot landscapes.

Planning, monitoring and evaluation: looking ahead and looking back



4

LET WATER BE LEADING: ADOPT A RIVER-BASIN AND ECOSYSTEM-BASED APPROACH

Restoring the functioning of river basins and adopting an ecosystem approach as the basis for human development and security will be of prime importance for the sustainable use of water resources and climate-resilient and sustainable development across scales.

Steering spatial development towards achieving a new balance between human land use and eco-system functioning is crucial. A major challenge in finding a new balance between human land use and river basin and eco-system functioning is to bridge the physical world and the realms of governance.

Acknowledging the opportunities that a river-basin and ecosystem approach will provide, is key in developing coherent strategies on all scales and from source to sea.

Important conditions for climate-resilient and sustainable spatial and economic development

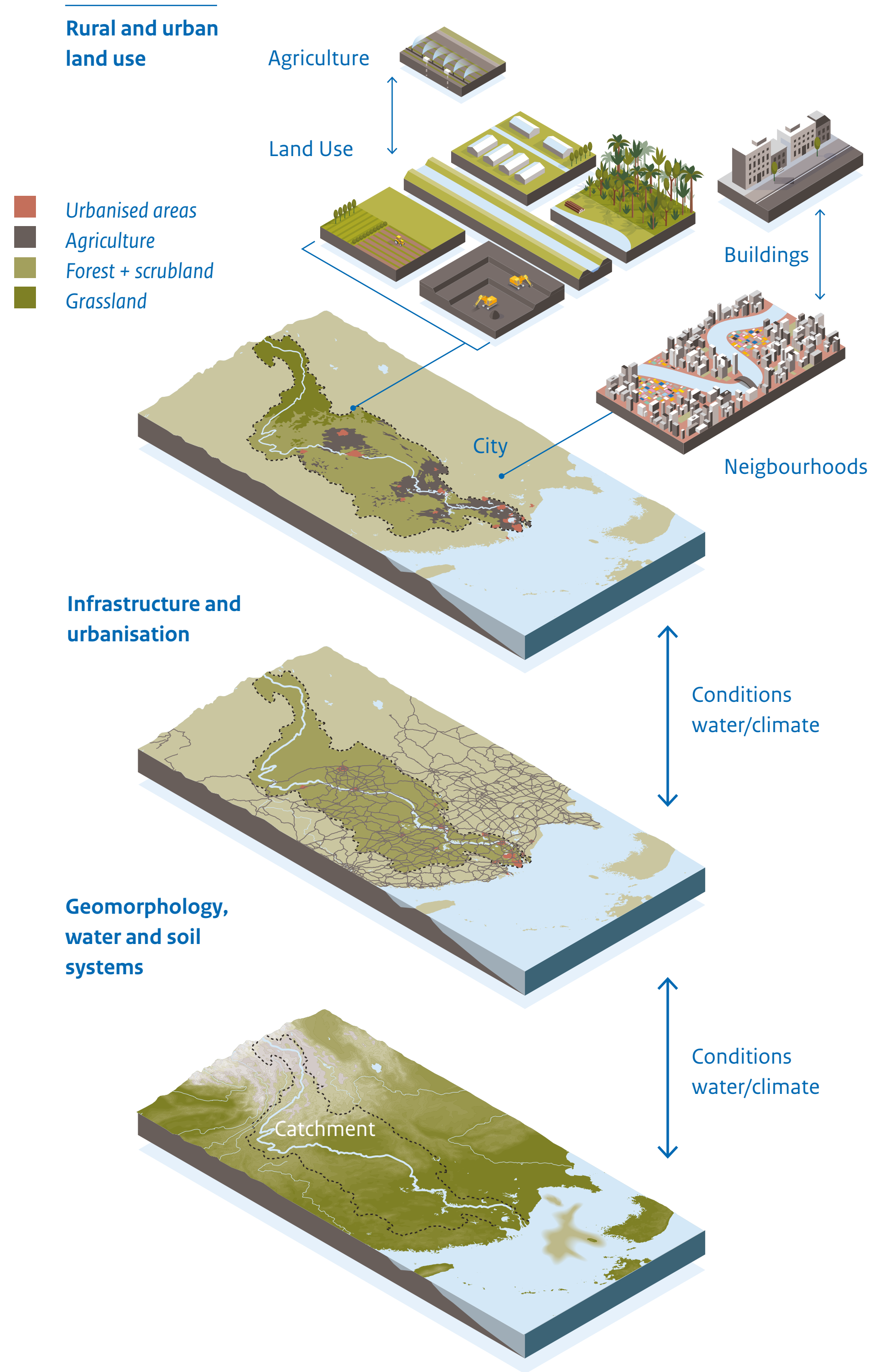
A coherent long-term strategevy across scales, interests and sectors with nested goals and targets.

Acknowledgement that each layer has its own challenges and temporal dynamics.

Acknowledgement that each scale has its specific network of stakeholders.

Direction, coordination and facilitation are needed, but without providing a blueprint.

A learning environment that facilitates sharing knowledge and information between all stakeholders across scales.



Local land and water use, building and management

- Reduce water use
- Reduce emissions
- Improve water and soil management
- Implement zoning restrictions
- Water-proof buildings and infrastructure
- Apply nature-based solutions

Dams, urbanisation, electricity and ICT networks, transport infrastructure

- Water-proof urban planning and infrastructural development
- Apply nature-based solutions and design

Integrated river basin strategy and plan across borders

Balancing development and conserving / restoring natural patterns, processes, buffers and qualities.

- Regulate water and sediment dynamics
- Regulate water use, polluting emissions
- Spatial zoning
- Transboundary agreements

Source: PBL based on Zang et al., 2014

5

ENVISIONING THE FUTURE: DEVELOP HIGH AMBITION PATHWAYS

To bend the trend and break away from business-as-usual approaches, imagination will be required to sketch a world with high ambitions to reduce water- and climate-related risks, improve the living conditions for all across the globe and restore ecosystem qualities.

Mission-oriented policies will be needed to challenge actors and guide innovation and know-how directly towards meeting critical goals. When guided by sustainable development and an inclusive 'common-good' approach, High ambition pathways will be unique in providing integrative solutions to the challenges.

