# Executive Summary

***Observational records and climate projections provide abundant evidence that freshwater resources are vulnerable and have the potential to be strongly impacted by climate change, with wide-ranging consequences on human societies and ecosystems.***

**Observed warming over several decades has been linked to changes in the large-scale hydrological cycle** such as: increasing atmospheric water vapour content; changing precipitation patterns, intensity and extremes; reduced snow cover and widespread melting of ice; and changes in soil moisture and runoff. Precipitation changes show substantial spatial and interdecadal variability. Over the 20th century precipitation has mostly increased over land in high northern latitudes, while decreases have dominated from 10°S to 30°N since the 1970s. The frequency of heavy precipitation events (or proportion of total rainfall from heavy falls) has increased over most areas *(likely)*. Globally, the area of land classified as very dry has more than doubled since the 1970s *(likely)*. There have been significant decreases in water storage in mountain glaciers and Northern Hemisphere snow cover. Shifts in the amplitude and timing of runoff in glacier- and snowmelt-fed rivers, and in ice-related phenomena in rivers and lakes, have been observed *(high confidence)*. [2.1]

**Climate model simulations for the 21st century are consistent in projecting precipitation increases in high latitudes *(very likely)* and parts of the tropics, and decreases in some subtropical and lower mid-latitude regions *(likely)*.** Outside these areas, the sign and magnitude of projected changes varies between models, leading to substantial uncertainty in precipitation projections.[1] Thus projections of future precipitation changes are more robust for some regions than for others. Projections become less consistent between models as spatial scales decrease. [2.3.1]

**By the middle of the 21st century, annual average river runoff and water availability are projected to increase as a result of climate change[2] at high latitudes and in some wet tropical areas, and decrease over some dry regions at mid-latitudes and in the dry tropics.**[3] Many semi-arid and arid areas (e.g., the Mediterranean basin, western USA, southern Africa and north-eastern Brazil) are particularly exposed to the impacts of climate change and are projected to suffer a decrease of water resources due to climate change. *(high confidence)* [2.3.6]

**Increased precipitation intensity and variability is projected to increase the risks of flooding and drought in many areas.** The frequency of heavy precipitation events (or proportion of total rainfall from heavy falls) will *very likely* increase over most areas during the 21st century, with consequences to the risk of rain-generated floods. At the same time, the proportion of land surface in extreme drought at any one time is projected to increase *(likely)*, in addition to a tendency for drying in continental interiors during summer, especially in the subtropics, low and mid-latitudes. [2.3.1, 3.2.1]

[1] Projections considered are based on the range of non-mitigation scenarios developed by the IPCC Special Report on Emissions Scenarios (SRES).
[2] This statement excludes changes in non-climatic factors, such as irrigation.
[3] These projections are based on an ensemble of climate models using the mid-range SRES A1B non-mitigation emissions scenario. Consideration of the range of climate responses across SRES scenarios at the mid-21st century suggests that this conclusion is applicable across a wider range of scenarios.

**Water supplies stored in glaciers and snow cover are projected to decline in the course of the century**, thus reducing water availability (through a seasonal shift in streamflow, an increase in the ratio of winter to annual flows, and reductions in low flows) in regions supplied by melt water from major mountain ranges, where more than one-sixth of the world population currently lives *(high confidence)*. [2.1.2, 2.3.2, 2.3.6]

**Higher water temperatures and changes in extremes, including floods and droughts, are projected to affect water quality and exacerbate many forms of water pollution**—from sediments, nutrients, dissolved organic carbon, pathogens, pesticides and salt, as well as thermal pollution, with possible negative impacts on ecosystems, human health, and water system reliability and operating costs *(high confidence)*. In addition, sea-level rise is projected to extend areas of salinisation of groundwater and estuaries, resulting in a decrease of freshwater availability for humans and ecosystems in coastal areas. [3.2.1.4, 4.4.3]