At the same time, productive and participative approaches on all scales and by all stakeholders will be required to generate innovation as well as transparency and accountability in collaborative processes, and to build trust and institutional, informal and professional capacities.

Contribution to SDGs

Projected improvement 2070 compared to 2020
based on quantified indicators
qualitative appreciation

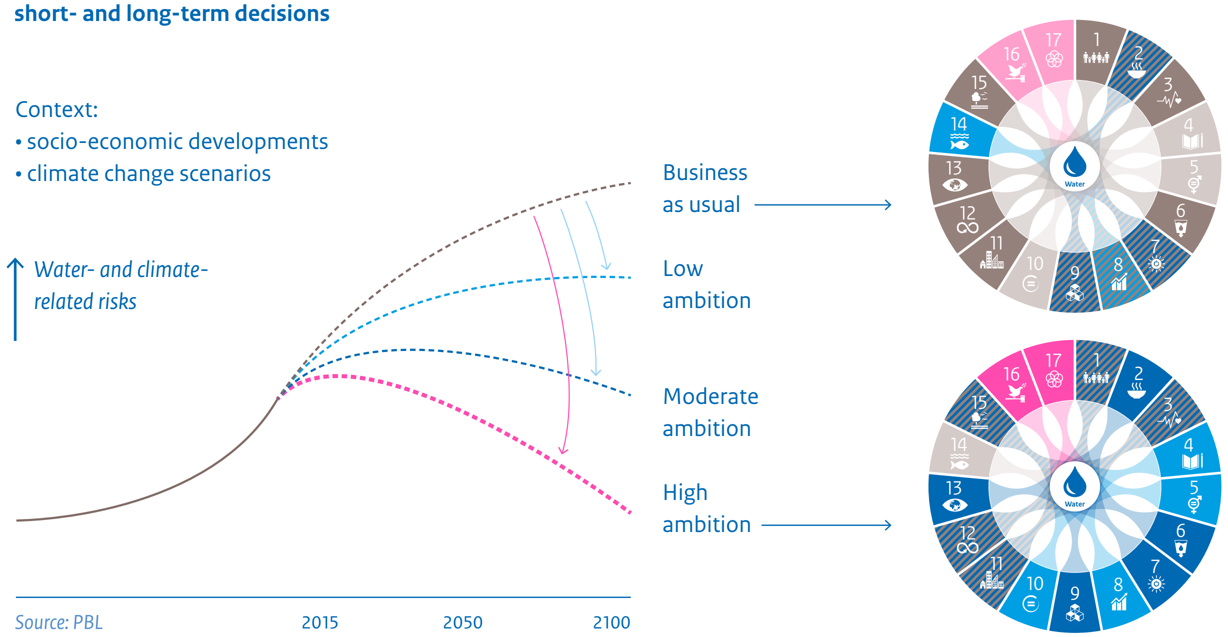
Projected deterioration 2070 compared to 2020
based on quantified indicators
qualitative appreciation

partial improvement, partial deterioration or standstill 2070 compared to 2020

Important condition for transition
assumed to be fulfilled
assumed not to be fulfilled

A High ambition pathway to guide future development and cohesive short- and long-term decisions

Context:
- socio-economic developments
- climate change scenarios



Source: PBL

It is time-intensive to organise constructive participative processes, involving the relevant sectors and communities. These processes are essential, however, for building a shared understanding of the challenges and exploring and finding solutions. This way, trust is being built amongst engaged parties, enabling the development of sustainable, equitable and resilient pathways towards the future.

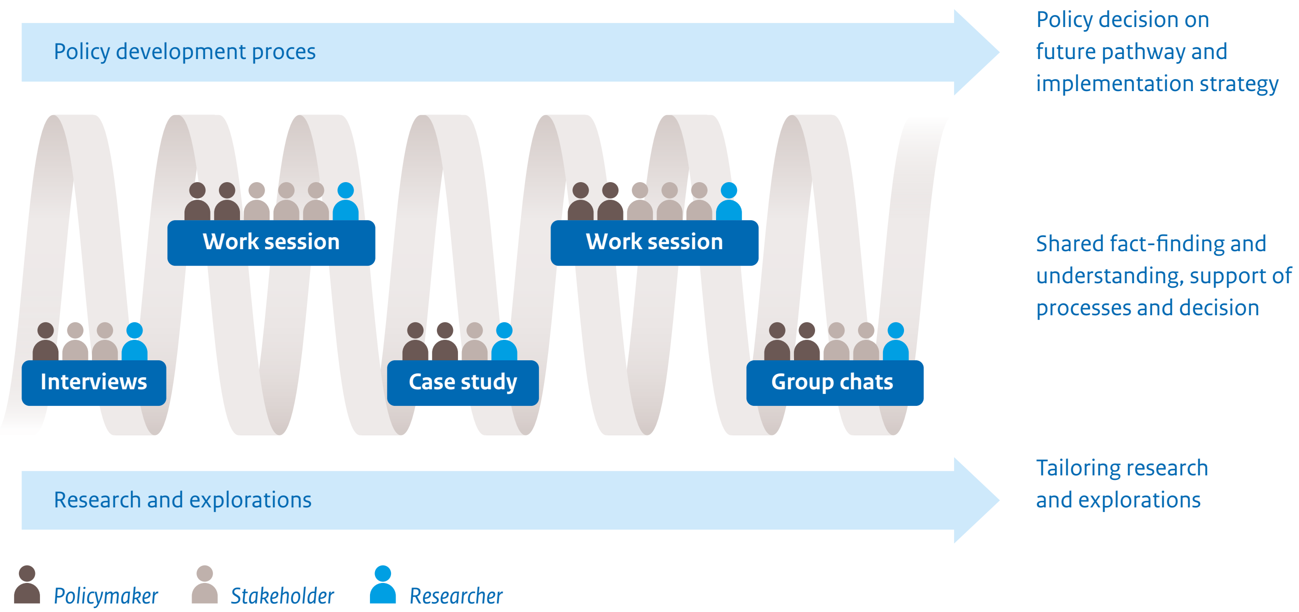
Integrated policy development

Phase 1
Exploring the challenges and elaborating the strategic goals

Phase 2
Exploring potential strategies and solutions

Phase 3
Exploring preferred options and further elaboration of goals

Phase 4
Choosing preferred option, setting targets and organising implementation



Source: PBL

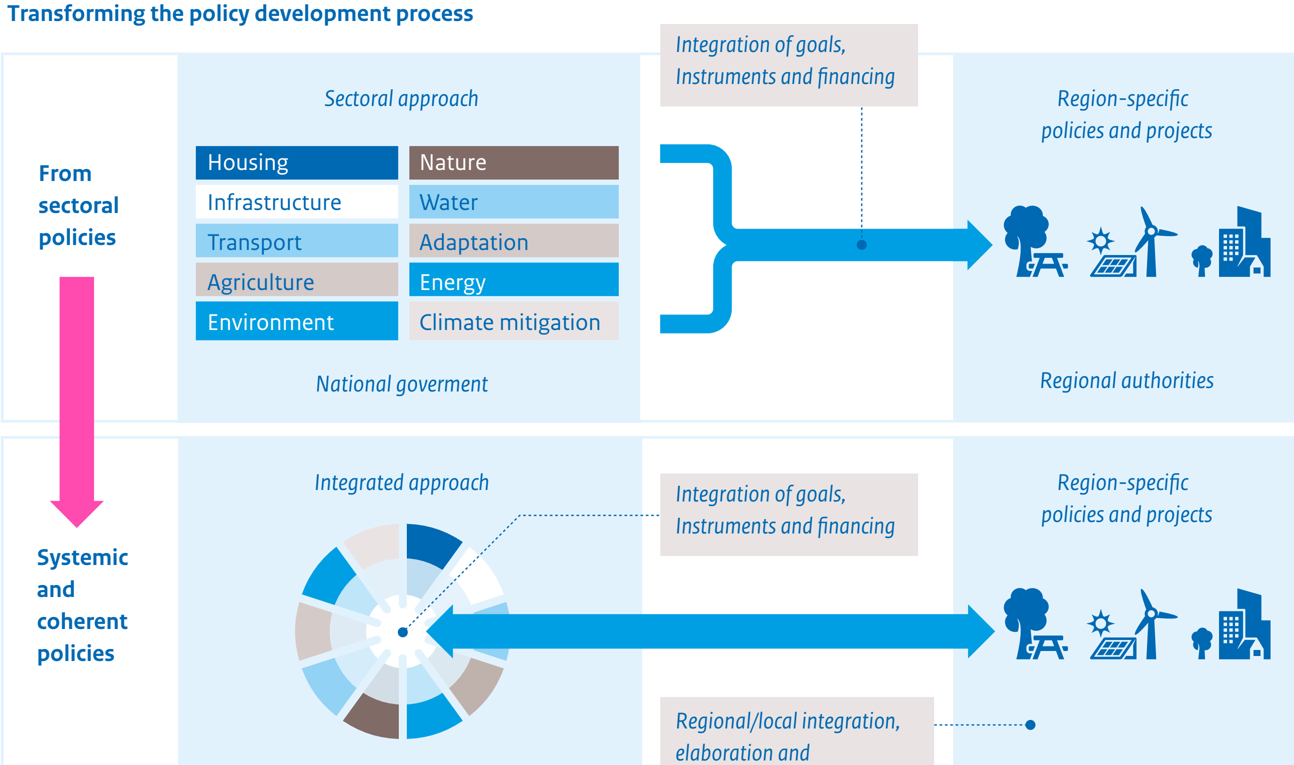
6

IMPROVING POLICY COHERENCE

Working into the same direction calls for a transition from sectoral to systemic policy development. Consistent goals across sectors, scales and time frames and overarching monitoring processes for effective and adaptive policy implementation are needed for effective systemic policies.

Policy integration requires a transdisciplinary approach to governance and engagement, across the various scales, to work effectively into the same direction. This includes collaboration across sectors and organisation of stakeholder involvement to mobilise knowledge, support and commitment in the various societal domains. The integration also calls for due attention for knowledge and model development and improved data management to support the more complex analyses, integrated future explorations and monitoring processes. This intensified collaborative approach is not only essential for transforming policy development, but also builds capacity across institutions, within professions and on an individual and informal basis. Last but not least, regulatory frameworks and financing mechanisms will need to be adjusted to facilitate rather than obstruct the integrated and cross-sectoral approaches.