**Globally, the negative impacts of future climate change on freshwater systems are expected to outweigh the benefits** *(high confidence)*. By the 2050s, the area of land subject to increasing water stress due to climate change is projected to be more than double that with decreasing water stress. Areas in which runoff is projected to decline face a clear reduction in the value of the services provided by water resources. Increased annual runoff in some areas is projected to lead to increased total water supply. However, in many regions this benefit is likely to be counterbalanced by the negative effects of increased precipitation variability and seasonal runoff shifts on water supply, water quality and flood risks. *(high confidence)* [3.2.5]

**Changes in water quantity and quality due to climate change are expected to affect food availability, stability, access and utilization.** This is expected to lead to decreasing food security and increased vulnerability of poor rural farmers, especially in the arid and semi-arid tropics and Asian and African megadeltas. [4.2]

**Climate change affects the function and operation of existing water infrastructure—including hydropower, structural flood defences, drainage, and irrigation systems—as well as water management practices**. Adverse effects of climate change on freshwater systems aggravate the impacts of other stresses, such as population growth, changing economic activity, land use change and urbanisation *(very high confidence)*. Globally, water demand will grow in the coming decades primarily due to population growth and increasing affluence; regionally, large changes in irrigation water demand as a result of climate changes are expected *(high confidence)*. [1.3, 4.4, 4.5, 4.6]

**Current water management practices may not be robust enough to cope with the impacts of climate change** on water supply reliability, flood risk, health, agriculture, energy and aquatic ecosystems. In many locations, water management cannot satisfactorily cope even with current climate variability, so that large flood and drought damages occur. As a first step, improved incorporation of information about current climate variability into water-related management would assist adaptation to longer-term climate change impacts. Climatic and non-climatic factors, such as growth of population and damage potential, would exacerbate problems in the future. *(very high confidence)* [3.3]

**Climate change challenges the traditional assumption that past hydrological experience provides a good guide to future conditions.** The consequences of climate change may alter the reliability of current water management systems and water-related infrastructure. While quantitative projections of changes in precipitation, river flows and water levels at the river-

basin scale are uncertain, it is very likely that hydrological characteristics will change in the future. Adaptation procedures and risk management practices that incorporate projected hydrological changes with related uncertainties are being developed in some countries and regions. [3.3]

**Adaptation options designed to ensure water supply during average and drought conditions require integrated demand-side as well as supply-side strategies.** The former improve water-use efficiency, e.g. by recycling water. Expanded use of economic incentives, including metering and pricing to encourage water conservation and development of water markets and implementation of virtual water trade, holds considerable promise for water savings and reallocation of water to highly valued uses. Supply-side strategies generally involve increases in storage capacity, abstraction from water courses, and water transfers. Integrated water resources management provides an important framework to achieve adaptation measures across socio-economic, environmental and administrative systems. To be effective, integrated approaches must occur at the appropriate scale or scales needed to facilitate effective actions for specific outcomes. [3.3]

**Mitigation measures can reduce the magnitude of impacts of global warming on water resources, in turn reducing adaptation needs.** However, they can have considerable negative side effects, such as increased water requirements for afforestation/reforestation activities or bio-energy crops, if these are not sustainably located, designed and managed. On the other hand, water management policy measures, e.g., hydrodams, can influence greenhouse gas emissions. Hydrodams are a source of renewable energy. Nevertheless, they produce greenhouse gas emissions themselves. The magnitude of these emissions depends on specific circumstance and mode of operation. [Section 6]

**Water resources management clearly impacts on many other policy areas** e.g., energy, health, food security, nature conservation. Thus, the appraisal of adaptation and mitigation options needs to be conducted across multiple water-dependent sectors. Low-income countries and regions are likely to remain vulnerable over the medium term, with fewer options than high-income countries for adapting to climate change. Therefore, adaptation strategies should be designed in the context of development, environment and health policies. [Section 7]

**Several gaps in knowledge exist in terms of observations and research needs related to climate change and water.** Observational data and data access are prerequisites for adaptive management, yet many observational networks are shrinking. There is a need to improve understanding and modelling of changes in climate related to the hydrological cycle at scales relevant to decision making. Information about the water-related impacts of climate change is incomplete, especially with respect to water quality, aquatic ecosystems, groundwater, including their socio-economic dimensions. Finally, current tools to facilitate integrated appraisals of adaptation and mitigation options across multiple water-dependent sectors are inadequate. [Section 8]