Transforming the policy development process



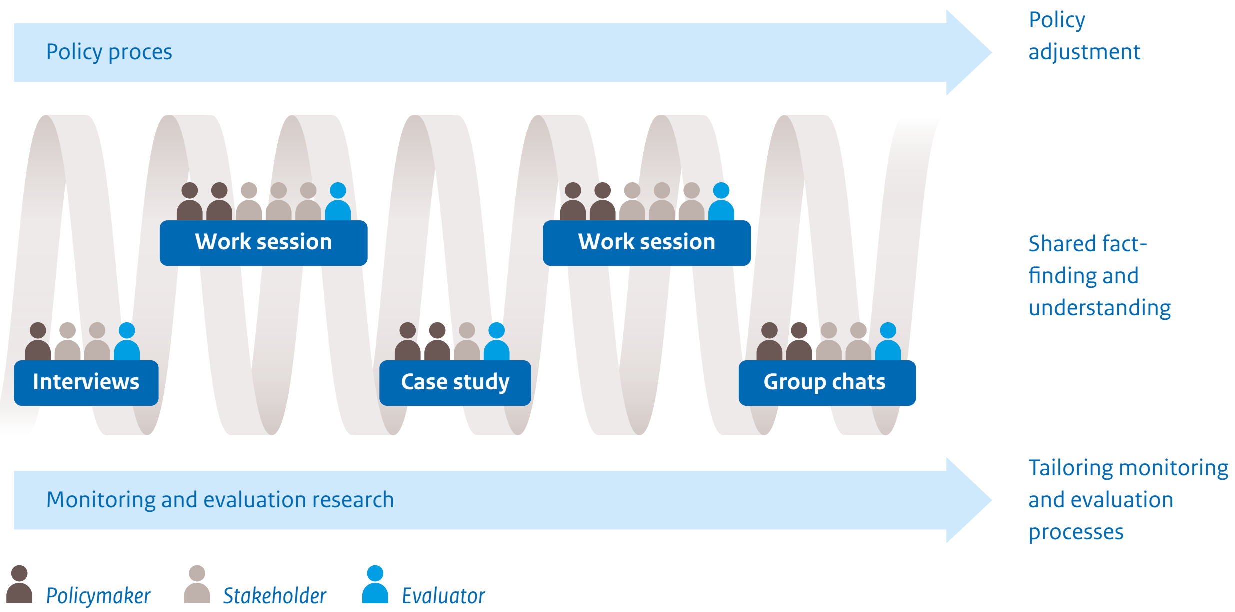
Source: PBL

Participative monitoring and evaluation processes critical for success

Given the complexity of the challenges and future uncertainties, blueprints will not be effective. With respect to the development of the long-term mission, goals and strategy (see previous page), it is important to organise participative monitoring and evaluation processes to support:

- technical learning (how measures work)
- social learning (collaboration, shared understanding, building trust)
- policy learning (what works, what does not, where and how to adjust)
- system learning (increased understanding of system dynamics)

Participative monitoring and evaluation



Source: PBL

7

STRENGTHENING GLOBAL WATER GOVERNANCE AND CAPACITY

The urgency of water- and climate-related risks, the unequal distribution of risks and capabilities across the globe and the still low level of political awareness, call for a global, overarching, stimulating and facilitating governance process to bend the trend across scales.

Water is not yet on the UN agenda
While 74% of all natural disasters are water-related and 82% of the Nationally Determined Contributions list water as an adaptation priority (UNFCCC, 2021), water is not mentioned in either the Paris Agreement or the Glasgow Climate Pact.

The COP27 Sharm El Sheikh Implementation Plan ‘SHIP’ is the first time water is positioned as a means towards achieving climate resilience. On UN level, there are various water-orientated processes, but an overarching UN Water agreement or process, comparable with the COPs on climate change, the Global Biodiversity Convention and the UN Sustainable Development Agenda, is lacking. Water has neither an institutional nor a political position at the United Nations.

Recent water declarations in preparing the foundations for the UN Water Conference 2023 all point in the same direction

Recent water declarations

- High Level Panel on Water, 2016–2018
- Water Action Decade, 2018–2028
- Resolution on the UN 2023 Water Conference, UN, 2020
- Water Dialogues for Results, Bonn, Germany, 2021
- 9th World Water Forum, Dakar, Senegal, 2022
- Asia-Pacific Water Forum, Kumamoto, Japan, 2022
- 2nd High-level International Conference on Water Decade, Dushanbe, Tajikistan, 2022
- UN Oceans Conference, Lisbon, Portugal, 2022
- Parliamentarians for Global Action, Preparatory meeting, UN 2022

Source: PBL

→

All water declarations are pointing in the same direction, emphasising the pivotal role of water in sustainable development, stating the lack of progress on many water and water-related SDGs, acknowledging the disrupting impacts of climate change and the need for cross-sectoral policy coherence, and recommending accelerated actions and improved financing and governance across scales.

→

UN processes

- UN Convention on Global Biodiversity, 1992
- Sendai Framework on Disaster Risk Reduction, 2015
- Addis Ababa Action Agenda, Third International Conference on Financing for Development, 2015
- The 2030 Agenda for Sustainable Development, 2015
- Paris Agreement, 2015
- New Urban Agenda, 2016

Putting water on the UN agenda will underline the importance of water
In line with the global commitments on climate change mitigation, biodiversity conservation and sustainable development, an overarching global commitment and process will be needed for addressing water- and climate-related risks to increase awareness and the urgency to act, and to accelerate and support the transition to a water-secure and climate-resilient future from global to local levels.

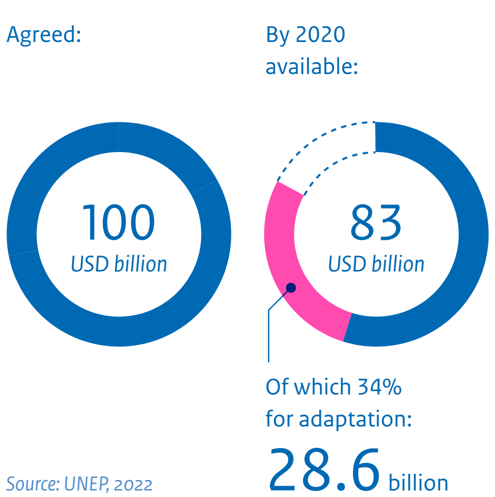
Embedding water in, for example, the UN’s High Level Political Forum on Sustainable Development, the SDG review, COPs on Climate and Biodiversity, high level conferences on food, energy and oceans, within the Social Forum of the Human Rights Council, will underline the urgency to act and strengthen mainstreaming water across the UN system, preventing the creation of a parallel universe with siloed water conferences. Mainstreaming water throughout the UN system, supported by mandate, capacity and leadership, will build towards a unified water governance approach. The importance of global conventions and related COP processes cannot be overstated. They underline the importance and urgency of topics, provide an enabling environment for international cooperation, and can support national and other public authorities and stakeholders to develop and implement new strategies.

8

SCALING UP FUNDING FOR WATER AND CLIMATE ADAPTATION

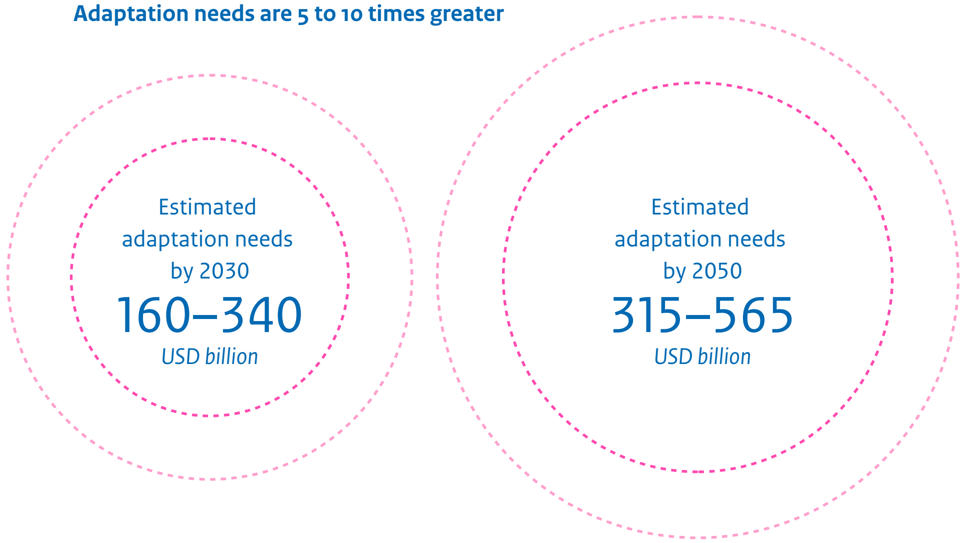
Water- and climate-related risks; an equity-based principle makes the damage caused on local levels into a global responsibility. Low- and middle-income countries are facing a huge financing gap if they are to solve their water- and climate-related problems and reduce their adaptation deficit.

Agreed total annually required climate financing



Source: UNEP, 2022

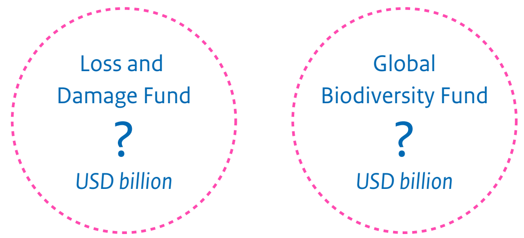
Adaptation needs are 5 to 10 times greater



Internationally, there are insufficient funds to support investments in water and climate adaptation projects, especially in low-income and developing countries. Although the UNFCC reports that more than 80% of developing countries have started to develop adaptation plans — largely related to water challenges (UNFCCC, 2021; UNEP, 2022) — the required financing is lagging behind (Timperley, 2021).
In 2020, international climate-related financing for developing countries reached USD 83 billion, 28.6 billion (34%) of which for climate adaptation. The total in financing originally pledged in support of adaptation and mitigation in developing countries was USD 100 billion. Thus, in 2020, the gap was at least USD 17 billion.

Accounting for inflation, the estimated annual financing that is required to meet adaptation needs ranges from USD 160 to 340 billion by 2030, and from USD 315 to 565 billion by 2050. The estimated amount needed for adaptation in the period up to 2030 is roughly between 5 and 10 times higher than the current international financial support. Without a structural increase in these financing flows, the related financial gap will continue to widen.

New global funds announced for loss and damage and for biodiversity protection



- *how much?*
- *when available?*
- *how to be filled?*
- *how to be accessed and distributed?*

At the UN Climate Change Conference COP27, in November 2022, a breakthrough agreement was reached to provide 'loss and damage' funding for vulnerable countries hit hard by climate disasters. And at the Biodiversity COP15 in December 2022, it has been agreed to create a Global Biodiversity Fund to support the developing countries in their efforts for biodiversity conservation. However, there are no details on how much money will be made available, how it will be distributed, when it will start flowing and how it can be accessed by the countries and people who desperately need it. This will be on the agenda of the coming COPs.

Adaptive capacity: population and annual GDP for various groups of countries, 2021

GDP nations	Population *(billion)*	%	GDP *(USD trillion)*	%
Low	0.71	9%	0.5	1%
Lower middle	3.40	43%	8.7	9%
Upper middle	2.50	32%	27.1	28%
High	1.24	16%	59.9	62%
Total	7.85	100%	96.2	100%

The intensity and scale of the challenges overstretch the capabilities, especially those of low-income and developing countries, deserving urgent global support.

'Water- and climate-related risks: an equity-based capitalisation principle makes damages at the local level a global responsibility.'

– Hochrainer-Stigler et al. (2021)

9

BUILDING A SHARED WATER AGENDA AND PROCESS TO CREATE PERSPECTIVE

A shared water agenda and guiding objectives and targets across scales will be needed to work towards the same goals, on all levels, from global to local, allowing concerted decisions on strategies, actions and financing and realising a water-secure world for all.

Building a shared water agenda can direct actions and processes from global to local
For reducing greenhouse gas emissions, there are future pathways, goals and targets on both global and national scales, but for water security and reducing climate risks these are still lacking.
The four hotspot landscapes are rooted in the physical world and represent clusters of water- and climate-related risks. To reduce these risks, urgent action is needed in all these hotspot areas, on all levels, from global to local:

River basins and river systems, because they are the critical geographical landscape for long-term, climate-resilient and sustainable development across the globe. In transboundary river basins, increasing water stress may also increase the risk of conflict, if not managed adequately.

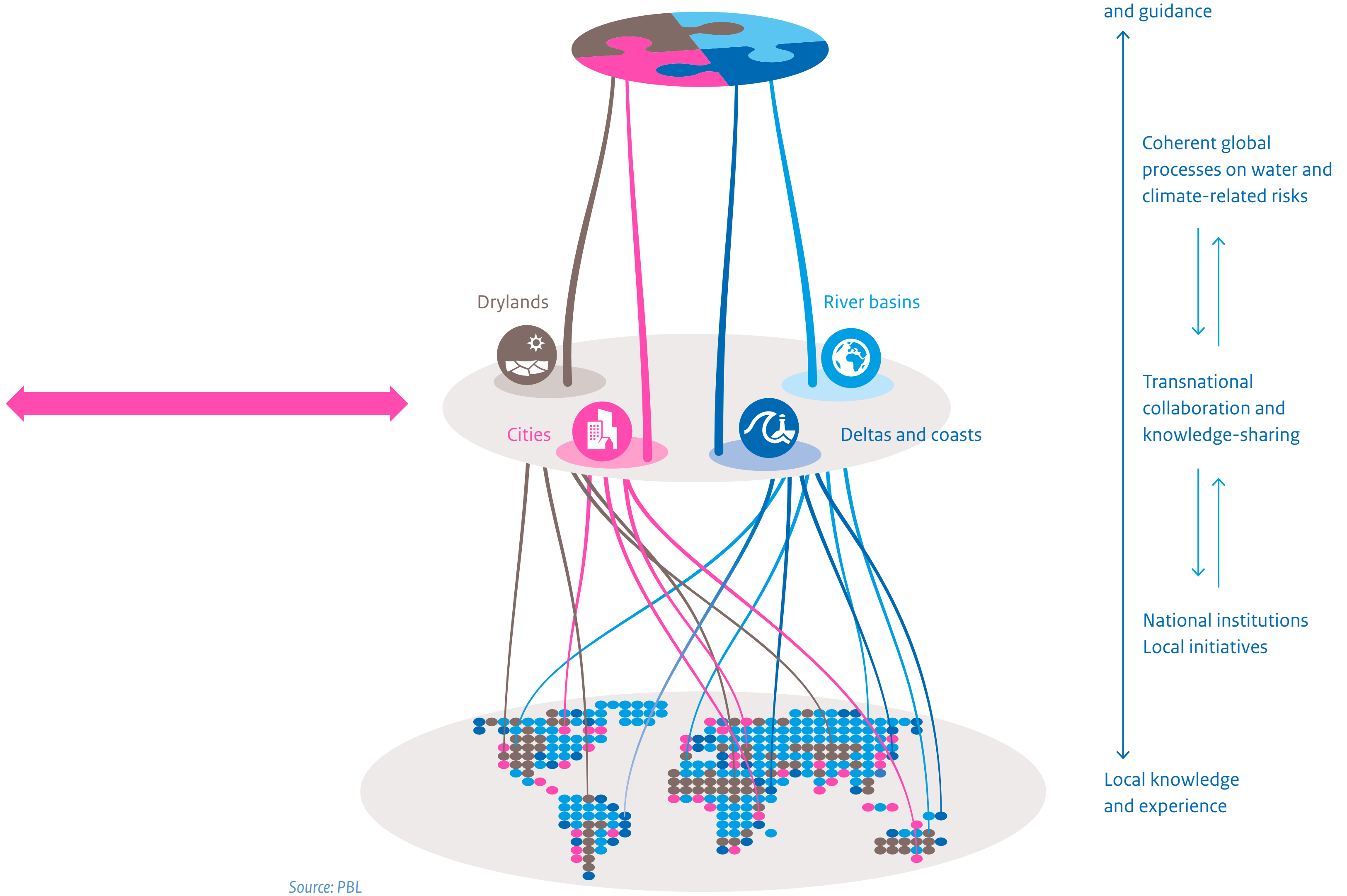
Deltas, coasts, islands and drylands, because they are at the forefront of climate- and water-related insecurity impacts and are already facing severe threats. If action is delayed, these areas in the coming decades may be confronted with serious limits to their ability to adapt to impacts such as sea level rise, heat and drought.

Cities, because, by 2070, they will be accommodating over 70% of the world population and already are hotspots of water insecurity, exposure to climate change and weather extremes.

Our study shows much improvement in water security and a reduction in climate-related risks can be achieved across landscapes and regions. Our approach may be used in a further exploration of strategies, in a multi-actor and multi-scale process, to support setting coherent goals and targets on all scales (*What needs to be achieved?*) as well as coherent implementation strategies (*What needs to be done and how?*), from global to local levels.

Hotspot landscapes deserve a global strategy
Preventing loss of lives, ecological disruption and migration and conflict: hotspot landscapes deserve a global stategy. The intensity and scale of the challenges overstretch the capabilities of especially the developing countries and deserve urgent global attention, plans and financing, in order to prevent millions (short term) to billion (long term) of people being displaces from their homelands, river areas, deltas, low-lying coastal areas and islands.

Strengthening global governance and building a shared water agenda



Source: PBL

PRIORITIES FOR A SAFE LANDING

While global attention and support is critical, working on water-secure and climate-resilient development needs to start today. Our study provides a set of first- and second-tier priorities as a basis for urgent action that is needed to start bending the trend.

First- and second-tier priorities to bend the trend and take action
While further exploration of future pathways is needed, developments and investments cannot wait and actions to bend the trend must start now. Building on our study, we identify first- and second-tier priorities for the hotspot landscapes that require urgent action being taken at any scale and by any actor.

Prevent unsustainable investments, especially in urban development and infrastructure
A no-regret priority is to prevent unsustainable developments and investments. Over the next decades, an annual USD 2.7 to 3.7 trillion is expected to be invested in urban development and infrastructure.
The investments will take place on less than 1% of the global land area. This offers opportunities for effectively improving human well-being and reducing water- and climate-related risks. However, if these investments are based on business-as-usual approaches, there is a good chance that they will increase water- and climate-related risks, rather than reduce them.

Source: PBL, 2018

Towards a short-term and long-term shared water agenda

A shared water agenda needs to address the short-term urgencies and organise a process to optimise long-term High ambition pathways, reducing water- and climate-related risks. Not as a blueprint but as a mission statement and a promising perspective across landscapes, regions, countries and cities.

River basins

1st Tier priorities

- Reconsider dams or build only ecologically friendly hydropower facilities that do not trap sediments
- Improve protection and apply zoning and building regulations in flood-prone areas
- Prevent further loss of wetlands

2nd Tier priorities

- Implement regulations to reduce nutrient emissions and other pollutants as well as water use in agriculture, industries and cities
- Reduce sand mining and innovate the use of building materials
- Restore wetlands on a large scale
- Improve river-basin approaches and transboundary agreements

Deltas, coasts and Islands

1st Tier priorities

- Stop subsidence by reducing groundwater abstraction and restructuring freshwater supply
- Improve flood protection and apply zoning and building regulations in flood-prone areas
- Prevent further loss of wetlands

2nd Tier priorities

- Implement regulations to reduce nutrient emissions and other pollutants as well as water use in agriculture, industries and cities
- Reduce sand mining and innovate in building materials
- Restore wetlands on a large scale
- Initiate upstream–downstream river-basin approaches

Drylands

1st Tier priorities

- Increase efforts in improving agricultural water use efficiency in combination with soil and crop management
- Explore potential use of groundwater in Sub-Saharan Africa
- Improve water buffer and water reuse systems

2nd Tier priorities

- Implement regulations to reduce nutrient emissions and other pollutants from agriculture, industries and cities
- Integrate agriculture and agroforestry and stimulate green wall developments
- Improve urban–rural interaction regarding water and nutrient use as well as in- and out-migration

Cities

1st Tier priorities

- Always combine sanitation systems with wastewater treatment systems
- Integrate available green and blue infrastructure in urban development
- Stimulate water- and heat-proof construction
- Increase flood protection levels, apply zoning and building regulations

2nd Tier priorities

- Implement regulations to reduce nutrient emissions and other pollutants as well as water use by households and industries
- Reduce sand mining and innovate in building materials
- Improve urban–rural interaction

APPENDIX

APPENDIX: OVERVIEW OF MEASURES

1. Overview of measures in River basins (NA = Not Applied)

Ambition level →	**Business as usual (Bau)**	**Low**	**Moderate**	**High**	**Source**
General context: socio-economic development, land use and climate change scenario					
Socio-economic trends (land use change)	SSP2	SSP2	SSP2	SSP2 + land use cf. Sharing the Planet (SP)	SSP2, SP, Immovilli and Kok, 2022
Climate change	RCP6.0	RCP6.0	RCP6.0	RCP6.0	IPCC 2021
Agriculture: improving crop management and water conservation, reducing water use and nutrient emissions					
Improved nutrient and seed management to close the yield gap	SSP2, improved management to close yield gap, as projected by IMAGE	Further closure of the yield gap by 0.25% per year	Further closure of the yield gap by 0.5% per year	Further closure of the yield gap by 0.75% per year	WEnR
Improved soil moisture conservation	NA	Towards 10% soil moisture conservation in 2050	Towards 25% soil moisture conservation in 2050	Towards 50% soil moisture conservation in 2050	WEnR
Improved rainwater harvesting	NA	Towards rainwater harvesting on 10% of croplands in 2050	Towards rainwater harvesting on 25% of croplands in 2050	Towards rainwater harvesting on 50% of croplands in 2050	WEnR
Increased infiltration	NA	Low increase in infiltration capacity	Medium increase in infiltration capacity	High increase in infiltration capacity	WEnR Jagermeyr, 2021
Improved irrigation efficiency • Flood irrigation 52% • Sprinkler irrigation 78% • Drip irrigation 88%	Default irrigation system per country	25% of non-rice irrigation replaced by sprinkler between 2020 and 2050	Half of non-rice irrigation replaced by sprinkler between 2020 and 2050	Towards drip irrigation where applicable (depending on crops), sprinklers for the rest, and surface irrigation for rice crops	WEnR
Reservoir capacity and operation	New reservoirs as in SSP2, only hydropower	New reservoirs as in SSP2, only hydropower	New reservoirs as in SSP2, managed for hydropower but also used for water supply	New reservoirs as in Sharing the Planet, managed for hydropower but also used for water supply	WEnR, PBL

Ambition level →	Business as usual (Bau)	Low	Moderate	High	Source
Complying with Environmental Flow Requirements (EFR)	NA	NA	Standard environmental flow requirements are imposed, based on the VMF method: EFR = 45%, 30%, 15% in low, medium, high flow months, respectively	Enhanced environmental flow requirements are imposed, based on the VMF method: EFR = 60%, 45%, 30% in low, medium, high flow months, respectively	WEnR
Sustainable intensification of fertilizer use	Fertilizer use conform SSP2, which by 2070 will be 60% more than today	Sustainable intensification of fertilizer use conform SSP1, which by 2070 will be 19% more than today	Sustainable intensification of fertilizer use conform SSP1, which by 2070 will be 19% more than today	Sustainable intensification of fertilizer use conform SSP1, which by 2070 will be 18% more than today	PBL
Implementation of nutrient buffer zones along agricultural land	NA	NA	Total of 11.6 million ha buffer zone by 2070, which is 0.2% of the total agricultural land (5500 million ha)	Total of 9.8 million ha buffer zone in 2070, which is 0.2% of the total agricultural land (4600 million ha)	PBL
Households and industries: improving sanitation and reducing water use and emissions to surface water					
Increased water use efficiency households and industries	SSP2 withdrawal and consumption	Save 0.25% per year (withdrawal and consumption) compared to Business as usual	Save 0.5% per year (withdrawal and consumption) compared to Business as usual	Save 0.75% per year (withdrawal and consumption) compared to Business as usual	WEnR
Sanitation: 2015: 20% unimproved	10% less unimproved sanitation	17% less unimproved sanitation	19% less unimproved sanitation	19% less unimproved sanitation	PBL
2015 globally: 40% sewer connection	18% increase in sewer connections, compared to 2015	32% increase (GDP-based) in sewer connections, compared to 2015	40% increase sewer connections, compared to 2015	40% increase sewer connections, compared to 2015	PBL
14% improvement in wastewater treatment, globally, in 2015	14% increase in global nutrient removal	26% increase in global nutrient removal	90% nutrient removal in low- and high-income countries → 36% increase in global nutrient removal	37.4% increase in global nutrient removal. P-free detergents in all countries, from 2050 onwards	PBL

Ambition level →	Business as usual (Bau)	Low	Moderate	High	Source
Riverine flood risks: reducing impacts of flooding on population and economic damage					
Improved protection levels using dykes/levees or alternative measures (water-robust building, zoning)	Dykes and levees are kept at their current strength and height, neglecting climate change and increasing socio-economic developments.	Only the alternative measures water-robust building and spatial zoning are used, and only those with highest benefit-cost ratio (BCR) locally.	The alternative measures water-robust building and spatial zoning are used, and only those with highest benefit-cost ratio (BCR) locally. In addition, dykes and levees are raised and strengthened to cover remaining flood risk.	Dykes and levees are raised and strengthened to keep future economic flood risk constant at the current level.	VU (IVM), Deltares
Applying nature-based solutions	NA	Optimised with wetland restoration (see Ecology) (where BCR is positive)	Optimized with wetland restoration (see Ecology) (where BCR is positive)	NA	VU (IVM)
Hydropower dams: renewable energy production and reducing ecological impact					
Reduced ecological impacts	208 large dams 744 diversion canal systems	= Bau	42 large dams 2031 small-scale ecological facilities	0 large dams 2124 small-scale ecological facilities	PBL
Freshwater ecosystems: improving ecological qualities and ecosystem functioning					
Reduced ecological impacts of dams	See Hydropower dams				PBL
Reduced water use in agriculture	See Agriculture				WEnR
Reduced water use in households and industries	See Households and industries				WenR
Reduced nutrient emissions from cities and agriculture	See Households and industries See Agriculture				PBL
Restored wetlands	6% area loss compared to 2015	= Bau	= Bau	48% new wetland area compared to 2015	PBL FWCII
Reducing risks of transboundary conflict					
Reduced water use	See Agriculture and Cities and industries				
Improved institutional resilience	Institutional qualities by 2065 will be the same as they are today	Institutional qualities across all river basins improve one step	= Low	Institutional qualities across all river basins improve two steps	PBL

2. Specific and additional measures in Deltas and coasts (NA = Not Applied)

Ambition level →	Business as usual (Bau)	Low	Moderate	High	Source
Reducing subsidence by reducing groundwater abstraction and restructuring freshwater supply system					
Reduced water use by improving water efficiency	See River basins: • agriculture • households and industry				WenR
Using alternative freshwater resources	Qualitative exploration of potential alternative resources: treated river water, treated wastewater, desalinated brackish or salt water, offshore fresh groundwater. Conditions for *High ambition pathway*: 1. based on renewable energy 2. low climate vulnerability 3. preserving ecological qualities 4. social equity in accessibility				PBL, Deltares
Reducing sediment mining by reducing sand demand from building sector					
Mix of 6 measures focussing on reducing sand demand/use	No measures	No systematic reduction	50% implementation of all measures, globally	100% implementation of all measures, globally	Zhang et al., 2022
Sediment accretion strategies					
Feasibility of various measures	Potential measures: 1. river sediment diversions 2. tidal flooding 3. sedimentation structures 4. vegetation planting Explored measures potentially promising, but feasibility low due to already existing infrastructure and cities.				Cox et al., 2022
Reducing coastal flood risks: reducing impacts of flooding on population and economic damage					
Improved protection levels using dykes/levees or alternative measures (water-robust building, zoning, foreshore vegetation)	Dykes and levees are kept at their current strength and height, neglecting climate change and increasing socio-economic developments.	Only the alternative measures foreshore vegetation, water-robust building and spatial zoning are used, and only those with highest benefit-cost ratio (BCR) locally.	The alternative measures foreshore vegetation, water-robust building and spatial zoning are used, and only those with highest benefit-cost ratio (BCR) locally. In addition, dykes and levees are raised and strengthened to cover remaining flood risk.	Dykes and levees are raised and strengthened to keep future economic flood risk constant at the current level.	VU (IVM), Deltares
Applying nature-based solutions	NA	Developing foreshore vegetation and mangroves (where BCR is positive)	Developing foreshore vegetation and mangroves (where BCR is positive)	NA	VU (IVM)

3. Specific and additional measures in Drylands (NA = Not Applied)

Ambition level →	Business as usual (Bau)	Low	Moderate	High	Source
Reducing water yield gap					
Improved water conservation and reduced water use by improving water efficiency	Cf. River basins				
Improved crop and soil management	Cf. River basins				
Unused groundwater tapped in Sub-Saharan Africa	Qualitative appreciation of the BGS' (2022) assessment of potential of groundwater systems in Sub-Saharan Africa, revealing a potential additional and sustainable water supply of 130 litres/day per person				British Geological Survey, 2022
Improved water and nutrient reuse urban ↔ rural	NA	NA	NA	Implementation, resulting in 10% efficiency gain	PBL
Reducing local water conflict risks and migration					
Improved local crop production, reduced water yield gap	Cf. Drylands				WEnR
Improved governance quality	Worldwide governance index 2020 + middle-of-the-road projection	In the Low, Moderate and High ambition pathway the governance quality per country increases logarithmically			PBL, based on Kaufman and Kraay, 2021

4. Specific and additional measures in Cities (NA = Not Applied)

Ambition level →	Business as usual (Bau)	Low	Moderate	High	Source
Reducing water use, improving water efficiency					
Reduced water use, improved water efficiency	Cf. River basins, households and industries				WEnR
Improving sanitation and reducing nutrient emissions from wastewater treatments					
Improved sanitation	Cf. River basins				PBL
Improved wastewater treatment	Cf. River basins				PBL
Improved detergents	Cf. River basins				PBL
Reducing flood risks					
River cities	Cf. River basins				VU (IVM), Deltares, PBL
Delta and coastal cities	Cf. Deltas and coasts				VU (IVM), Deltares, PBL
Improving local food security Dryland cities					
Improved local crop production	Cf. Drylands foodsheds				
Improving Blue Green Infrastructure					
Area and types of blue green infrastructure	Qualitative appreciation of relevance of Blue and Green infrastructure with respect to 1. reducing urban flooding due to rainfall 2. reducing the heat island effect 3. improving groundwater infiltration 4. contributing to the quality of the living environment				IHE, PBL
Integrated design and planning urban development					
Integrated approach and design: cities in their landscape	NA	NA	NA	Inspirational design approaches for: • River cities • Delta and coastal cities • Dryland cities	ONE Architects, IHE, PBL

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PHOTOGRAPHY

River basins, p. 34
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Golden Triangle at Mekong River, Chiang Rai, Thailand. The Mekong is an intensively used transboundary river, running from the Tibetan Plateau through China, Myanmar, Laos, Thailand, Cambodia and Vietnam and only second to the Amazon in aquatic biodiversity.

Deltas and coasts, p. 80
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View on Port in Manila, Philippines. Cityscape with poor areas and business center in the distance, highly vulnerable for sea level rise.

Drylands, p. 118
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Madagascar, local farmers in the drylands of Madagascar profit from the temporal availability of water after rainfall.

Cities, p. 144
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Downtown area of Maputo, the capital city of Mozambique. As most African cities, Maputo has to cope with climate change challenges, while providing adequate housing, water services and a safe and healthy living environment to a fast-growing population.

COLOPHON

The Geography of Future Water Challenges
Bending the Trend

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